Technical Report Documentation Page

1. Report No. FHWA-PD-91-015	2. PB92171883	3. Recipient's Catalog No.
4. Title and Subtitle Bridge Inspector's Training Manual 90		5. Report Date May 1991
		6. Performing Organization Code
7. Author(s) Raymond A. Hartle, P.E., William J. Amrhein, P.E., Kenneth E. Wilson III, P.E., Dennis R. Baughman, P.E., John J. Tkacs, P.E.		8. Performing Organization Report No. 17391-HRH
9. Performing Organization Name and Address Michael Baker, Jr., Inc. 4301 Dutch Ridge Road Beaver, PA 15009		10. Work Unit No. (TRAIS)
		11. Contract or Grant No. DTFH61-89-C-00103
12. Sponsoring Agency Name and Address Federal Highway Administration (HHI-20) Turner-Fairbank Highway Research Center 6300 Georgetown Pike McLean, Virginia 22101		13. Type of Report and Period Covered Final Manual October 1989 - May 1991
		14. Sponsoring Agency Code
15. Supplementary Notes Baker Project Manager: Charles M. Schubert, P.E. FHWA Contracting Officer's Technical Representative: John M. Hooks, P.E.		

16. Abstract

This document, the *Bridge Inspector's Training Manual (BITM) 90*, is a comprehensive manual on programs, procedures, and techniques for inspecting and evaluating a variety of in-service highway bridges. It is intended to replace the *BITM 70* which was first published in 1970 to assist in training highway personnel for the new discipline of bridge safety inspection. *BITM 70* has been in use for 20 years and has been the basis for several training programs varying in length from a few days to two weeks. Comprehensive supplements to *BITM 70* have been developed to cover inspection of fracture critical bridge members, movable bridges, and culverts.

BITM 90 is a revision and upgrading of the previous manual. Improved bridge inspection techniques are presented, and state-of-the-art inspection equipment is included. New or expanded coverage is provided on culverts, fracture critical members, cable-stayed bridges, prestressed segmental bridges, and underwater inspection. Previous supplemental manuals on culvert inspection, fracture critical inspection, movable bridge inspection, and nondestructive testing are excerpted and referenced. These previous special manuals are still valid supplements to *BITM 90*.

A three-week comprehensive training program on bridge inspection, based on the *BITM 90*, has been developed. The program consists of a one-week course, "Engineering Concepts for Bridge Inspectors," and a two-week course, "Safety Inspection of In-Service Bridges." Together, these two courses meet the definition of a comprehensive training program in bridge inspection as defined in the National Bridge Inspection Standards. The one-week course is optional for technicians, inspectors, or engineers who have an adequate background in bridge engineering concepts.

17. Key Words Bridge Inspection, Bridge Evaluation, Culvert Inspection, Fracture Critical Members, Underwater Inspection	18. Distribution Statement This report is available to the public from the National Technical Information Service in Springfield, Virginia 22161 and from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	586	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

ACKNOWLEDGEMENTS

We would like to express appreciation to the following individuals and organizations who contributed to the development and review of this training program:

Applied Science Associates, Inc.
Association of Diving Contractors, Inc. (Messrs. Castle, Harter, Hazelbaker, Hux, Maggard, McGeehan, and McGovern)
R. Richard Avent, Ph.D., P.E. (Louisiana State University)
Ronald C. Brechler, P.E. (Michael Baker, Jr., Inc. - Phoenix)
Jeffrey J. Campbell, P.E. (Michael Baker, Jr., Inc. - Beaver, Pennsylvania)
William D. Domico, P.E. (Figg Engineering Group)
John W. Fisher, Ph.D. (Lehigh University)
Roger W. Hove, P.E.
Robert J. Hoyle, Jr., P.E., S.E.
M. Patrick Kane, P.E.
Frank J. Kempf, Sr., P.E. (Michael Baker, Jr., Inc. - Harrisburg)
Heinz P. Koretzky, P.E. (Pennsylvania DOT - Retired)
KTA - Tator, Inc.
David A. Miller, P.E.
John A. Schultz, Jr., S.E. (Hazelet and Erdal, Inc.)
Frieder Seible, Ph.D., P.E. (SEQAD Consulting Engineers, Inc.)
Daryl B. Simons, Ph.D., P.E. (Simons and Associates, Inc.)
Robert K. Simons, Ph.D., P.E. (Simons and Associates, Inc.)

Special thanks to the AASHTO Task Force members:

Theo Bowman (Indiana DOH)
Bruce Brakke, P.E. (FHWA Representative - Iowa Division)
Charles Hunter, P.E. (Tennessee DOT)
Richard Kerr, P.E. (Florida DOT)
Thomas Lulay, P.E. (Oregon DOT)
Larry Sessions, P.E. (Florida DOT)
Robert Thomas, P.E. (Connecticut DOT - Retired)
Robert Wood (FHWA Representative, Washington, D.C.)

We would also like to thank the following individuals and organizations for providing information or visual aids for this training program:

Kathleen H. Almand (American Iron and Steel Institute)
American Traffic Safety Services Association
Bridge Grid Flooring Manufacturers Association
The D.S. Brown Company
Concrete Reinforcing Steel Institute
Cosmec, Inc.
Barry Dickson (West Virginia University)
Dynamic Isolation Systems, Inc.
Elgard Corporation
Exodermic Bridge Deck Institute
Geerhard Haaijer, Ph.D. (American Institute of Steel Construction, Inc.)
John M. Hanson, Ph.D. (Wiss, Janney, Elster Associates, Inc.)
Richard P. Knight, P.E. (Dynamic Isolation Systems, Inc.)
Louisiana Department of Transportation and Development
Merriman, Inc.
William R. Mochel, P.E. (Illinois Department of Transportation)
Pennsylvania Department of Transportation
Professional Service Industries, Inc. - Pittsburgh Testing Laboratory Division
Schupack Suarez Engineers, Inc.
Paul W. Verrill (Maine Department of Transportation)
Watson Bowman Associates, Inc.
Stewart C. Watson (Stafford/Watson, Inc.)
Western Wood Structures, Inc.
Weston Geophysical Corporation

We would also like to acknowledge the contributions of staff members at Michael Baker, Jr., Inc.:

Edward E. Moldovan, Jr.
Roberta J. Chambers
Scott D. Vannoy
Edward J. Adamczyk, P.E.
Robert W. Bondi, P.E.
Paul L. Coblentz, P.E.
Thomas L. Hooks
Stephen J. Hoyer
Gerald H. Jones, P.E.
Guy R. Lang
Karen G. Lucci
Thomas P. Macioce
Susan Manes-Harrison
J. Eric Mann, P.E.
Robert M. Marchak
Kelly A. McKindley
Krisha E. Medziuch
Charles L. Molnar
J. Keith Seibel
John W. Terracio
Terri A. Vojnovich
Ruth J. Williams
Lori A. Wittebort

Table of Contents

List of Figures

Preceding page blank

Chapter 5 Continued

Chapter 6

Chapter 7

Chapter 9 Continued

Chapter 10

Chapter 11

Chapter 15

Chapter 16

Chapter 17

Chapter 18

Chapter 19

Chapter 20

Chapter 20 Continued

Chapter 21

Chapter 21 Continued

List of Tables

Abbreviations

Agencies and Standards

AASHO	-	American Association of State Highway Officials (1921 to 1973)
AASHTO	-	American Association of State Highway and Transportation Officials (1973 to present)
ACI	-	American Concrete Institute
ADC	-	Association of Diving Contractors
AISC	-	American Institute of Steel Construction
AISI	-	American Iron and Steel Institute
AITC	-	American Institute of Timber Construction
ASCE	-	American Society of Civil Engineers
ASTM	-	American Society for Testing and Materials
CRSI	-	Concrete Reinforcing Steel Institute
DOT	-	Department of Transportation
FAA	-	Federal Aviation Administration
FHWA	-	Federal Highway Administration
IBTT	-	International Bridge Tunnel and Turnpike
NAUI	-	National Association of Underwater Instructors
NBI	-	National Bridge Inventory
NBIS	-	National Bridge Inspection Standards
NBS	-	National Bureau of Standards
NCHRP	-	National Cooperative Highway Research Program
NFPA	-	National Forest Products Association
NHI	-	National Highway Institute
NICET	-	National Institute for Certification in Engineering Technologies
NIST	-	National Institute of Standards and Testing (1980 to present)
OSHA	-	Occupational Safety and Health Administration
PADI	-	Professional Association of Diving Instructors
PCA	-	Portland Cement Association
PCI	-	Prestressed Concrete Institute
SI&A	-	Structure Inventory and Appraisal
SSPC	-	Steel Structures Painting Council
TRB	-	Transportation Research Board
USGS	-	United States Geological Survey

Preceding page blank

Units

ft	-	foot
in	-	inch
kip	-	1000 pounds
ksi	-	kips per square inch
lb	-	pound
mm	-	millimeter
mph	-	miles per hour
pcf	-	pounds per cubic foot
psi	-	pounds per square inch
sq	-	square
°F	-	degree Fahrenheit

Others

ADT	-	average daily traffic
CCA	-	chromated copper arsenate
CE	-	carbon equivalent
CIP	-	cast-in-place
CSE	-	copper sulfate electrode
FCM	-	fracture critical member
GF	-	girder-floorbeam
GFS	-	girder-floorbeam-stringer
JB	-	junction box
LMC	-	latex-modified concrete
LSDC	-	low slump dense concrete
MCC	-	motor control centers
MFD	-	magnetic field disturbance
NDT	-	nondestructive testing
PLC	-	programmable logic controller
PMC	-	polymer modified concrete
PTFE	-	polytetrafluoroethylene
QA	-	quality assurance
QC	-	quality control
ROV	-	remotely operated vehicle
SIP	-	stay-in-place
TFE	-	polytetrafluoroethylene

Preface

This manual is intended for use by bridge inspectors. It provides information about the inspection and evaluation of a wide variety of bridge types. Specific details are provided concerning what to look for and where to look. While the examples used in this manual represent the most commonly encountered conditions, they should not be considered to be exhaustive. Additional information is available in the supplements to this manual, as well as the resources listed in the bibliography.

Chapters 1 through 6 of this manual provide a general foundation for the training of bridge inspectors. Chapter 1 is an introduction to the manual and presents a brief history of the National Bridge Inspection Program. Chapter 2 provides a history of bridges, including materials, design methods, and construction techniques, from prehistoric bridges to today's modern bridges. Chapter 3 presents the basic principles of mechanics, using simple examples as illustrations and relating the principles of mechanics specifically to bridges. Chapter 4 describes bridge materials, presenting the properties, types and causes of deterioration, and methods of examination for the primary bridge materials - timber, concrete, and steel. Chapter 5 covers the fundamentals of bridge inspection, describing responsibilities, duties, preparation, procedures, equipment, and safety. Chapter 6 presents the basic components and elements of bridges, describing their identification and function.

Chapters 7 through 13 provide a detailed coverage of the inspection and evaluation of various bridge features. Chapter 7 deals with decks, as well as appurtenances and approach roadways. Chapter 8 describes common timber superstructures. Chapter 9 covers common concrete superstructures, including reinforced concrete and prestressed concrete. Chapter 10 presents common steel superstructures, including beams and girders, trusses, arches, and rigid frames. Chapter 11 deals with bearings of both steel and neoprene. Chapter 12 describes substructures, including those comprised of timber, stone masonry, concrete, iron, or steel. Chapter 13 covers waterways and includes scour potential assessment.

Chapters 14 through 21 provide a variety of additional guidelines that are essential for the training of bridge inspectors. Chapter 14 presents the methods of recordkeeping, documentation, and preparation of the inspection report. Chapter 15 presents various advanced inspection techniques. Chapter 16 describes protective systems for each of the primary bridge materials. Chapter 17 describes features unique to underwater inspection. Chapter 18 defines fracture critical members and describes features unique to their inspection. Chapter 19 describes the inspection of culverts. Chapter 20 describes the inspection of movable bridges. Chapter 21 deals with special bridges - suspension bridges, cable-stayed bridges, and segmental concrete bridges - and covers the identification and inspection of their various special elements.

The appendices of this manual contain the National Bridge Inspection Standards and a sample bridge inspection report. The manual also contains a glossary of commonly used bridge inspection terms and a bridge bibliography. A wide variety of figures and tables are presented throughout the manual, supplementing the text with valuable illustrations and photographs.

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

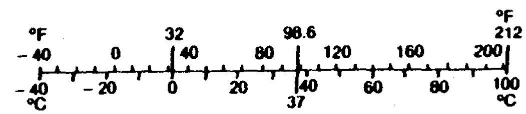
Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimetres	mm
ft	feet	0.305	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
		AREA		
in^2	square inches	645.2	millimetres squared	mm^2
ft^2	square feet	0.093	metres squared	m^2
yd^2	square yards	0.836	metres squared	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	kilometres squared	km^2
		VOLUME		
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft^3	cubic feet	0.028	metres cubed	m^3
yd^3	cubic yards	0.765	metres cubed	m^3

NOTE: Volumes greater than 1000 L shall be shown in m^3.

Symbol	When You Know	Multiply By	To Find	Symbol
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
		TEMPERATURE (exact)		
°F	Fahrenheit temperature	5(F-32)/9	Celcius temperature	°C

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi
		AREA		
mm^2	millimetres squared	0.0016	square inches	in^2
m^2	metres squared	10.764	square feet	ft^2
ha	hectares	2.47	acres	ac
km^2	kilometres squared	0.386	square miles	mi^2
		VOLUME		
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m^3	metres cubed	35.315	cubic feet	ft^3
m^3	metres cubed	1.308	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams	1.102	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F



* SI is the symbol for the International System of Measurement

(Revised April 1989)

1

Introduction

Abbreviations Used in this Chapter

AASHO	-	American Association of State Highway Officials (1921 to 1973)
AASHTO	-	American Association of State Highway and Transportation Officials (1973 to present)
AASHTO Manual	-	*Manual for Maintenance Inspection of Bridges*
Coding Guide	-	FHWA *Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges*
FCM	-	fracture critical member
FHWA	-	Federal Highway Administration
HEC	-	*Hydraulic Engineering Circular*
Manual 70	-	*Bridge Inspector's Training Manual 70*
Manual 90	-	*Bridge Inspector's Training Manual 90*
NBIS	-	National Bridge Inspection Standards
NDT	-	nondestructive testing
NHI	-	National Highway Institute
NICET	-	National Institute for Certification in Engineering Technologies

1

Introduction

1.1 Overview

In the past 20 years since the Federal Highway Administration's landmark publication, *Bridge Inspector's Training Manual 70* (*Manual 70*), bridge inspection and inventory programs of state and local governments have evolved into sophisticated bridge management programs. During the 1990's, the state governments will be implementing comprehensive bridge management systems which will rely heavily on accurate, consistent bridge inspection data.

Advances in technology and construction have greatly enhanced current bridge design. However, the emergence of previously unknown problem areas and the escalating cost of replacing older bridges make it imperative that existing bridges be evaluated properly to be kept open and safe.

This manual (*Manual 90*) updates *Manual 70*, reflecting 20 years of change.

This chapter serves as an introduction to the National Bridge Inspection Program. The first section provides a brief history of the National Bridge Inspection Program. Understanding the history of the program will enable the inspector and engineer to better understand the various reasons for the inspection program and the events which have led to the enhancement of the inspection program.

The second section describes the current bridge safety inspection program. The current program reflects many of the concerns of the past and examines recent emphases which are of concern to bridge inspectors.

1.2 History of the National Bridge Inspection Program

Background

During the bridge construction boom of the 1950's and 1960's, little emphasis was placed on safety inspection and maintenance of bridges. This changed when the 2,235-foot Silver Bridge, at Point Pleasant, West Virginia, collapsed into the Ohio River. On December 15, 1967, 46 people were killed (see Figure 1-1).

Figure 1-1 Collapse of the Silver Bridge

This tragic collapse aroused national interest in the safety inspection and maintenance of bridges. The U.S. Congress was prompted to add a section to the "Federal Highway Act of 1968" which required the Secretary of Transportation to establish a national bridge inspection standard. The Secretary was also required to develop a program to train bridge inspectors.

The 1970's

Thus, in 1971, the National Bridge Inspection Standards (NBIS) came into being. The NBIS set national policy regarding bridge inspection frequency, inspector qualifications, report formats, and inspection and rating procedures.

Three manuals were subsequently developed. These manuals were vital to the early success of the NBIS. The first manual was the Federal Highway Administration (FHWA) *Bridge Inspector's Training Manual 70*. This manual set the standard for inspector training.

The second manual was the American Association of State Highway Officials (AASHO) *Manual for Maintenance Inspection of Bridges*, released in 1970.

The third manual was the FHWA *Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges* (*Coding Guide*), released in July 1972.

With the publication of *Manual 70*, the implementation of national standards and guidelines, the support of AASHO, and a newly available FHWA bridge inspector's training course for use in individual states, improved inventory and appraisal of the nation's bridges seemed inevitable. Several states began in-house training programs, and the 1970's looked promising. Maintenance and inspection problems associated with movable bridges were even addressed. In 1977, a supplement to *Manual 70*, the *Bridge Inspector's Manual for Movable Bridges*, was added.

However, the future was not to be trouble free. Two predominant concerns were identified during this period. One concern was that bridge repair and replacement needs far exceeded available funding. The other was that NBIS activity was limited to bridges on the Federal Aid highway systems. This resulted in no incentive for inspection and inventory of bridges not on Federal Aid highway systems.

These two concerns were addressed in the "Surface Transportation Assistance Act of 1978." This act provided badly needed funding for rehabilitation and new construction and required that all public bridges over 20 feet in length be inspected and inventoried in accordance with the NBIS by December 31, 1980.

In 1978, the American Association of State Highway and Transportation Officials (AASHTO) revised their *Manual for Maintenance Inspection of Bridges* (*AASHTO Manual*). In 1979, the NBIS and the FHWA *Coding Guide* were also revised. These publications, along with *Manual 70*, provided state agencies with definite guidelines for compliance with the NBIS.

The 1980's

The National Bridge Inspection Program was now maturing and well positioned for the coming decade. Two additional supplements to *Manual 70* were published - the *Culvert Inspection Manual* and *Inspection of Fracture Critical Bridge Members*. These manuals were the products of research in these problem areas.

Culverts became an area of interest after several tragic failures. The 1979 NBIS revisions also prompted increased interest in culverts.

An emerging national emphasis on fatigue and fracture critical bridges was sharply focused by the collapse of Connecticut's Mianus River Bridge in June 1983.

With the April 1987 collapse of New York's Schoharie Creek Bridge, national attention turned to underwater inspection. Of the 577,000 bridges in the national inventory, over 86% are over waterways. The FHWA responded with *Scour at Bridges*, a technical advisory published in September 1988. This advisory provided guidelines pertaining to scour assessment. Further documentation is available on this topic in the *Hydraulic Engineering Circular No. 18* (*HEC-18*).

In October 1988, NBIS was modified, based on suggestions made in the "1987 Surface Transportation and Uniform Relocation Assistance Act," to require states to identify bridges with fracture critical details and establish special inspection procedures. The same requirements were made for bridges requiring underwater inspections. The NBIS revisions also allowed for adjustments in the frequency of inspections and the acceptance of National Institute for Certification in Engineering Technologies (NICET) Level III and IV certification for inspector qualifications.

In December 1988, the FHWA issued a revision to the *Coding Guide*. This time the revision would be one of major proportions, shaping the National Bridge Inspection Program for the next decade. The *Coding Guide* now provides inspectors with additional direction in performing uniform and accurate bridge inspections.

1.3 Today's National Bridge Inspection Program

Much has been learned in the field of bridge inspection and many training programs have been implemented. State inspection efforts are more organized, better managed and much broader in scope. The technology used to inspect and evaluate bridge members and bridge materials has significantly improved.

Areas of emphasis in bridge inspection programs are changing and expanding as new problems become apparent, as newer bridge types become more common, and as these newer bridges age enough to have areas of concern. Guidelines for inspection ratings have been refined to increase uniformity and consistency of inspections. Data from bridge inspections is critical input into a variety of analyses and decisions by State agencies and the Federal Highway Administration.

As discussed, the NBIS has kept current with the field of bridge inspection. The 1988 National Bridge Inspection Standards appear in Appendix A. The standards are divided into the following sections:

- Application of standards
- Inspection procedures
- Frequency of inspections
- Qualifications of personnel
- Inspection report
- Inventory

The FHWA has made a considerable effort to make available to the nation's bridge inspectors the information and knowledge necessary to accurately and thoroughly inspect and evaluate the nation's bridges. The following three documents were designed as supplements to the original *Manual 70*. *Manual 90* does not replace these supplemental documents. Therefore they are also supplements to this manual (*Manual 90*).

Movable Bridge Manual

1. *Bridge Inspector's Manual for Movable Bridges*

   FHWA-IP-77-10 1977 150 pages

   This manual describes the electrical and mechanical systems in use on movable bridges. It is to be used as an instructional manual for training bridge inspectors and as a reference for experienced inspectors. It is currently out of print.

Culvert Manual

2. *Culvert Inspection Manual*

   FHWA-IP-86-2 July 1986 215 pages

This manual provides guidelines and procedures for conducting and documenting inspections of culverts. Specific guidelines for evaluating major hydraulic and structural components are included.

Fracture Critical Manual

3. *Inspection of Fracture Critical Bridge Members*

   FHWA-IP-86-26 September 1986 221 pages

   This manual contains information about planning, identification, inspection, documentation, and evaluation of fracture critical bridge members.

FHWA Training

In addition to the manuals listed above, the FHWA has developed and offered the following training courses relative to bridge inspection through the National Highway Institute (NHI):

- "Bridge Inspector's Training Course Part I - Engineering Concepts for Bridge Inspectors"

  This one-week course presents engineering concepts, as well as inspection procedures and information about bridge types, bridge components, and bridge materials. The one-week course is for new inspectors with little or no practical bridge inspection experience.

- "Bridge Inspector's Training Course Part II - Safety Inspection of In-Service Bridges"

  This two-week course is for experienced inspectors or engineers who perform or manage bridge inspections. Emphasis is on inspection applications and procedures. The uniform coding and rating of bridge components is also an objective of the two-week course. A unique feature of this course allows for customization of the course content by the host agency. Optional topics can be scheduled, and their level of coverage can be selected. These topics include identification and inspection of fracture critical members (FCMs), underwater inspection, culverts, field trips, case studies, movable bridges, and coatings. Several special bridge types may also be discussed at the host agency's request.

- "Culvert Inspection"

  This two-day course is built around the *Culvert Inspection Manual.*

- "Inspection of Fracture Critical Bridge Members"

  This two-day course is designed to acquaint bridge inspectors with procedures for making visual bridge inspections of FCMs.

- "Nondestructive Testing Methods for Steel Bridges"

  This four and one-half day course provides an understanding of the basic theory, fundamentals, applications, limitations, code restrictions, and the advantages and disadvantages of nondestructive testing (NDT) methods most often associated with steel highway bridges.

- **Demonstration Project 80 - "Bridge Inspection Techniques and Equipment"**

  This two and a half day course provides information on innovative inspection techniques and equipment allowing the inspection of difficult-to-reach bridge components, fracture critical members, and underwater members. A prime course reference is *Underwater Inspection of Bridges* (FHWA-DP-80-1).

Throughout all the expansions and improvements in bridge inspection programs and capabilities, one factor remains constant: the overriding importance of the inspector's ability to effectively inspect bridge components and materials and to make sound evaluations with accurate ratings. The validity of all analyses and decisions based on the inspection data is dependent on the quality and the consistency of the data collected in the field.

Across the nation, the duties, responsibilities, and qualifications of bridge inspectors vary widely. The two keys to a knowledgeable, effective inspection are training and experience in performing actual bridge inspections. Training of bridge inspectors has been, and will continue to be, an active process within state highway agencies for many years. This manual is designed to be an integral part of that training process.

2

Evolution of Bridge Design and Materials

Milestones in Early American Bridges
(Pre-1900)

1697	-	*	Frankford Avenue Bridge, Philadelphia, Pennsylvania, first known American stone arch bridge; the three-span, 75-foot long structure is considered the oldest bridge in the United States that continues to serve as part of a modern highway system
1764	-		Leffingwell's Bridge, Norwich, Connecticut, first truss bridge in America
1801	-		Jacobs Creek Bridge, Uniontown, Pennsylvania, first metal suspension bridge in America, with a 70-foot span; was the first suspension bridge in the world with a rigid, level deck suitable for vehicles
1804	-		Theodore Burr granted a patent for his Burr arch-truss
1805	-		Palmer's 550-foot, three-span Permanent Bridge, Philadelphia, Pennsylvania, first known American covered bridge
1820	-		Ithiel Town granted a patent for his lattice truss, became very popular because it could be built by average carpenters
1839	-	*	Dunlap's Creek Bridge, Brownsville, Pennsylvania, first all-metal bridge in America, an 80-foot span consisting of five tubular cast iron arch ribs
1840	-		William Howe granted a patent for his truss, which substituted wrought iron for tension verticals, beginning the transition in bridge building from wood to iron
1849	-	*	Wheeling Suspension Bridge, Wheeling, West Virginia, first long-span wire-cable suspension bridge in the world (1,010 feet between towers)
1862	-	*	Bridgeport Covered Bridge, longest single-span covered bridge in the United States, at 233 feet, Marysville and Virginia City, California; an arch reinforced Howe truss
1866	-	*	Cornish-Windsor Covered Bridge, Windsor, Vermont, two-span, 460 feet in length, longest covered bridge in the United States
1869	-	*	Bollman Truss Bridge, Savage, Maryland, two-span, 160 feet in length, design facilitated rapid expansion of early American railroads
1874	-	*	Eads Bridge over the Mississippi River, a three-span, 1,546-foot arch in St. Louis, Missouri, first significant structural application of steel; first major use of compressed air for subaqueous work in the United States
1879	-		First all-steel bridge, Glasgow, Missouri, a five-span Whipple-Murphy truss
1883	-	*	Roebling's Brooklyn Bridge, Brooklyn, New York, when completed, the longest suspension bridge in the world at 1595 feet; first to use steel cables
1883	-	*	James J. Hill Stone Arch Bridge, Minneapolis, Minnesota, of the Burlington Northern Railroad, oldest existing mainline railroad bridge over the Mississippi River and a key in development of the Northwest; total length is 2,490 feet
1883	-	*	Smithfield Street Bridge, Pittsburgh, Pennsylvania, adaptation of contemporary European engineering practice, the lenticular truss, to American needs; oldest steel through truss in the United States
1889	-	*	Alvord Lake Bridge, San Francisco, California, built by Ernest Ransome, oldest reinforced concrete bridge in the United States; a 20-foot span
1892	-	*	George S. Morison's truss-cantilever bridge, Memphis, Tennessee, established specifications that became standards for U.S. railroad bridges; first permanent structure to cross the lower Mississippi River, has a 790-foot span and two 660-foot spans

* Bridge is still standing

2

Evolution of Bridge Design and Materials

2.1 Introduction

In many buildings and other structures, the engineering tends to be obscured by the architecture. In a bridge, however, the engineering, in effect, is the architecture and can possess a beauty of its own.

Anyone studying the history of bridges will soon discover that the evolution of bridge design and materials does not follow a straight time-line. This chapter will focus on the evolution of bridges as it relates to various historical periods. These general periods include prehistoric, the Roman Empire, the Middle Ages, the Renaissance, the eighteenth and nineteenth century (Europe), early American, and the twentieth century. An overview will be presented in chronological order, providing an introduction to the subject rather than an exhaustive treatment, since entire books have been written on the history of bridges.

Before examining the historical evolution, it is important to discuss the types of bridges to be encountered. There are three basic types of bridges, classified according to how the load is supported (see Figure 2-1):

- Beam
- Arch
- Cable-supported

Beam Bridges

Loads on beam bridges are transmitted vertically to the supports. Gravity is the only force involved. Simple beams require their greatest bending strength at the center of the span. Some examples of beam bridges include:

- Timber stringer bridges
- Prestressed concrete boxes
- Steel girders and trusses

Two variations of the beam which deserve mention here, but which will be explained in detail in the next chapter, are continuous beams and cantilever beams. Both of these bridge types transmit their loads vertically to their supports but involve more sophisticated engineering.

Arch Bridges

Arches generally transmit their loads by pushing diagonally (rather than vertically) on their supports. Stone was the building material of early arches. Modern arch bridges are made of steel or reinforced concrete.

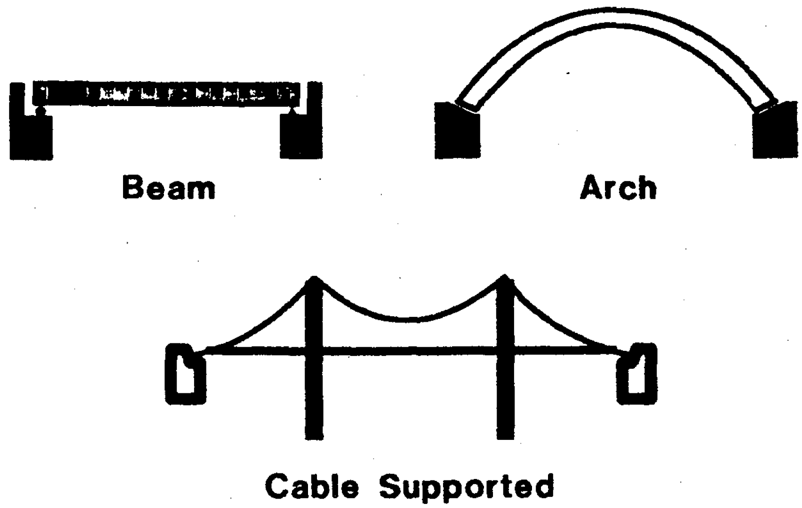


Figure 2-1 Three Basic Bridge Types (Source: 18)

Cable-Supported Bridges

Cable-supported bridges are the reverse of the arch, in that cables generally transmit their loads by pulling on their supports. Through the years, cables have been made of vines, rope, metal chains, and steel wire .

2.2 Prehistoric Bridges

The first bridges were natural bridges formed by geological erosion due to water flow. Examples can be found at Natural Bridges National Monument and Rainbow Bridge National Monument, located in Utah. Another example is the Natural Bridge, located in Virginia. Natural arches were formed by weathering, freeze-thaw cycles, and wind erosion. Examples of these arches can be found in Arches National Park, located in Utah.

First Man-Made Bridge

The first man-made bridge was most likely a felled tree placed across a stream or gorge. A log bridge is the most basic beam bridge possible. Variations of log bridges are very common today and can be found on many hiking trails throughout the country.

Eventually man discovered that a flat stone slab laid across a stream could provide a more durable (and heavier) bridge than a single log. By placing several stone slabs in a line, wider openings could be bridged. This type of bridge is called a clapper bridge. Examples of clapper bridges can still be found today in England (see Figure 2-2).

By weaving vines together and stringing them across a chasm, early man also developed the idea of the suspension bridge. Early footbridges were constructed by securing a bamboo mat on top of and between two parallel suspended vine ropes.

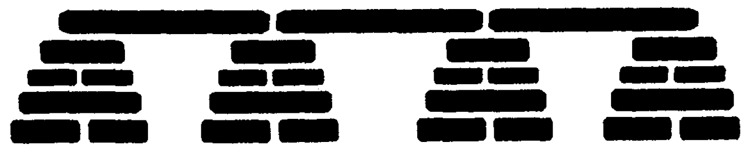


Figure 2-2 Stone Clapper Bridge

As civilizations developed, the effective use of available materials increased. The use of stone masonry for construction of arches dates back to at least 3000 B.C., when the two-stone arch was first developed in the eastern Mediterranean region. Two stones formed the basic framework of the structure while stones were placed around the outside of the opening. The false arch, or corbelled arch, later originated in Greece, in approximately 1000 B.C. This type of arch is formed by projecting stones from each side of an opening until they meet at the center. Since the projecting stones carry the applied vertical loads on cantilever arms, rather than by direct compression of the individual stones, as is the case with a true arch ring, they are called false arches. These false arches served as entrances to underground vaults and to fortified palace walls. It is not known, however, whether these earlier arches were used for bridges.

While Western bridge technology began with the Romans and their use of the stone arch, there is evidence that the Chinese constructed large wooden bridges at a very early date. It is thought that cantilever bridges were used for spans of up to 130 feet, while suspension bridges were used for spans as long as 250 feet. This theory is supported by the fact that the character "chiao", which denotes a bridge, has been a part of the Chinese alphabet since about 1000 B.C.

2.3 Bridges of the Roman Empire

It is generally agreed that the Etruscans, who lived in north central Italy from the eighth to the fourth century B.C., were familiar with the true stone arch. The Etruscans are credited with having taught the Romans this form of construction. During the period from 300 B.C. to 200 A.D., the Romans used semi-circular stone arches for the construction of both aqueducts and highways. Many examples of their work remain today not only in Rome, but throughout Europe as well (see Figure 2-3).

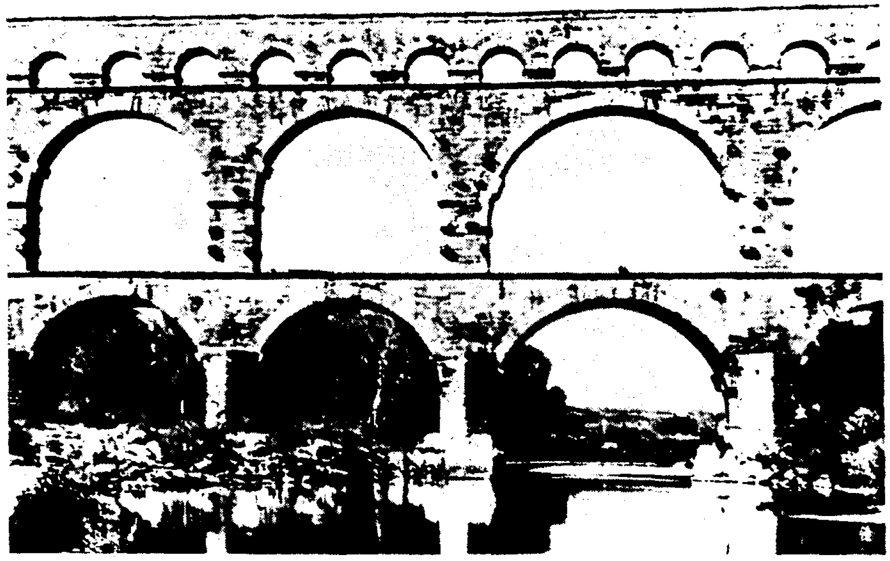


Figure 2-3 The Pont Du Gard Bridge

Roman bridges marked the introduction of sophisticated bridge design. In addition to stone bridges, Romans were also skilled in the construction of timber bridges. One of the earliest records of any bridge refers to a pile-supported wooden bridge built by Julius Caesar over the Rhine River in Germany in 55 B.C.

The Romans are credited with several significant achievements in bridge construction. They were the first to use natural cement (a volcanic ash mixed with lime). The cement was used mostly for underwater foundations. The construction of underwater foundations was improved with the innovative development of the cofferdam, an open box-like structure surrounding the foundation area that permits the water to be pumped out. For shallow water foundations, silt was often dredged out of the area and the dredged space was refilled with natural cement.

Even with these advancements in construction techniques, the foundation proved to be the downfall of Roman bridges built over waterways. The stone piers were built to resist the thrust of adjoining arches. As a result, the piers were massive and thus restricted the waterway. The currents created by this restriction of the waterway caused an erosion of the stream bed, called scour. Scour was probably the principal reason for the failure of most Roman bridges.

Several Roman bridges are still standing, a testament to the ingenuity of these early bridge builders. One of the most famous and recognizable is the Pont Du Gard Bridge, built about 27 B.C., an aqueduct located in France (see Figure 2-3).

2.4 Bridges of the Middle Ages

After the fall of the Roman Empire, commerce and travel decreased; for several centuries, bridge building was almost at a standstill. With the coming of the Crusades, bridge building was again prompted. Stone masonry arch construction, however, continued to be the principal type of bridge structure from the twelfth until the eighteenth century. Although the Romans had specialized in the construction of semi-circular arches, the bridges of this period varied from the pointed or Gothic arch to the flat or elliptical arch. The Roman custom of making the piers thick enough to support the unbalanced pressure of only one arch still persisted. The medieval bridges, fortified for war, were built this way not only because the builders did not fully understand the principles involved, but also to prevent the collapse of the entire bridge due to the failure of only one arch. For unknown reasons, the improved construction techniques used on the great Gothic cathedrals (the ribbed vault and the flying buttress) were not applied to bridge construction.

One of the best known bridges of this era was the original London Bridge, built from 1176 to 1209. The large number of short irregular spans, together with the massive piers and cutwaters, made the bridge an almost impassable dam (see Figure 2-4). The bridge was torn down in 1824 and replaced in 1831 by the second London Bridge, which has since been dismantled and reconstructed at a resort in Arizona.

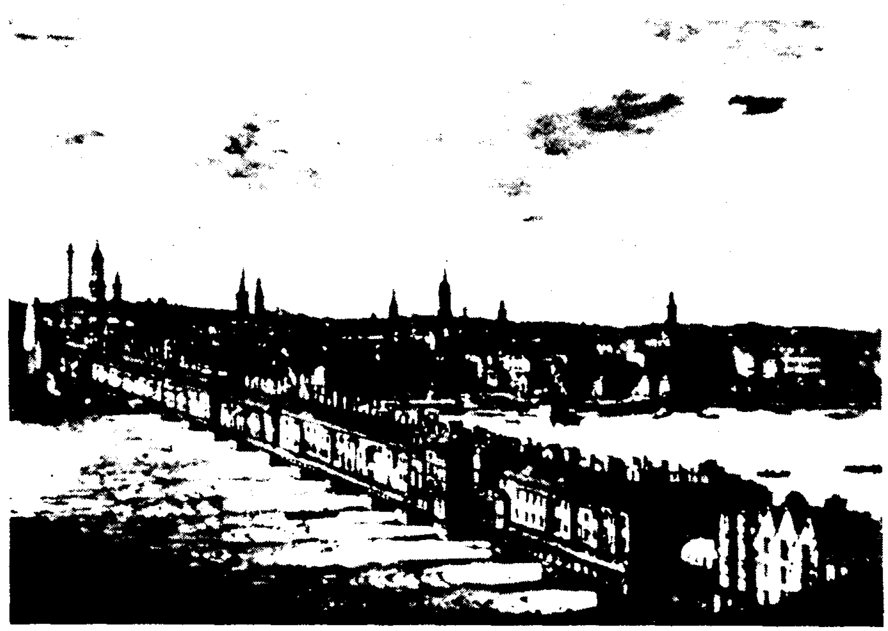


Figure 2-4 The Original London Bridge

2.5 The Renaissance

While many new ideas were conceived during the Renaissance, it was hundreds of years before these concepts received widespread application. Leonardo da Vinci developed the concepts of portable military bridges and bascule bridges, but he did not build them. Palladio (1518-1580) published a treatise describing four different types of truss bridge; he also designed and built a number of wooden truss bridges. Most bridge construction, however, used the traditional stone arch, with increased emphasis on beauty of design. Bridges came to be regarded as civic works of art (see Figure 2-5).

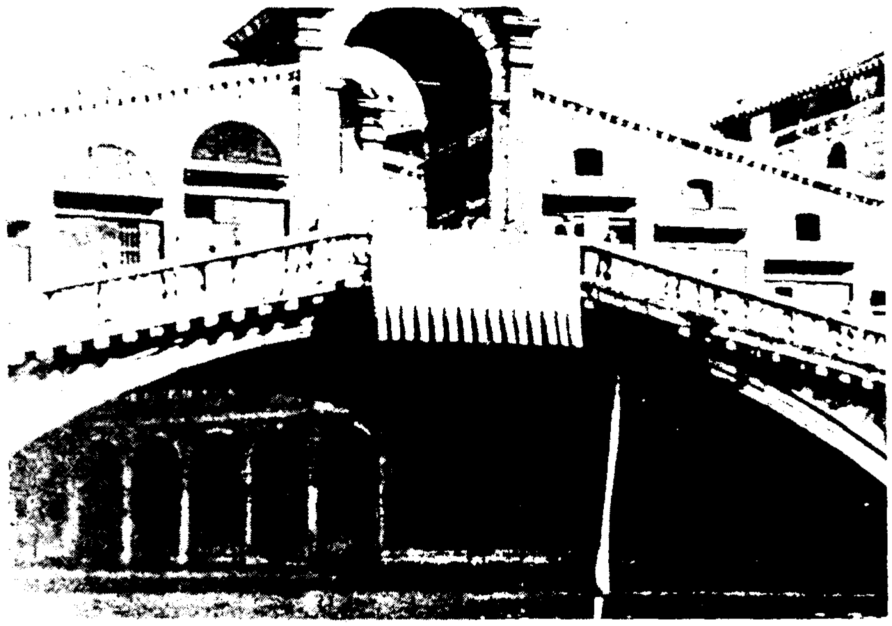


Figure 2-5 The Rialto Bridge

2.6 The Eighteenth and Nineteenth Centuries (Europe)

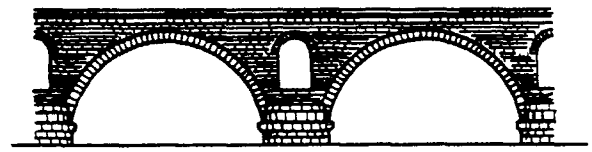
It was not until the late eighteenth century that the idea of interdependent arches was explored. The idea of transferring the thrust of an arch beyond its immediate vertical support to the next arch was not new, for it had been the principle of the Gothic flying buttress (see Figure 2-6). However, it was not used until the construction of the bridge over the Seine at Neuilly, near Paris, from 1768 to 1774. The piers were designed to take only vertical loads, and the thrust was transferred from one arch to the next until reaching the end abutments, thus significantly reducing the width of the piers.

Also during this period, the truss principle was rediscovered. A number of covered wooden truss bridges were constructed in Switzerland and other European countries.

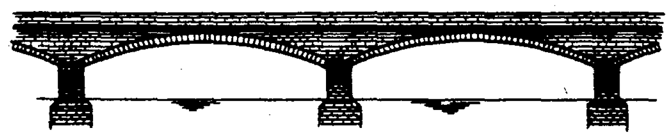
2.7 Early American Bridges

Early American colonists followed traditional European methods of bridge building, primarily the stone arch. However, their efforts soon turned to exploring the limits of their most abundant resource: timber. The first timber bridge in America to provide clear spans longer than possible with a single log or beam was built over the Connecticut River in 1785 and was designed by Colonel Enock Hale. Hale's bridge utilized a braced stringer concept which ushered in a new era of longer span timber bridge design.

The next significant development was that of the timber truss. The advantages of the timber truss were that it utilized short timber members that were easily accessible, transported, and fabricated. Disadvantages of the timber truss were that it was susceptible to damage by fire and rot. The practice of covering the bridges with a roof and siding was in part a protective measure against rot.



ROMAN ARCH



EIGHTEENTH CENTURY ARCH

Figure 2-6 Development of the Eighteenth Century Arch from the Roman Arch (Source: 18)

The first timber trusses were reinforced with arches. This was done as a precaution because little was known about the behavior of trusses. The most successful truss of this type was the Burr arch-truss. The true truss (i.e., with no arch reinforcing) became a popular design when Ithiel Town was granted a patent for his lattice truss in 1820. Town's truss consisted of a web of light planks crisscrossed at an angle of 45° to 60° like a lattice and fastened together with wooden pins (see Figure 2-7).

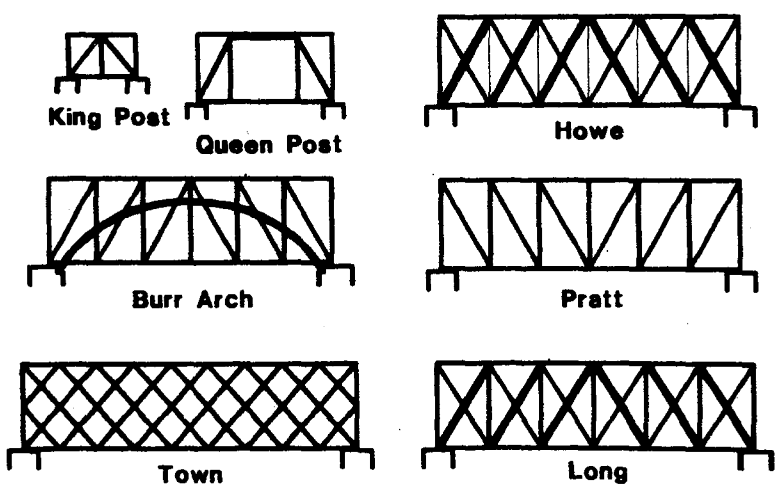


Figure 2-7 Early American Trusses

The Howe truss design, which was the basis of most early railroad trusses, was patented in 1840 by William Howe. This design utilized a multiple king post system and was the testing bed for the use of iron truss members.

The first rational analysis of the stresses in the members of truss spans came in a book published by Squire Whipple in 1847 entitled *A Work On Bridge Building*. Until that time, most bridges were constructed by empirical methods, frequently with the use of models tested to destruction.

One of the first scientifically designed trusses was the Pratt truss, which was structurally the reverse of the Howe truss. The diagonals of a Pratt truss are pure tension members and were wrought iron rods, while the vertical compression members were of wood or cast iron. A few of these old cast and wrought iron trusses remain in service today.

Meanwhile, the first true suspension bridge (one in which the roadway is suspended from the cables and not resting on them) was completed in 1801 by James Finley. This bridge, over Jacobs Creek in Fayette County, Pennsylvania, had a 70-foot span and was of iron chain construction.

First Use of Steel in Bridges

The modern era of bridge building can be said to have begun in 1855, when the Bessemer process of making steel was developed. The first bridge in America to make significant use of steel was the Eads Bridge over the Mississippi River in St. Louis (see Figure 2-8). This structure, a three-span steel arch bridge more than 1,500 feet in length, was completed in 1874, requiring six years for its construction. Although the Eads Bridge was a steel arch, many of the bridges built during the next fifty or more years were steel trusses, most of which were constructed after 1904.

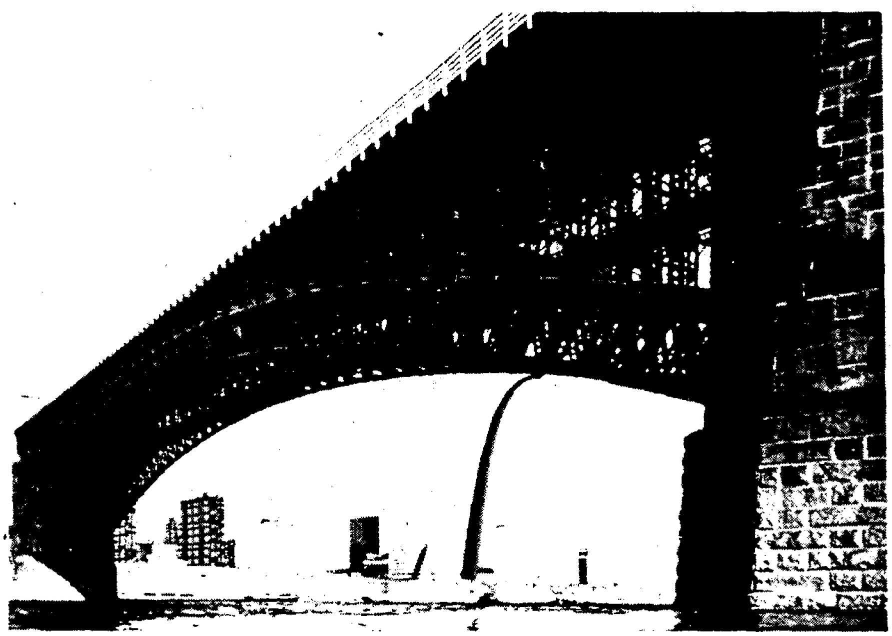


Figure 2-8 The Eads Bridge

Concurrently with the development of truss bridges came the development of steel I-beam and girder bridges. As steel rapidly replaced wrought iron for girder construction, the most common type of short span bridge was the riveted, built-up plate girder. This type of bridge beam generally consists of a web plate, side plates, flange angles, and flange plates.

As the nineteenth century came to an end, bridge engineers continued to extend the limits of their knowledge. The Brooklyn Bridge, perhaps our nation's most famous bridge, was completed in 1883 using steel wire for the suspension and stay cables. Steel reinforced concrete, first used in America in the Alvord Lake Bridge in 1889, would provide bridge engineers with entirely new challenges.

2.8 Twentieth Century Bridges

During the first half of the twentieth century, there were rapid advances in the use of reinforced concrete (see Figure 2-9). New bridges were constructed such as:

- Simple span slabs
- Tee beams
- Rigid frames
- Arches

Concrete Bridges

Reinforced concrete construction combines the compressive strength of concrete with the tensile strength of the reinforcing steel. The reinforcement functionally replaces the portion of the concrete that is in tension.

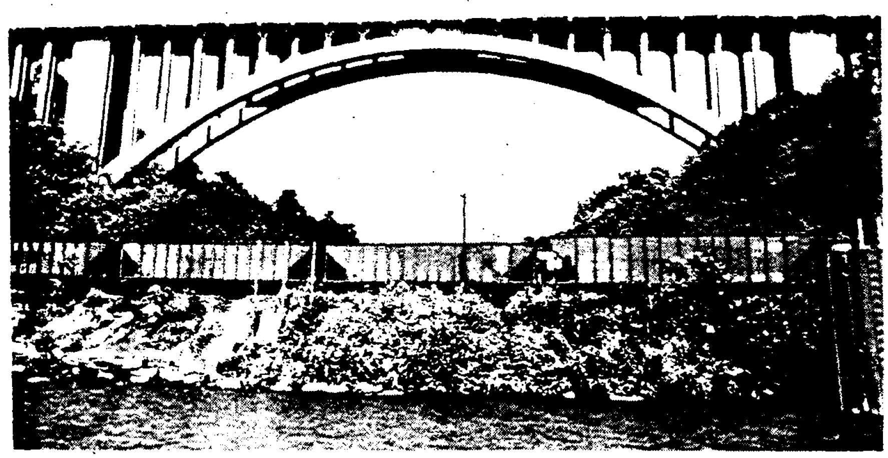


Figure 2-9 Reinforced Concrete Bridge

Although a bridge superstructure may consist of steel trusses, beams, or girders, reinforced concrete plays an important role in the total structure. The bridge deck, piers, abutments, and wingwalls are usually made of reinforced concrete.

Steel Bridges

While the use of concrete expanded, the steel industry advanced. As steel plants developed larger rolling mills, it was possible to substitute rolled beams of I-sections for riveted girders. Many of our steel highway bridges use rolled beams (see Figure 2-10).

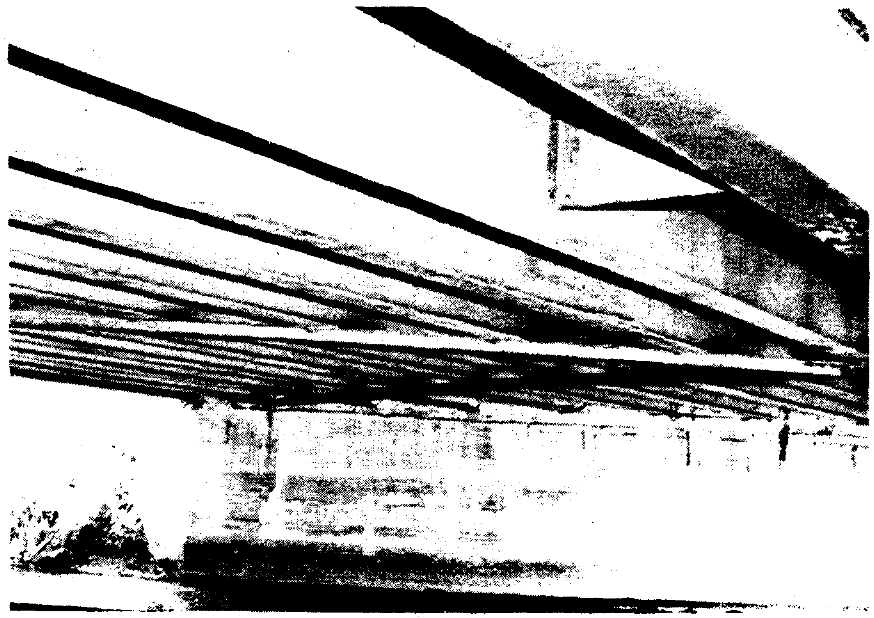


Figure 2-10 Steel Multi-Beam Bridge

The steel truss continued to be the favorite for long span bridges well into the twentieth century, although suspension bridges, along with concrete and masonry arches, were also used extensively. For smaller spans, reinforced concrete slabs, tee beams, wide flange steel beams, and built-up steel plate girders were all used. The development of parkways in the late 1920's and early 1930's generated another structure, the slender and attractive reinforced concrete rigid frame bridge.

Movable bridges were also developed in certain areas to accommodate waterway traffic. Occasionally floating bridges (both movable and fixed) have been used. Types of movable bridges include bascule bridges, or drawbridges, which can be single-leaf or double-leaf; swing bridges, which are balanced on a central pier and are rotated horizontally; and vertical lift bridges (see Figure 2-11).

Composite Construction

Composite construction designs were developed in the early 1940's. With this type of design, a mechanical lock between the steel beams or girders and the concrete deck slab is developed using shear connectors. Composite construction results in a longer span with the same cross section as non-composite construction (see Figure 2-12).

Technological Advances

Following World War II, a number of technological advances in bridge construction occurred. Long span steel girders were introduced, largely replacing the multiple short truss span bridges (see Figure 2-13). The use of welding replaced riveted construction for spans too long for the rolled beam sections. The use of high strength bolts replaced field driven rivets.

The first prestressed concrete bridge in the United States was the Walnut Lane Bridge in Philadelphia, built in 1949. Prestressed concrete is now a widely used bridge construction material.

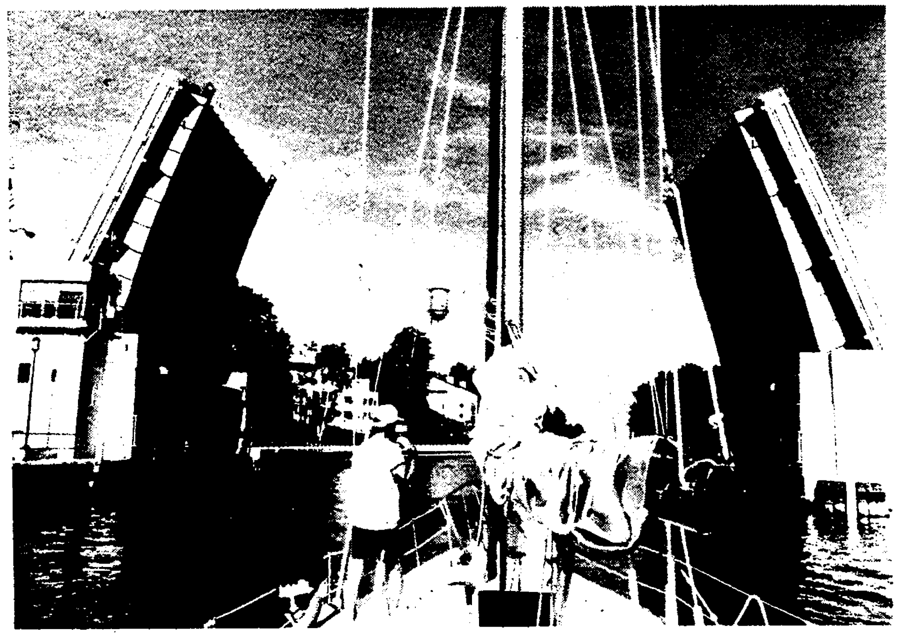


Figure 2-11 Bascule Bridge

Figure 2-12 Composite Deck Construction

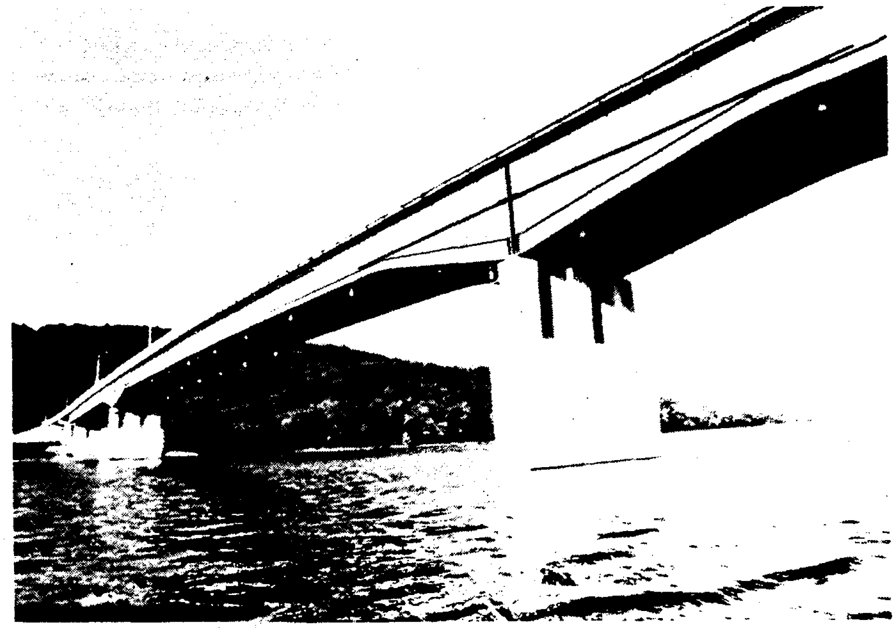


Figure 2-13 Long Span Steel Girder Bridge

Use of Computers

Probably the most significant development in bridges over the last 20 years has been the use of the computer. The computer has revolutionized the design and construction of bridges through such applications as:

- Multi-dimensional stress analysis
- Wind analysis
- Scour analysis
- Seismic/earthquake analysis
- Failure analysis
- Fast-track designs
- Alternative designs
- Curved bridges
- Computer aided drafting
- Bridge management systems
- Erection plans

Figure 2-14 shows a typical computerized bridge design.

2.9 Modern Bridge Trends

Bridge engineers today are combining the favorable qualities of existing materials to design structures which are longer, more cost effective, and more durable. New construction methods are being investigated which take advantage of increased material strength and add economy to long span construction. In addition, new materials are being developed that have increased strength properties.

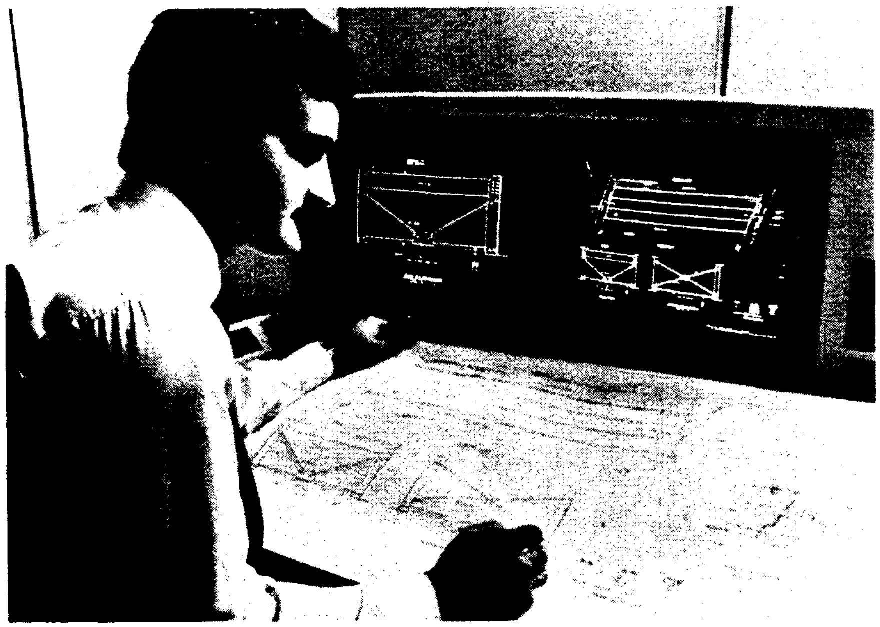


Figure 2-14 Computerized Bridge Design

Design and Construction

The modern cable-stayed bridge is perhaps the most dramatic trend in new bridge construction. The use of cable-stays dates back to the eighteenth century. However, due to a lack of technical knowledge and poor construction, many of these early bridges failed. Since the 1970's, the use of the computer has promoted the rediscovery of cable-stayed bridges. A cable-stayed bridge is described as having the floor system supported in a horizontal position by cables directly anchored to a centrally located tower. The ends of the cables are anchored at the top of the tower and fixed at the connection to the floor system. The Sunshine Skyway Bridge over Tampa Bay, Florida is an example of a cable-stayed bridge. The deck is 8860 feet long and is 175 feet above the bay. There are 21 cable-stays running through each of two towers (see Figure 2-15).

The Sunshine Skyway Bridge also incorporates some other features of modern bridges involving the use of prestressed segmental concrete. The substructure units of the Sunshine Skyway Bridge were constructed from precast foundation units, hollow columns, and headers. The advantages of using precast elements are quicker construction schedules and improved quality control of the concrete.

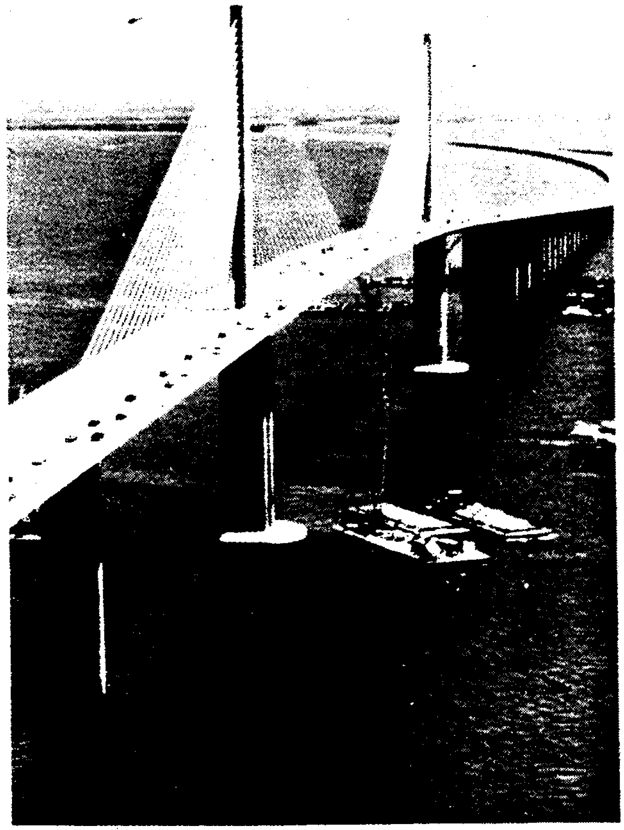


Figure 2-15 Sunshine Skyway Bridge (Source: Figg Engineering Group)

The advantages of precast segmental box girder construction methods include (refer to Section 21.4):

- Use of repetitive manufacturing techniques
- Structural geometry is easily adapted to both horizontal and vertical curvature
- Reduced effects of concrete shrinkage and creep
- No need for formwork during construction

Box girders are also steel or cast-in-place concrete. Box girders are often used for curved bridges due to their torsional strength.

The use of timber in bridge construction is also making a comeback. With manufacturing improvements such as glue laminated beams, protective systems, as well as new construction techniques, timber is once again a cost effective alternative for a short span bridge.

Bridge Rehabilitation

The greatest challenge for today's bridge industry is probably not in the area of new design, but rather in the area of rehabilitation. Innovative solutions to maintaining the nation's existing bridges are very challenging. The role of the bridge inspector is one of providing basic data input in the decision-making process leading to the priority of bridge rehabilitation. This role is vital to the survival of our nation's highway system (see Figure 2-16).

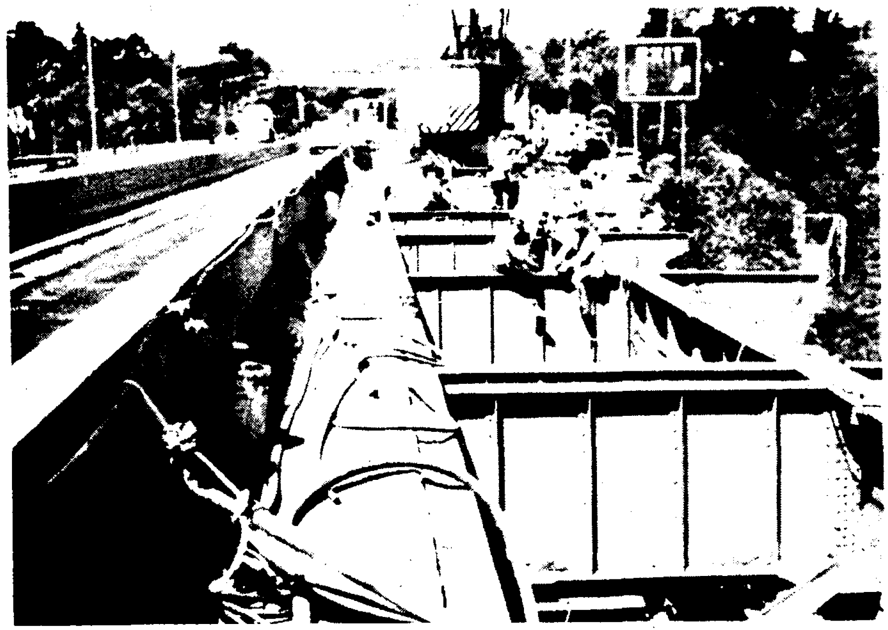


Figure 2-16 Bridge Rehabilitation Project

3

Bridge Mechanics

Basic Equations of Bridge Mechanics

$$S = \frac{P}{A} \qquad f_a = \frac{P}{A}$$

$$\varepsilon = \frac{\Delta L}{L} \qquad f_b = \frac{Mc}{I}$$

$$E = \frac{S}{\varepsilon} \qquad f_v = \frac{V}{A_w}$$

$$\text{Bridge Load Capacity Rating} = \frac{\text{Allowable Load} - \text{Dead Load}}{\text{Rating Vehicle Live Load Plus Impact}} \times \text{Vehicle Weight (Tons)}$$

where:

A	=	area; cross-sectional area
A_w	=	area of web
c	=	distance from neutral axis to extreme fiber (or surface) of beam
E	=	modulus of elasticity
f_a	=	axial stress
f_b	=	bending stress
f_v	=	shear stress
I	=	moment of inertia
L	=	original length
M	=	applied moment
P	=	force; axial force
S	=	stress
V	=	vertical shear force due to external loads
ΔL	=	change in length
ε	=	strain

3

Bridge Mechanics

3.1 Introduction

Mechanics is the branch of physical science that deals with energy and forces and their relation to the equilibrium, deformation, or motion of bodies. The bridge inspector will primarily be concerned with statics, or the branch of mechanics dealing with solid bodies at rest and with forces in equilibrium.

The two most important reasons for studying bridge mechanics are:

- To understand how bridge members function
- To recognize the impact a defect may have on the load carrying capability of a bridge member

While this chapter presents the basic principles of bridge mechanics, the references listed in the bibliography should be referred to for a more complete presentation of this subject.

3.2 Bridge Design Loadings

Bridge members are designed to withstand the loads acting on them in a safe and economical manner. Loads may be concentrated or distributed depending on the way in which they are applied to the structure.

A concentrated load, or point load, is applied at a single location or over a very small area. Vehicle loads are considered concentrated loads.

A distributed load is applied to all or part of the member, and the amount of load per unit of length is generally constant. Bridge decks, wearing surfaces, and bridge parapets produce distributed loads. Secondary loads, such as wind and ice, are also usually distributed loads.

Highway bridge design loads are established by the American Association of State Highway and Transportation Officials (AASHTO) in their *Standard Specifications for Highway Bridges* (*Specifications*) and supplemented by agency criteria as applicable. Bridge design loadings can be divided into three principal categories:

- Dead loads
- Primary live loads
- Secondary loads

3.2.1 Dead Loads

Dead loads do not change as a function of time and are considered full-time, permanent loads acting on the structure. They consist of the weight of the materials used to build the bridge (see Figure 3-1). Dead load includes both the self weight of structural members and other permanent external loads.

Example of self weight: A 20 foot long beam weighs 50 pounds per linear foot. The total weight of the beam is 1000 pounds. This weight is called the self weight of the beam.

Example of an external dead load: If a utility such as a water line is permanently attached to the beam in the previous example, then the weight of the water line plus the self weight of the beam comprises the total dead load.

Total dead load on a structure may change during the life of the bridge due to additions such as deck overlays, parapets, utility lines, and inspection catwalks.

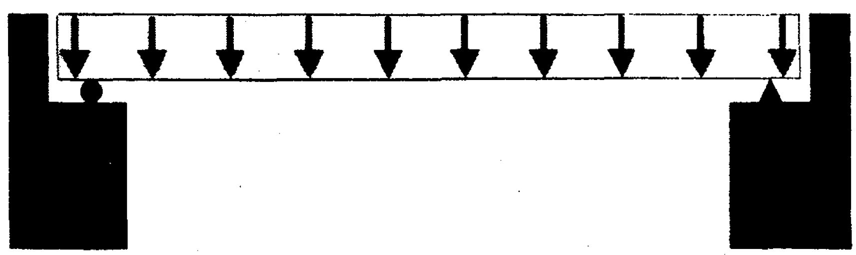


Figure 3-1 Dead Load on a Bridge

3.2.2 Primary Live Loads

Live loads are considered part-time or temporary loads, mostly of short-term duration, acting on the structure. In bridge applications, the primary live loads are moving vehicular loads (see Figure 3-2).

To account for the affects of speed, vibration, and momentum, highway live loads are typically increased for impact. Impact is expressed as a fraction of the live load, and its value is a function of the span length. The maximum value of impact is 30 percent of the live load, and impact decreases as the span length increases.

Standard vehicle live loads have been established by AASHTO for use in bridge design and rating. It is important to note that these standard vehicles do not represent actual vehicles. Rather, they were developed to allow a relatively simple method of analysis based on an approximation of the actual live load.

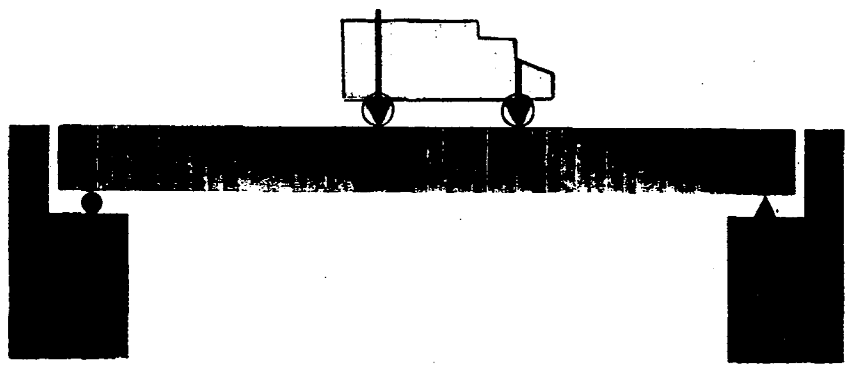


Figure 3-2 Vehicle Live Load on a Bridge

AASHTO Truck Loadings

There are two basic types of standard truck loadings described in the current AASHTO *Specifications*. The first type is a single unit vehicle with two axles spaced at 14 feet and designated as a highway truck or "H" truck (see Figure 3-3). The weight of the front axle is 20% of the gross vehicle weight, while the weight of the rear axle is 80% of the gross vehicle weight. The "H" designation is followed by the gross tonnage of the particular design vehicle.

Example of an H truck loading: H20-35 indicates a 20 ton vehicle with a front axle weighing 4 tons, a rear axle weighing 16 tons and the two axles spaced 14 feet apart. This standard truck loading was first published in 1935.

The second type of standard truck loading is a two unit, three axle vehicle comprised of a highway tractor with a semi-trailer. It is designated as a highway semi-trailer truck or "HS" truck (see Figure 3-4).

The tractor weight and wheel spacing is identical to the H truck loading. The semi-trailer axle weight is equal to the weight of the rear tractor axle, and its spacing from the rear tractor axle can vary from 14 to 30 feet. The "HS" designation is followed by a number indicating the gross weight in tons of the tractor only.

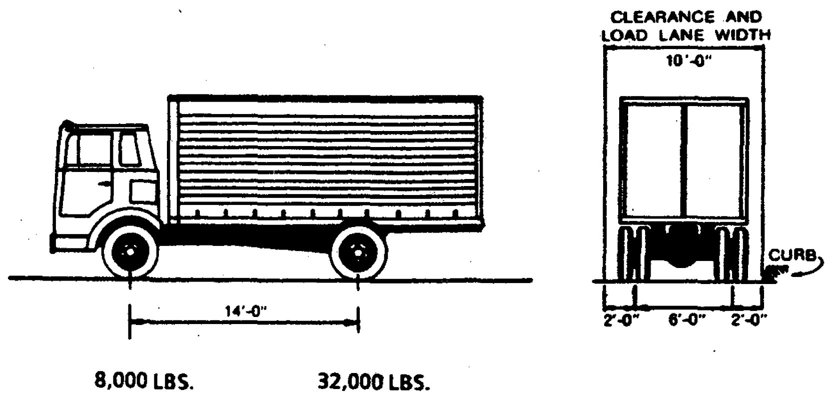


Figure 3-3 AASHTO H20 Truck (Source: 3)

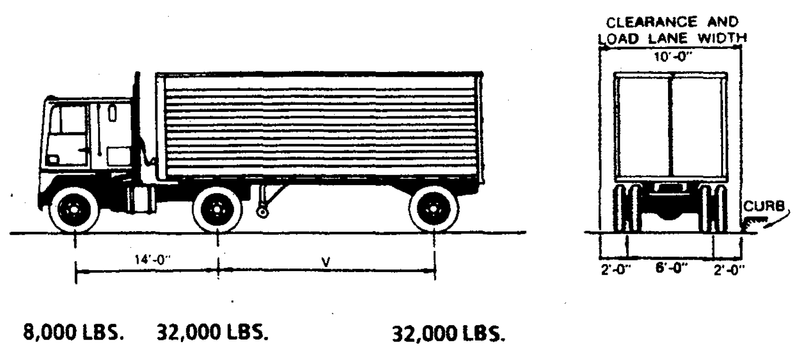


Figure 3-4 AASHTO HS20 Truck (Source: 3)

Example of an HS truck loading: HS20-44 indicates a vehicle with a front tractor axle weighing 4 tons, a rear tractor axle weighing 16 tons, and a semi-trailer axle weighing 16 tons. The tractor portion alone weighs 20 tons, but the gross vehicle weight is 36 tons. This standard truck loading was first published in 1944.

In specifications prior to 1944, a standard loading of H15 was used. In 1944, the policy of affixing the publication year of design loadings was adopted. In specifications prior to 1965, the HS20-44 loading was designated as H20-S16-44, with the S16 identifying the gross axle weight of the semi-trailer in tons.

AASHTO Lane Loadings

In addition to the standard truck loadings, a system of equivalent lane loadings was developed. Lane loading consists of a uniform load per linear foot of traffic lane combined with a concentrated load located on the span to produce the most critical situation (see Figure 3-5).

For design and load capacity rating analysis, an investigation of both a truck loading and a lane loading must be made to determine which produces the greatest stress for each particular member. Lane loading will generally govern over truck loading for longer spans.

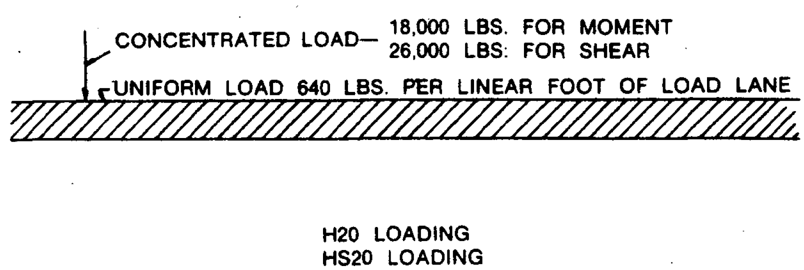


Figure 3-5 AASHTO Lane Loading (Source: 3)

Alternate Military Loading

The Alternate Military Loading is a single unit vehicle with two axles spaced at 4 feet and weighing 12 tons each. It has been part of the AASHTO *Specifications* since 1977. Bridges on interstate highways or other highways which are potential defense routes are designed for either an HS20 loading or an Alternate Military Loading.

Permit Vehicles

Permit vehicles are overweight vehicles which, in order to travel a state's highways, must apply for a permit from that state. They are usually heavy trucks (e.g., combination trucks, construction vehicles, or cranes) which have varying axle spacings depending upon the design of the individual truck. To ensure that these vehicles can safely operate on existing highways and bridges, most states require that bridges be designed for a permit vehicle or that the bridge be checked to determine if it can carry a specific type of vehicle. For safe and legal operation, agencies issue permits upon request which identify the required gross weight, number of axles, axle spacing, and maximum axle weights for a designated route.

3.2.3 Secondary Loads

In addition to dead loads and primary live loads, bridge components are designed to resist secondary loads, which include the following:

- **Earth pressure** - a horizontal force acting on earth-retaining substructure units, such as abutments and retaining walls
- **Buoyancy** - the force created due to the tendency of an object to rise when submerged in water
- **Wind load on structure** - wind pressure on the exposed area of a bridge
- **Wind load on live load** - wind effects transferred through the live load vehicles crossing the bridge
- **Longitudinal force** - a force in the direction of the bridge caused by braking and accelerating of live load vehicles
- **Centrifugal force** - an outward force that a live load vehicle exerts on a curved bridge
- **Rib shortening** - a force in arches and frames created by a change in the geometrical configuration due to dead load
- **Shrinkage** - applied primarily to concrete structures, this is a multi-directional force due to dimensional changes resulting from the curing process
- **Temperature** - since materials expand as temperature increases and contract as temperature decreases, the force caused by these dimensional changes must be considered
- **Earthquake** - bridge structures must be built so that motion during an earthquake will not cause a collapse
- **Stream flow pressure** - a horizontal force acting on bridge components constructed in flowing water
- **Ice pressure** - a horizontal force created by floating ice jammed against bridge components
- **Sidewalk loading** - sidewalk floors and their immediate supports are designed for a pedestrian live load not exceeding 85 pounds per square foot
- **Curb loading** - curbs are designed to resist a lateral force of not less than 500 pounds per linear foot
- **Railing loading** - railings are provided along the edges of structures for protection of traffic and pedestrians; the maximum transverse load applied to any one element need not exceed 10 kips

A bridge may be subjected to several of these loads simultaneously. The AASHTO *Specifications* have established a table of loading groups. For each group, a set of loads is considered with a coefficient to be applied for each particular load. The coefficients used were developed based on the probability of various loads acting simultaneously.

3.3 Material Response to Loadings

Each member of a bridge has a unique purpose and function, which directly affects the selection of material, shape, and size for that member. Certain terms are used to describe the response of a bridge material to loads. A working knowledge of these terms is essential for the bridge inspector.

Force

A force is the action that one body exerts on another body. Force has two components: magnitude and direction. The basic English unit of force is called a pound (abbreviated as lb.). A common unit of force which is used among engineers is a kip, which is 1000 pounds.

3.3.1 Stress

Stress is a basic unit of measure used to denote the intensity of an internal force. When a force is applied to a material, an internal stress is developed. Stress is defined as a force per unit of cross-sectional area.

$$\text{Stress (S)} = \frac{\text{Force (P)}}{\text{Area (A)}}$$

The basic English unit of stress is pounds per square inch (abbreviated as psi). However, stress can also be expressed in kips per square inch (ksi) or in any other units of force per unit area. An allowable unit stress is generally established for a given material.

Example of a stress: If a 30,000 lb. force acts uniformly over an area of 10 square inches, then the stress caused by this force is 3000 psi (or 3 ksi).

3.3.2 Deformation

Deformation is the local distortion or change in shape of a material due to stress.

Strain

Strain is a basic unit of measure used to describe an amount of deformation. It denotes the ratio of a material's deformed dimension to a material's original dimensions. For example, strain in a longitudinal direction is computed by dividing the change in length by the original length.

$$\text{Strain } (\varepsilon) = \frac{\text{Change in Length } (\Delta L)}{\text{Original Length (L)}}$$

Strain is a dimensionless quantity. However, it can also be expressed as a percentage or in units of length per length (e.g., inch/inch).

Example of strain: If a weight acting on a 20 foot long column causes an axial deformation of 0.002 feet, then the resulting axial strain is 0.002 feet divided by 20 feet, or 0.0001 foot/foot. This strain can also be expressed simply as 0.0001 (with no units) or as 0.01%.

Elastic Deformation

Elastic deformation is the reversible distortion of a material. A member is elastically deformed if it returns to its original shape upon removal of a force. Elastic strain is sometimes termed reversible strain because it disappears after the stress is removed.

Example of elastic deformation: A stretched rubber band will return to its original shape after being released from a taut position.

Plastic Deformation

Plastic deformation is the irreversible or permanent distortion of a material. A material is plastically deformed if it retains a deformed shape upon removal of a force. Plastic strain is sometimes termed irreversible or permanent strain because it remains after the stress is removed.

Example of plastic deformation: If a car crashes into a brick wall, the fenders and bumpers would deform. This deformation would remain even after the car backed away from the wall. Therefore, the fenders and bumpers have undergone plastic deformation.

Creep

Creep is a form of plastic deformation that occurs gradually at stress levels normally associated with elastic deformation. Creep is defined as the gradual continuing irreversible change in the dimensions of a member due to the sustained application of load.

Example of creep: If a lump of putty is left untouched on a table for several days, it will gradually settle and change in shape. This deformation is due to the sustained application of its own weight and illustrates the effects of creep.

Thermal Effects

In bridges, thermal effects are most commonly experienced in the longitudinal expansion and contraction of the superstructure. It is possible to disregard deformations caused by thermal effects when members are free to expand and contract. However, there may be members for which expansion and contraction is inhibited or prevented in certain directions. Thermal changes in these members can cause significant frictional stresses and must be considered by the inspector.

Materials expand as temperature increases and contract as temperature decreases. The amount of thermal deformation in a member depends on:

- A coefficient of thermal expansion, unique for each material
- The temperature change
- The member length

Example of thermal effects: Most thermometers operate on the principle that the material within the glass bulb expands as the temperature increases and contracts as the temperature decreases.

3.3.3 Stress-Strain Relationship

For most structural materials, values of stress and strain are directly proportional (see Figure 3-6). However, this proportionality exists only up to a particular value of stress called the elastic limit. Two other frequently used terms which closely correspond with the elastic limit are the proportional limit and the yield point.

When applying stress up to the elastic limit, a material deforms elastically. Beyond the elastic limit, deformation is plastic and strain is not directly proportional to a given applied stress. The material property which defines its stress-strain relationship is called the modulus of elasticity, or Young's modulus.

Modulus of Elasticity

Each material has a unique modulus of elasticity which defines the ratio of a given stress to its corresponding strain.

$$\text{Modulus of elasticity (E)} = \frac{\text{Stress (S)}}{\text{Strain } (\varepsilon)}$$

The modulus of elasticity applies only as long as the elastic limit of the material has not been reached. The units for modulus of elasticity are the same as those for stress (i.e., psi or ksi).

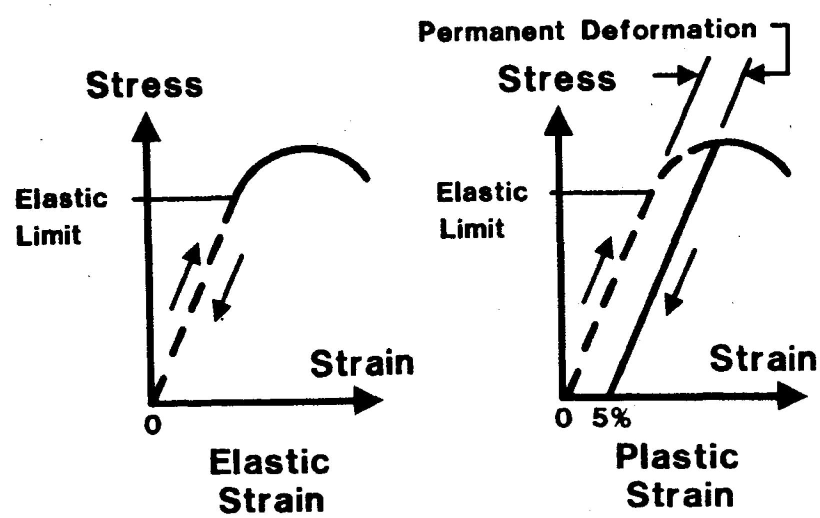


Figure 3-6 Stress-Strain Diagram

Example of modulus of elasticity: If a stress of 2900 psi is below the elastic limit and causes a strain of 0.0001, then the modulus of elasticity can be computed based on these values of stress and strain.

$$E = \frac{2900\text{ psi}}{0.0001} = 29{,}000{,}000\text{ psi} = 29{,}000\text{ ksi}$$

This is approximately equal to the modulus of elasticity for steel. The modulus of elasticity for concrete is approximately 3000 to 4500 ksi, and for commonly used grades of timber it is approximately 1600 ksi.

3.3.4 Ductility and Brittleness

Ductility is the measure of plastic (permanent) strain that a material can endure. A ductile material will undergo a large amount of plastic deformation before breaking. It will also have a greatly reduced cross-sectional area before breaking.

Example of ductility: A baker working with pizza dough will find that the dough can be stretched a great deal before it will break into two sections. Therefore, pizza dough is a ductile material. When the dough finally does break, it will have a greatly reduced cross-sectional area.

Structural materials that are generally ductile include:

- Steel
- Aluminum
- Copper

Brittle, or non-ductile, materials will not undergo significant plastic deformation before breaking. Failure of a brittle material occurs suddenly, with little or no warning.

Example of brittleness: A glass table may be able to support several magazines and books. However, if more and more weight is piled onto the table, the glass will eventually break with little or no warning. Therefore, glass is a brittle material.

Structural materials that are generally brittle include:

- Concrete
- Cast iron
- Stone

3.3.5 Fatigue

Fatigue is a material response that describes the tendency of a material to break when subjected to repeated loading. Fatigue failure occurs within the elastic range of a material after a certain number and magnitude of stress cycles have been applied.

Each material has a hypothetical maximum stress value to which it can be loaded and unloaded an infinite number of times. This stress value is referred to as the fatigue limit and is usually lower than the breaking strength for infrequently applied loads.

Ductile materials such as steel and aluminum have high fatigue limits, while brittle materials such as concrete have low fatigue limits. Wood has a high fatigue limit even though it is more like a brittle material than a ductile one.

Example of fatigue: If a steel paper clip is bent and then straightened again, it is unlikely that the paper clip will break into two pieces. However, if this action is repeated several times, the paper clip will eventually break. The paper clip failure is analogous to a fatigue failure.

For a description of fatigue categories for various steel details, refer to Chapter 18.

3.4 Bridge Response to Loadings

Each member of a bridge is intended to respond to loads in a particular way. The bridge inspector must understand the manner in which loads are applied to each member in order to evaluate if it functions as intended.

Bridge members respond to various loadings by resisting four basic types of forces. These are:

- Axial forces (compression and tension)
- Bending forces (flexure)
- Shear forces
- Torsional forces

Equilibrium

In calculating these forces, the analysis is governed by equations of equilibrium. Equilibrium equations represent a balanced force system and may be expressed as:

$$\Sigma V = 0$$
$$\Sigma H = 0$$
$$\Sigma M = 0$$

where: Σ = summation of
V = vertical forces
H = horizontal forces
M = moments (bending forces)

3.4.1 Axial Forces

An axial force is a push or pull type of force which acts in the long direction of a member. An axial force causes compression if it is pushing and tension if it is pulling (see Figure 3-7). Axial forces are generally expressed in units of pounds or kips.

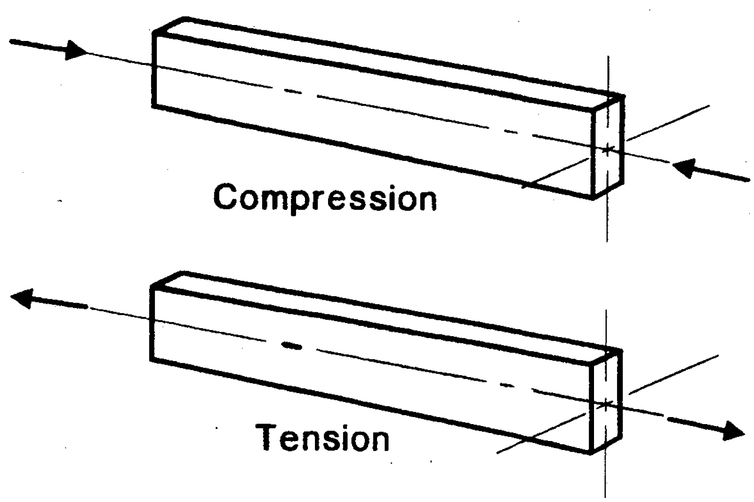


Figure 3-7 Axial Forces

Example of an axial force: A man sitting on top of a fence post is exerting an axial force that causes compression in the fence post. A group of people playing tug-of-war exerts an axial force that causes tension in the rope.

Truss members are common bridge elements which carry axial loads. They are designed for both compression and tension forces. Cables are designed for axial forces in tension. Columns are vertical bridge elements designed for compressive axial forces.

True axial forces act uniformly over a cross-sectional area. Therefore, axial stress can be calculated by dividing the force by the area on which it acts.

$$f_a = \frac{P}{A}$$

where:
f_a = axial stress
P = axial force
A = cross-sectional area

When bridge members are designed to resist axial forces, the cross-sectional area will vary depending on the magnitude of the force, whether the force is tensile or compressive, and the type of material used.

For tension and compression members, the cross-sectional area must satisfy the previous equation for an acceptable axial stress. However, the acceptable axial compressive stress is generally lower than that for tension because of a phenomenon called buckling.

Buckling

Buckling is the tendency of a member to deform or bend out of plane when subjected to a compressive force. As the length and slenderness of a compression member increases, the likelihood of buckling also increases.

Compression members require additional cross-sectional area or bracing to resist buckling.

Example of buckling: A paper or plastic straw compressed axially at both ends with an increasing force will eventually buckle.

3.4.2 Bending Forces

Bending forces in bridge members are caused by moment. A moment is commonly developed by a transverse loading which causes a member to bend. Bending moments produce both compression and tension forces at different locations in the member and can be positive or negative (see Figure 3-8). Moments are generally expressed in units of pound-feet or kip-feet.

Example of bending moment: When a rectangular rubber eraser is bent, a moment is produced in the eraser. If the ends are bent upwards, the top half of the eraser can be seen to shorten, while the bottom half can be seen to lengthen. Therefore, the moment produces compression forces in the top layers of the eraser and tension forces in the bottom layers.

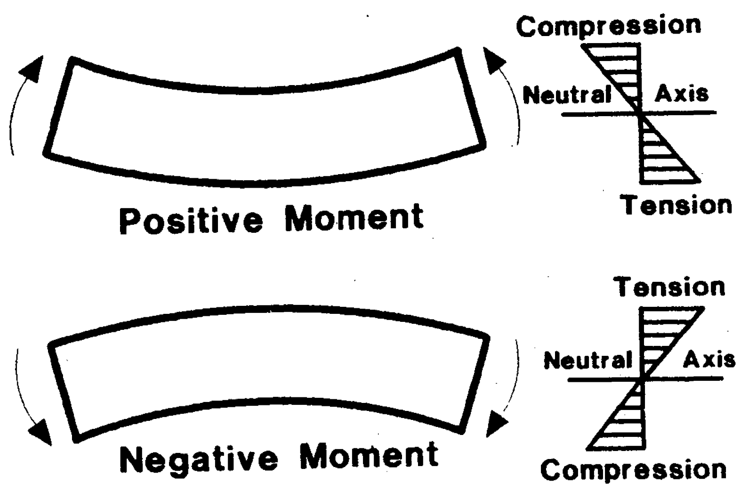


Figure 3-8 Positive and Negative Moment

Beams and girders are the most common bridge elements used to resist bending moments. The flanges are most critical because they provide the greatest resistance to the compressive and tensile forces developed by the moment (see Figure 3-9).

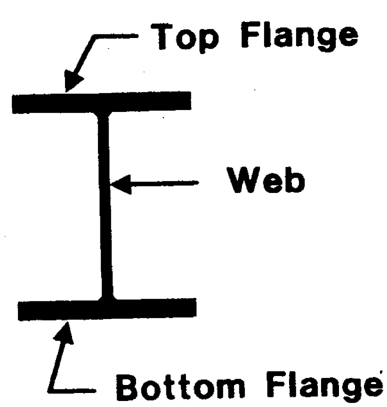


Figure 3-9 Girder Cross Section

Bending members have a neutral axis at which there are no bending stresses. On a cross section of a member, bending stresses vary linearly with respect to the distance from the neutral axis (see Figures 3-8 and 3-10).

The formula for maximum bending stress is (see Figure 3-10):

$$f_b = \frac{M\,c}{I}$$

where:
- f_b = bending stress on extreme fiber (or surface) of beam
- M = applied moment
- c = distance from neutral axis to extreme fiber (or surface) beam
- I = moment of inertia (a property of the beam cross-sectional area and shape)

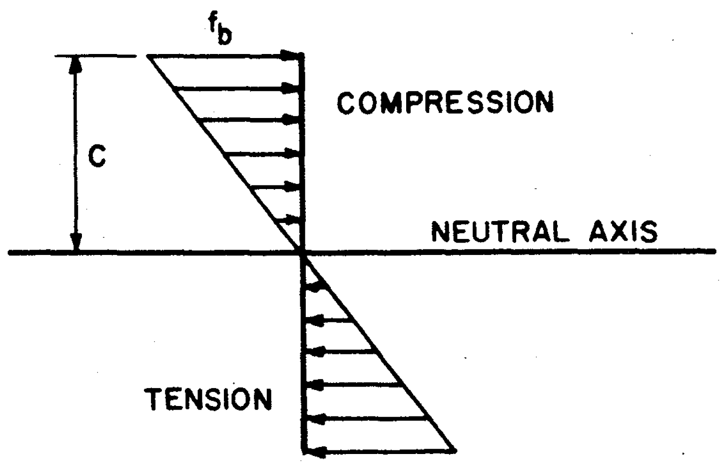


Figure 3-10 Bending Stresses

3.4.3 Shear Forces

Shear is a force which results from equal but opposite transverse forces which tend to slide one section of a member past an adjacent section (see Figure 3-11). Shear forces are generally expressed in units of pounds or kips.

Example of shear: When scissors are used to cut a piece of paper, a shear force has caused one side of the paper to separate from the other. Scissors are often referred to as shears since they exert a shear force.

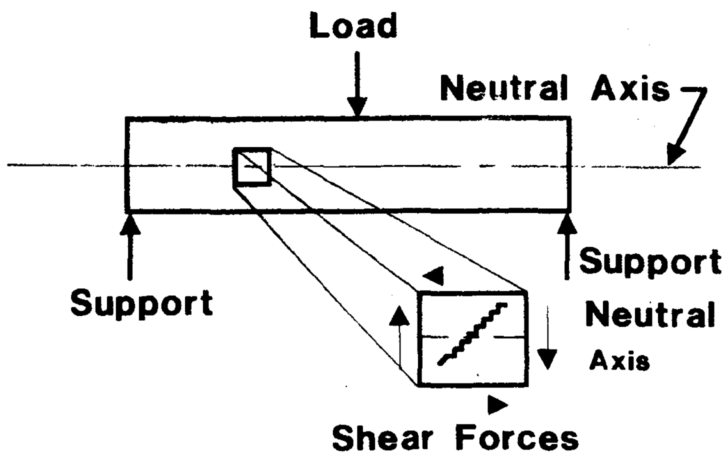


Figure 3-11 Shear Forces in a Member Element

Beams and girders are common shear resisting members. In an I- or T-beam, most of the shear is resisted by the web (see Figure 3-9). The shear stress produced by the transverse forces is manifested in a horizontal shear stress which is accompanied by a vertical shear stress of equal magnitude. Vertical shear strength is generally considered in most design criteria. The formula for vertical shear stress in I- or T-beams is:

$$f_v = \frac{V}{A_w}$$

where: f_v = shear stress
V = vertical shear due to external loads
A_w = area of web

In a solid rectangular beam, shear is resisted by the entire cross section, and the formula for vertical shear stress is:

$$f_v = \frac{3V}{2A}$$

where: A = cross-sectional area

3.4.4 Torsional Forces

Torsion is a force resulting from externally applied moments which tend to rotate or twist a member about its longitudinal axis. Torsional force is commonly referred to as torque and is generally expressed in units of pound-feet or kip-feet.

Example of torsion: One end of a ten foot long rectangular steel bar is clamped horizontally in a vise so that the long side is up and down. Using a large wrench, a moment is applied to the other end which causes it to rotate so that the long side is now left to right. The steel bar is resisting a torsional force or torque which has twisted it 90° with respect to its original orientation.

Bridge elements are generally not designed as torsional members. However, in some bridge superstructures where elements are framed together, torsional forces can occur in longitudinal members. When these members experience differential deflection, adjoining transverse members apply twisting moments resulting in torsion. In addition, curved bridges are generally subject to torsion (see Figure 3-12).

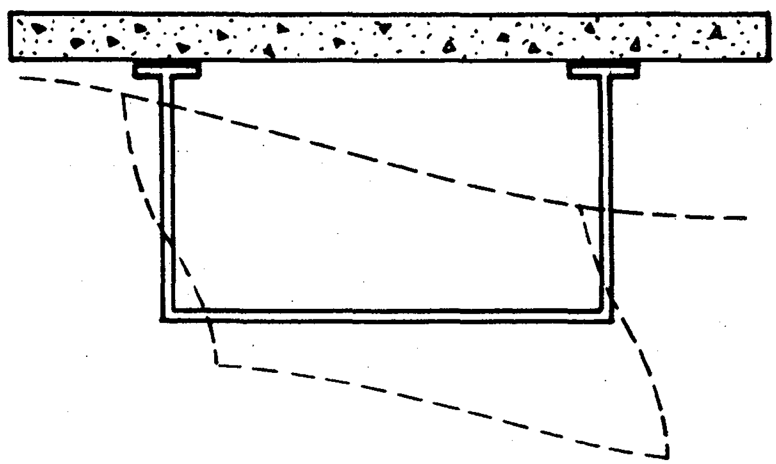


Figure 3-12 Torsional Distortion

3.4.5 Reactions

A reaction is a force provided by a support that is equal but opposite to the force transmitted from a member to its support (see Figure 3-13). Reactions are most commonly vertical forces, but a reaction can also be a horizontal force. A vertical reaction increases as the loads on the member are increased or as the loads are moved closer to that particular support. Reactions are generally expressed in units of pounds or kips.

Example of reactions: Consider a bookshelf consisting of a piece of wood supported at its two ends by bricks. The bricks serve as supports, and the reaction is based on the weight of the shelf and the weight of the books on the shelf. As more books are added, the reaction provided by the bricks will increase. As the books are shifted to one side, the reaction provided by the bricks at that side will increase, while the reaction at the other side will decrease.

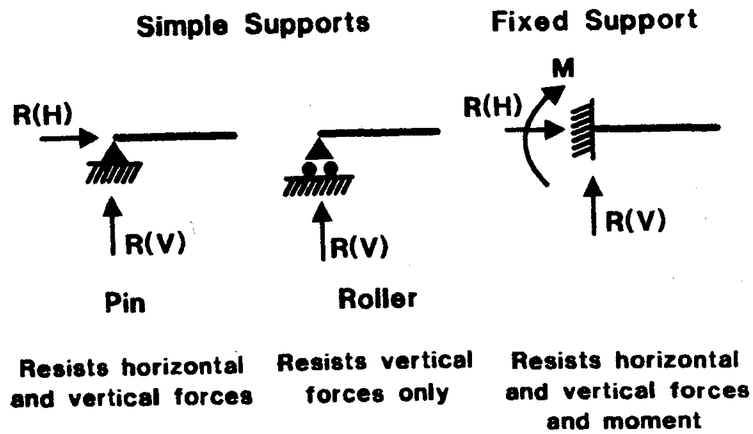


Figure 3-13 Types of Supports

The loads of the entire bridge always equal the reactions provided by the abutments and the piers. However, on a smaller scale, each individual beam and girder also exerts forces which create reactions provided by its supporting members.

3.5 Design Features

Beams and bridges are classified into three span classifications that are based on the nature of the supports and the interrelationship between spans. These classifications are:

- Simple
- Continuous
- Cantilever

Bridges also have two classifications that are based on the relationship between the deck and the beams. These classifications are:

- Non-composite
- Composite

Another design feature is the foundation, which ultimately supports the entire bridge.

Each of these design features has unique characteristics and behavior which the bridge inspector must understand.

3.5.1 Simple

A simple span is a span with only two supports, each of which is at or near the end of the span (see Figure 3-14).

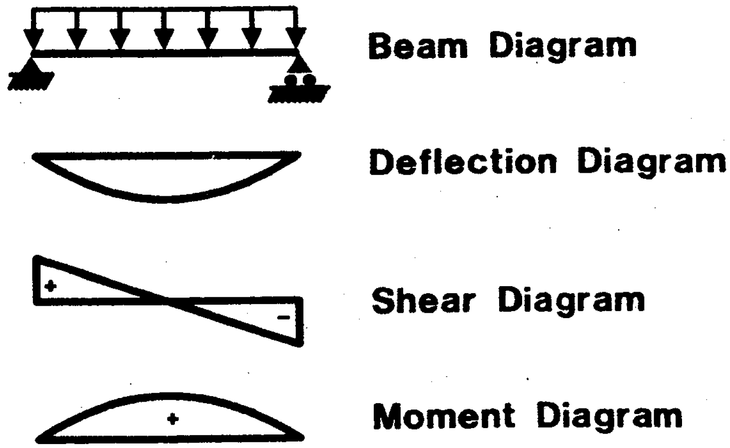


Figure 3-14 Simple Span

A simple span bridge can have a single span supported at the ends by two abutments or multiple spans with each span behaving independently of the others. Some characteristics of simple span bridges are:

- When loaded, the span deflects downward and rotates at the supports (i.e., the abutments)
- The sum of the reactions provided by the two supports equals the entire load
- Shear forces are maximum at the supports and zero at or near the middle of the spans
- Bending moment throughout the span is positive and maximum at or near the middle of the span (the same location at which shear is zero); bending moment is zero at the supports

A simple span bridge is easily analyzed using equilibrium equations. However, it does not always provide the most economical design solution.

3.5.2 Continuous

A continuous span is a configuration in which a beam has one or more intermediate supports and the behavior of the individual spans created is dependent on its adjacent spans (see Figure 3-15).

A continuous span bridge is one which is supported at the ends by two abutments and which spans uninterrupted over one or more piers. Some characteristics of continuous span bridges are:

- When loaded, the spans deflect downward and rotate at the supports (i.e., the abutments and the piers)
- The reactions provided by the supports depend on the span configuration and the distribution of the loads

- Shear forces are maximum at the supports and zero at or near the middle of the spans
- Positive bending moment is greatest at or near the middle of each span
- Negative bending moment is greatest at the intermediate supports (i.e., the piers); the bending moment is zero at the end supports (i.e., the abutments); there are also two locations per intermediate support at which bending moment is zero, known as inflection points

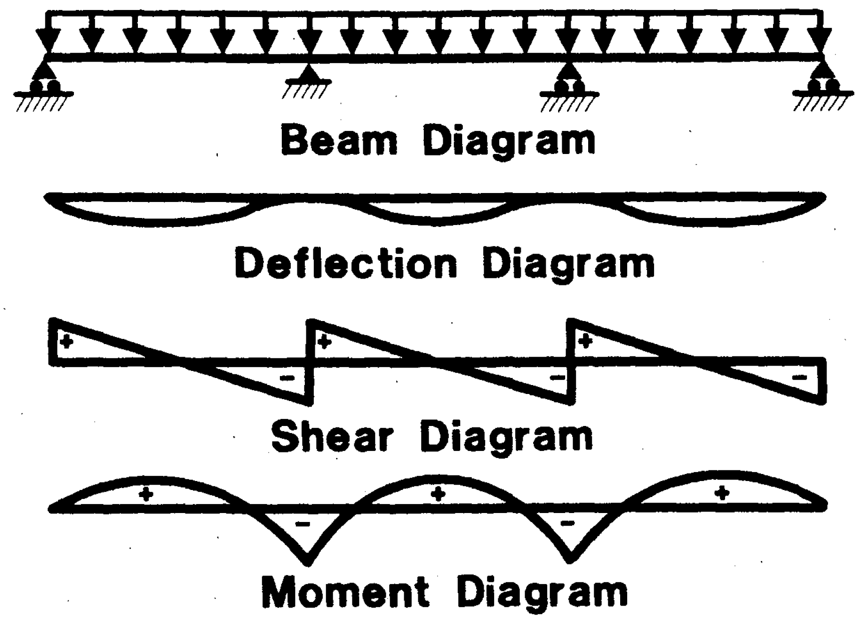


Figure 3-15 Continuous Span

A continuous span bridge allows longer spans and is more economical than a bridge consisting of many simple spans. This is due to its efficient design with members that are more shallow. However, a continuous bridge is more difficult to analyze than a simple span bridge and is more susceptible to overstress conditions if the abutments or piers settle. Simple span bridges and continuous span bridges are both commonly used.

3.5.3 Cantilever

A cantilever span is a span with one end restrained against rotation and deflection and the other end completely free (see Figure 3-16). The restrained end is also known as a fixed support (see Figure 3-13).

While a cantilever generally does not form an entire bridge, portions of a bridge can behave as a cantilever (e.g., cantilever bridges and bascule bridges). Some characteristics of cantilevers are:

- When loaded, the span deflects downward, but there is no rotation or deflection at the support
- The fixed support reaction consists of a vertical force and a resisting moment
- The shear is maximum at the fixed support and is zero at the free end

- The bending moment throughout the span is negative and maximum at the fixed support; bending moment is zero at the free end

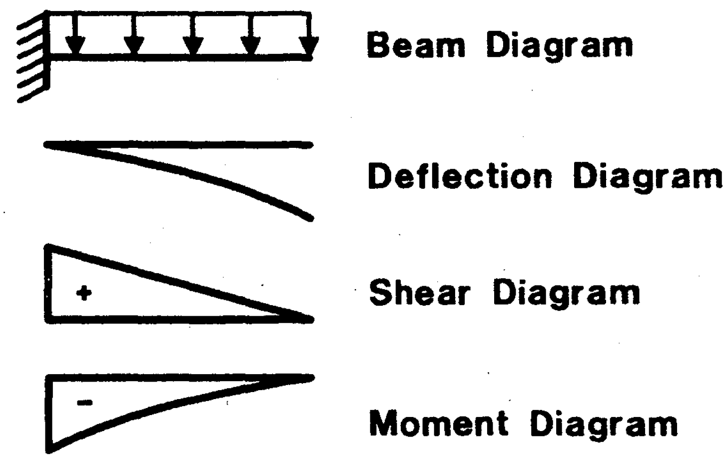


Figure 3-16 Cantilever Span

When cantilever spans are incorporated into a bridge, they are generally extensions of a continuous span. Therefore, moment and rotation at the cantilever support will be dependent on the adjacent span.

3.5.4 Non-Composite

A non-composite structure is one in which the beams act independently of the deck. Therefore, the beams alone must resist all of the loads applied to them, including the dead load of the beams, deck, and railing, and all of the live loads.

3.5.5 Composite

A composite structure is one in which the deck acts together with the beams to resist the loads (see Figure 3-17). The deck material must be strong enough to contribute significantly to the overall strength of the section. The most common combinations are concrete on steel and concrete on prestressed concrete. Composite action is provided by shear connectors such as studs, spirals, channels, or stirrups that are attached to the beams and are embedded in a concrete deck. This ensures that the beams and the deck will act as a unit by preventing slippage between the two when a load is applied.

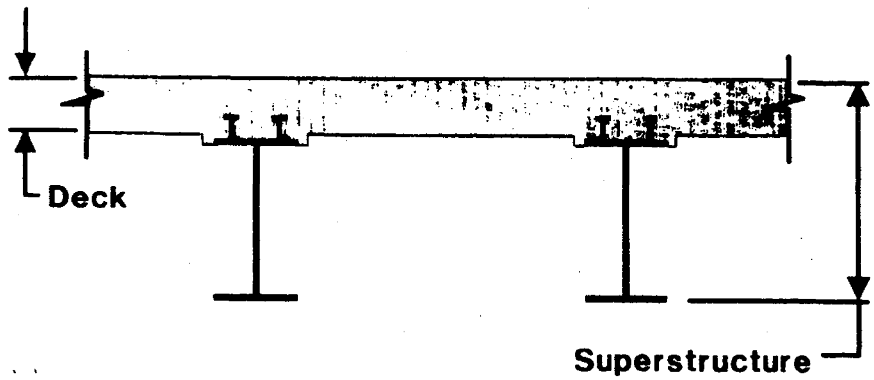


Figure 3-17 Composite Bridge with Concrete Deck on Steel Beams

Composite action is achieved only after the concrete deck has hardened. Therefore, some of the dead load must be resisted by the non-composite action of the beam alone. These dead loads include the weight of:

- The beam itself
- Any diaphragms and cross-bracing
- The concrete deck
- Any concrete haunch between the beam and the deck
- Any other loads which are applied before the concrete deck has hardened

Other dead loads, known as superimposed dead loads, are resisted by the beam and the concrete deck acting compositely. Superimposed dead loads include the weight of:

- Any anticipated future deck pavement
- Sidewalks
- Railings
- Any other loads which are applied after the concrete deck has hardened

Since live loads are applied to the bridge only after the deck has hardened, they are also resisted by the composite section.

The bridge inspector can identify a simple span, a continuous span and a cantilever span based on their configuration. However, the bridge inspector can not identify the relationship between the deck and the beams while at the bridge site. Therefore, bridge plans must be reviewed to determine whether a structure is non-composite or composite.

3.5.6 Foundations

Foundations are critical to the stability of the bridge since the foundation ultimately supports the entire structure. There are two basic types of bridge foundations:

- Spread footings
- Pile foundations

Spread Footings

A spread footing is used when the bedrock layers are close to the ground or when the soil is capable of supporting the bridge. A spread footing is typically a rectangular slab made of reinforced concrete. This type of foundation "spreads out" the loads from the bridge to the underlying rock or soil. While a spread footing is usually buried, it is generally covered with a minimal amount of soil. In cold regions, the bottom of a spread footing will be just below the recognized maximum frost line depth for that area.

Pile Foundations

A pile foundation is used when the soil is not suited for supporting the bridge or when the bedrock is not close to the ground surface. A pile is a long, slender support which is typically driven into the ground but can be partially exposed. It is made from steel, concrete, or timber. Various numbers and configurations of piles can be used to support a bridge foundation. This type of foundation transfers load to sound material well below the surface or, in the case of friction piles, to the surrounding soil. The terms "caisson," "drilled caisson," and "bored pile" are frequently used by engineers to denote drilled pile construction, sometimes referred to as pier foundations.

3.6 Load Capacity Ratings

It is important to note that one of the primary functions of a bridge inspection is to collect information necessary for a bridge load capacity rating. Therefore, the bridge inspector should understand the principles of bridge load ratings. Bridge load rating methods and guidelines are provided by AASHTO in the *Manual for Maintenance Inspection of Bridges.*

A bridge load rating is used to determine the usable live load capacity of a bridge. Each member of a bridge has a unique load rating, and the bridge load rating represents the most critical one. Bridge load rating is generally expressed in units of tons, and it is computed based on the following basic formula:

Bridge Load Capacity Rating =

$$\frac{\text{Allowable Load - Dead Load}}{\text{Rating Vehicle Live Load Plus Impact}} \quad \text{x} \quad \text{Vehicle Weight (Tons)}$$

3.6.1 Inventory

Highway bridges can be rated at two different load levels. One of these load levels is referred to as inventory rating. The inventory rating determines a load level which can safely utilize a bridge for an indefinite period of time. Using the allowable stress method, the inventory rating for steel is based on 55% of the yield stress (see Figure 3-18). This is comparable with design values.

Example of inventory load levels: If a steel has a yield stress of 36 ksi, then the allowable inventory stress is 55% of 36 ksi, or 19.8 ksi.

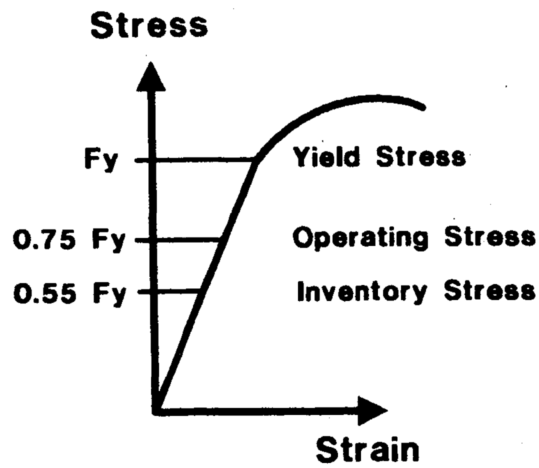


Figure 3-18 Bridge Load Capacity Rating Levels for Steel

3.6.2 Operating

The other load level is referred to as operating rating. The operating rating is higher than the inventory rating, and it is the absolute maximum permissible load level to which a bridge may be subjected. In no cases can the load levels used be greater than those permitted by the operating rating. For steel, the allowable stress for operating rating is 75% of the yield stress (see Figure 3-18).

Example of operating load levels: If a steel has a yield stress of 36 ksi, then the allowable operating stress is 75% of 36 ksi, or 27.0 ksi.

Special permits for heavier than normal vehicles may occasionally be issued by a governing agency (refer to Section 3.2.2). The load produced by the permit vehicle must not exceed the structural capacity determined by the operating rating.

3.6.3 Rating Vehicles

Rating vehicles are truck loads applied to the bridge to establish the inventory and operating ratings. These rating vehicles (see Figure 3-19) include:

- H loading
- HS loading
- Alternate Interstate Loading (Military Loading)
- Type 3 unit
- Type 3-S2 unit
- Type 3-3 unit
- The maximum legal load vehicles of the state

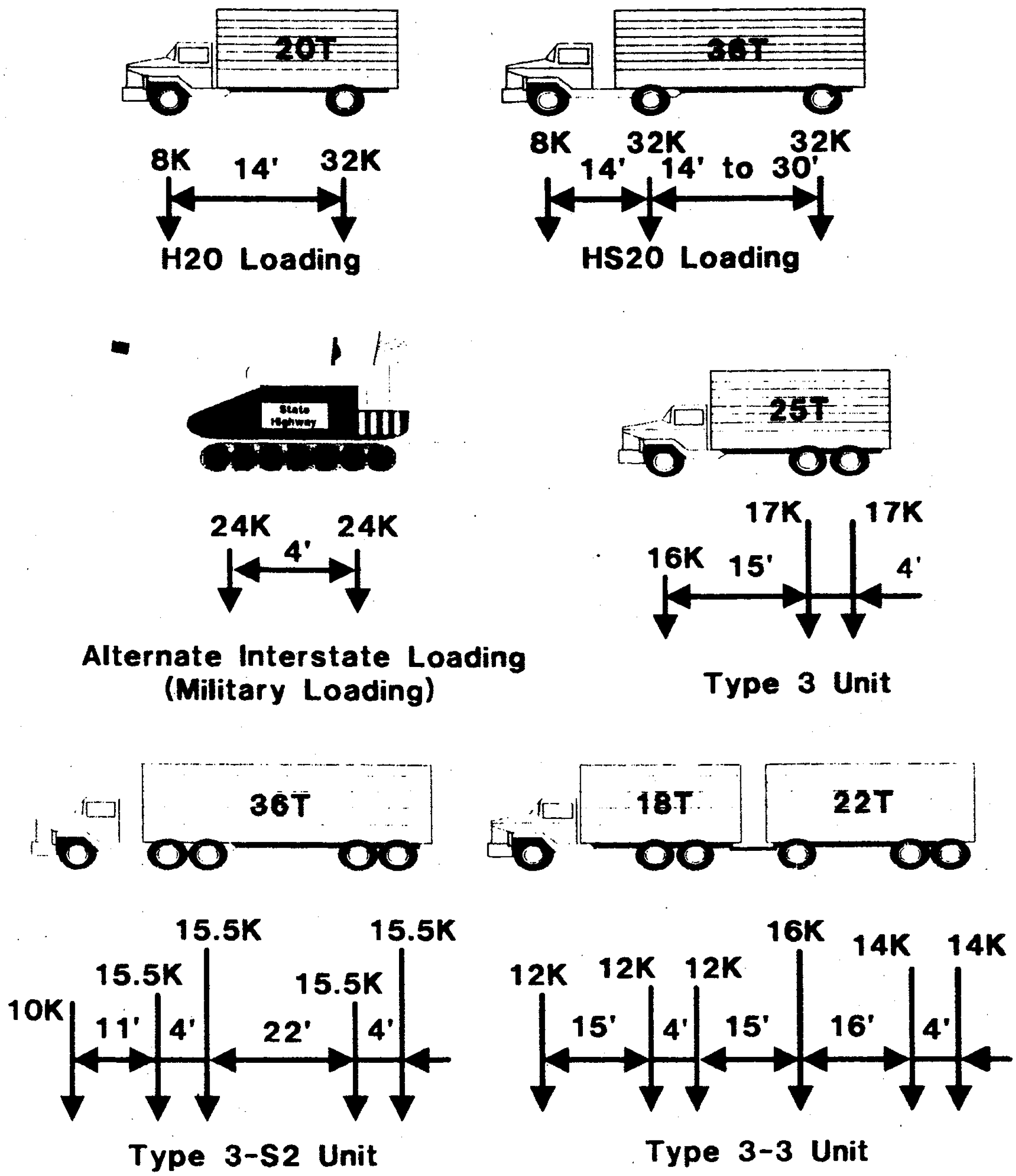


Figure 3-19 Rating Vehicles

The axle spacing and weights of the Type 3 unit, Type 3-S2 unit, and Type 3-3 unit are based on actual vehicles. However, as mentioned previously, the H and HS loadings do not represent actual vehicles.

These standard rating vehicles were chosen based on load regulations of most states and governing agencies. However, individual states and agencies may also establish their own unique rating vehicles.

4

Properties and Deterioration of Bridge Materials

Typical Properties of Common Bridge Materials

Material	Specific Weight, lb/in^3	Ultimate Strength			Yield Strength		Modulus of Elasticity, 10^6 psi	Modulus of Rigidity, 10^6 psi	Coefficient of Thermal Expansion, $10^{-6}/°F$	Ductility, Percent Elongation in 2 In.
		Tension, ksi	Compression, ksi	Shear, ksi	Tension, ksi	Shear, ksi				
TIMBER, air dry:										
Douglas fir	0.019	----	7.2	1.1	----	----	1.8	----	Varies:	----
Eastern spruce	0.016	----	5.4	1.0	----	----	1.3	----	1.7 to 2.5	----
Southern pine	0.022	----	7.3	1.3	----	----	1.6	----		----
CONCRETE:										
Medium strength	0.084	----	4.0	----	----	----	3.6	----	5.5	----
High strength	0.084	----	6.0	----	----	----	4.5	----	5.5	----
CAST IRON:										
Gray, 4.5% C (ASTM A-48)	0.260	25	95	35	----	----	10	4.1	6.7	0.5
Malleable (ASTM A-47)	0.264	50	90	48	33	----	24	9.3	6.7	10
STEEL:										
Structural (ASTM-A36)	0.284	58	----	----	36	21	29	11.5	6.5	23
High-strength-low-alloy (ASTM-A242)	0.284	70	----	----	50	30	29	11.5	6.5	21
Quenched and tempered alloy (ASTM-A514)	0.284	120	----	----	100	55	29	11.5	6.5	18
Stainless, (302)										
Cold-rolled	0.286	125	----	----	75	----	28	10.6	9.6	12
Annealed	0.286	90	----	----	40	22	28	10.6	9.6	50
GRANITE:	0.100	3	35	5	----	----	10	----	4	-----
ALUMINUM:										
Alloy 1100-H14 (99% Al)	0.098	16	----	10	14	8	10.1	3.7	13.1	20
Alloy 2014-T6 (4.4% Cu)	0.101	70	----	42	60	32	10.6	3.9	12.8	13
Alloy 6061-T6 (1% Mg)	0.098	42	----	27	37	20	10	3.7	13.1	17

Notes:
1. Properties of metals vary widely as a result of variations in composition, heat treatment, and mechanical working.
2. For ductile metals (e.g., steel and aluminum), the compressive strength is generally assumed to be equal to the tensile strength.
3. Timber properties are for loading parallel to the grain.
4. Source: 64.

4

Properties and Deterioration of Bridge Materials

4.1 Introduction

Common Bridge Materials

While many different materials are used to construct a bridge, the three primary materials are:

- Timber
- Concrete
- Steel

This chapter presents various properties of these basic materials and the various forms of deterioration which these materials undergo. It also briefly discusses examination techniques.

Properties

The behavior of a bridge under load is strongly influenced by the properties of the materials used in the bridge. Therefore, the properties of construction materials are of great importance to the bridge inspector. Both physical properties (i.e., properties related to the intrinsic nature of the material) and mechanical properties (i.e., properties describing the structural behavior of the material) are presented in this chapter.

Strengths and Weaknesses

Materials chosen for bridge construction differ, since each material has characteristic attributes (e.g., cost, strength, weight, durability, and appearance) . It is important for the bridge inspector to know these various strengths and weaknesses in order to understand the structural behavior of the entire bridge, as well as its many elements.

Types of Deterioration

The purpose of a bridge inspection is to report the condition of a bridge and then assess the integrity, safety, and load-carrying capacity of the bridge. Therefore, the bridge inspector must gain an understanding of the various types of deterioration which can reduce the bridge's integrity, safety, and capacity.

Signs of Deterioration and Distress

Not only is it important to understand the various types of deterioration, but the bridge inspector must also recognize the physical signs of deterioration and distress. By recognizing these signs, the inspector can help determine:

- What caused a particular condition?
- What will happen if the condition continues?
- What positive action can be taken to remedy the condition?

4.2 Timber

As of December 31, 1990, there were approximately 50,000 timber bridges in the United States, equivalent to 8 to 9% of the total number of bridges in the U.S. Many of these bridges are very old, but the use of timber structures is gaining new popularity. To preserve these old bridges and to safely maintain the new ones, it is important that the bridge inspector understand the basic characteristics of wood.

4.2.1 Properties of Timber

There are many characteristics which make wood a valuable material for use in bridges. Some of these include:

- A renewable resource
- Strong for its weight
- Relatively inexpensive
- Aesthetically pleasing
- Readily available
- Easy to fabricate and construct
- Resistant to deicing agents
- Resistant to damage from freezing and thawing
- Able to sustain overloads for short periods of time

Physical Properties

These characteristics stem from the unique physical properties of timber, which vary with the species and grade of the wood.

Hardwoods and Softwoods

One major physical property of wood is that it may be classified as hardwood or softwood. Hardwoods have broad leaves, and most hardwoods lose their leaves at the end of each growing season. Softwoods, or conifers, have needle-like or scale-like leaves, and most softwoods are evergreen and do not shed their leaves. The terms "hardwood" and "softwood" are misleading because they do not necessarily indicate the hardness or softness of the wood. Some hardwoods are softer than certain softwoods and vice versa.

Anatomy of Timber

A second major physical property of wood is its non-homogeneous anatomy. Wood, although an extremely complex organic material, has dominant and fundamental patterns to its cell structure. Some of the physical properties of this cell structure include (see Figure 4-1):

- Hollow cell composition - cell walls consist of cellulose and lignin, and are formed in an oval or rectangular shape which accounts for the high strength-to-weight ratio of wood; wood with thick cell walls is dense and strong; lignin bonds the cells together

- Growth rings - revealed in the cross section of a tree; they are distinct annual rings of wood, denser toward the end of each session, sometimes darker in color in that part of each ring (as in Douglas fir and southern pine), sometimes with little color difference (spruces and true firs); depends on species
- Sapwood - the active, outer part of the tree that conducts sap and stores food throughout the tree; is generally permeable and easy to treat with preservatives; sapwood is of lighter color than heartwood
- Heartwood - the inactive, inner part of the tree which serves to support the tree; may be resistant to decay due to toxic materials deposited in the heartwood cells; usually of darker color than sapwood
- Wood rays - groups of cells, running from the center of the tree horizontally to the bark, which are responsible for cross grain strength
- Grain - the wood fibers oriented along the long axis of logs and timbers; the direction of greatest strength

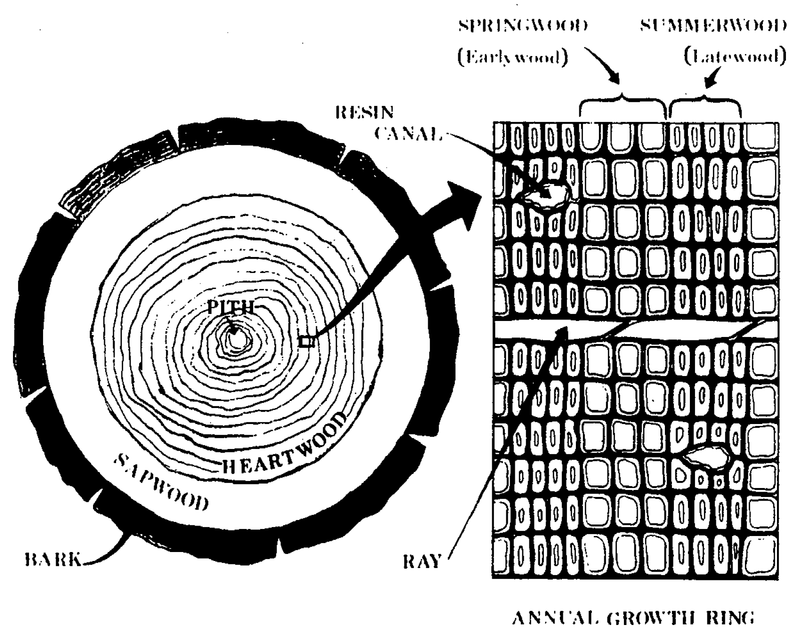


Figure 4-1 Anatomy of Timber

Growth Features

A third major physical property is that a variety of growth features adversely affect the strength of wood. Some of these features include:

- Knots and knot holes - due to intergrown limbs and associated grain deviation
- Sloping grain - caused by the normal taper of a tree or by sawing in a direction other than parallel to the grain
- Splits, checks, and shakes - separation of the cells across the grain, primarily due to rapid or uneven drying and differential shrinkage in the radial and tangential directions during seasoning; a shake is a type of check which occurs along the periphery of an annual ring, peculiar to a few species (see Figure 4-2)
- Reaction wood - a type of abnormal wood that is formed in leaning trees; the pith is off center; the wood is gelatinous and displays cross grain shrinkage checks when seasoned

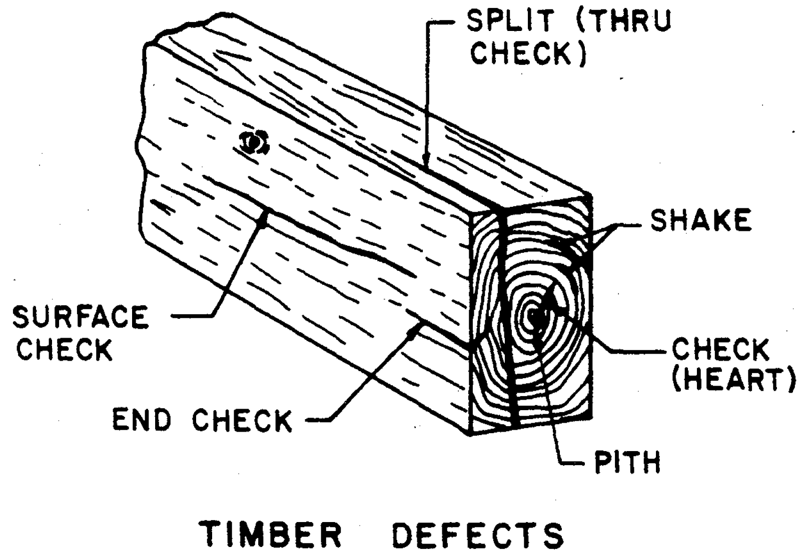


Figure 4-2 Timber Defects

Moisture Content

A fourth major physical property is that moisture content affects wood. It not only causes dimensional instability and fluctuations of weight, but it also affects the strength and decay resistance of wood. Timber (treated or untreated) generally has a unit weight of about 50 pounds per cubic foot (pcf).

Mechanical Properties

In addition to the physical properties of timber, there are also several important mechanical properties which govern the use of timber in structures.

Orthotropic Behavior

One major mechanical property relates to the orthotropic behavior of wood. Wood is considered a non-homogeneous and an orthotropic material. It is non-homogeneous because of the random occurrences of knots, splits, checks, and the variance in cell size and shape. It is orthotropic because wood has mechanical properties that are unique to its three principal axes of anatomical symmetry (longitudinal, radial, and tangential). This orthotropic behavior is due to the orientation of the cell fibers in wood (see Figure 4-3).

As a result of its orthotropy, wood has three distinct sets of strength properties. Because timber members are longitudinal sections of wood, strength properties are commonly defined for the longitudinal axis. However, an exception is perpendicular to grain bearing strength. American Society for Testing and Materials (ASTM) standards are issued which present strength properties for various types of wood.

Fatigue Characteristics

A second major mechanical property relates to the fatigue characteristics of wood. Because wood is a fibrous material, it tends to be less sensitive than steel or iron to repeated loads. The presence of knots and sloping grain reduces the strength of wood considerably more than does fatigue; therefore, fatigue is generally not a limiting factor in timber design.

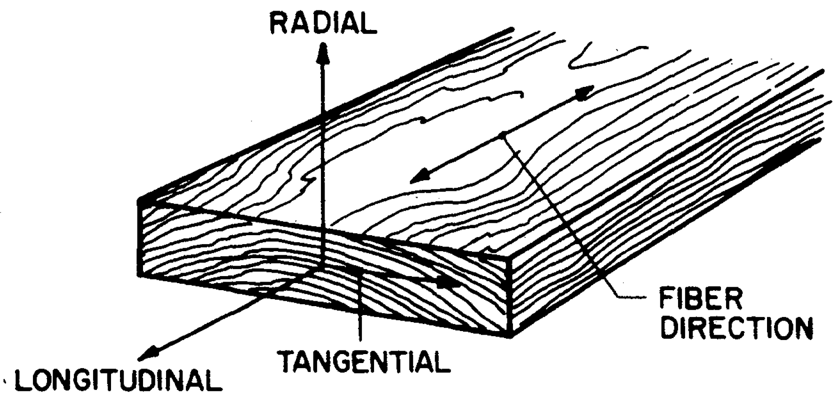


Figure 4-3 Three Principal Axes of Wood

Impact Resistance

A third major mechanical property relates to impact resistance. Wood is able to sustain short-term loads of about twice the level it can bear on a permanent basis, provided the cumulative duration of such loads is limited.

Creep Characteristics

A fourth major mechanical property relates to the creep characteristics of wood. Creep occurs when a load is maintained on wood. That is, the initial deflection of the member increases with time. Green timbers may sag appreciably, if allowed to season under load. Initial deflection of unseasoned wood under permanent loading can be expected to double with the passage of time. Therefore, to accommodate creep, twice the initial elastic deformation is often assumed for design. Partially seasoned material may also sag to some extent. However, thoroughly seasoned wood members will exhibit little permanent increase in deflection with time. Glulam timbers are thoroughly seasoned but sawn timbers are not.

Grades of Timber

The most widely used species of wood for bridge construction are Douglas fir and southern pines. The southern pines include several species graded and marketed under identical grading rules. Other species such as western hemlock and eastern spruce are suitable for bridge construction if appropriate allowable stresses are used.

The table at the beginning of Chapter 8 lists properties of southern pines and Douglas firs for grades used in bridge construction. These properties are intended for Allowable Stress Design. Other more dense species and select grades with higher properties are also used. For wet conditions, some of the properties must be reduced. Refer to *Design Values for Wood Construction*, National Forest Products Association.

Unlike steel, the elastic modulus of wood varies with the grades.

The ultimate strength properties of wood in the table at the beginning of this chapter are for air-dried wood, clear, straight grained, free of strength-reducing defects.

Preservative treatment for decay resistance does not alter the allowable stresses for design.

4.2.2 Types and Causes of Timber Deterioration

Although wood is an excellent material for use in bridges, untreated wood is vulnerable to damage from fungi, parasites, and other sources. The untreated inner cores of treated timbers and poles are vulnerable to these predators if they can gain access through the outer treated shell. The degree of vulnerability varies with the species and grade of the timber. Bridge inspectors must be able to recognize the signs of the various types of damage and be able to evaluate their effect on the structure.

Fungi

Decay is the primary cause of timber bridge replacement, whether the structure has served a long or short period of time. A major cause of decay is living fungi, which are plants that feed on the cell walls of wood (see Figure 4-4). Favorable conditions for fungi to grow can only occur when these four requirements exist:

- Sufficient oxygen - 20% minimum
- A favorable temperature range - between 32°F and 90°F
- An adequate food supply
- An adequate supply of moisture - 30% minimum

Figure 4-4 Decay of Wood by Fungi

Although there are numerous types and species of fungi, only a few cause decay in timber bridge members. Some fungi types include:

- Molds - cottony or powdery circular growths varying from white or light colors to black; molds themselves do not cause decay but their presence is an indication that conditions favorable to the growth of fungi exist
- Stains - specks, spots, streaks, or patches, varying in color, which penetrate the sap wood; sapstain is harmless to wood; it is usually a surface phenomenon and, like molds, implies conditions where harmful fungi can flourish
- Soft rot - attacks the wood, making it soft and spongy; only the surface wood is affected, and thus it does not significantly weaken the member
- Brown rot - feeds upon the cellulose and makes the wood dark brown and crumbly
- White rot - feeds upon both the cellulose and the lignin and makes the wood white and stringy

Brown and white rots are responsible for structural damage to wood while the other fungi types simply provide a sign that favorable conditions exist for growth.

Parasites

Parasites tunnel in and hollow out the insides of timber members for food and shelter. Some common types of parasites include:

- Termites
- Carpenter ants
- Powder-post beetles
- Marine borers
- Caddisflies

Termites

Termites are pale-colored, soft-bodied insects that feed on wood. All damage is inside the surface of the wood; hence, it is not visible. The only visible signs of infestation are white mud shelter tubes or runways extending up from the earth to the wood and on the sides of masonry substructures.

Carpenter Ants

Carpenter ants are large, black ants that gnaw galleries in soft or decayed wood (see Figure 4-5). The ants may be seen in the vicinity of the infested wood, but the accumulation of sawdust on the ground at the base of the timber is also an indicator of their presence.

Powder-Post Beetles

Powder-post beetles also hollow out the insides of timber members and leave the outer surface pocked with small holes. Often a powdery dust is dislodged from the holes. The inside may be completely excavated.

Figure 4-5 Carpenter Ant Damage to a Timber Member

Marine Borers

Marine borers are water-borne and cause their most severe damage in the area between high and low water, although damage may extend to the mud line. They do not occur in fresh water (see Figures 4-6 and 4-7).

One type of marine borer is the mollusk borer, or shipworm. The shipworm is one of the most serious enemies of marine timber installations. The most common species of shipworm is the teredo. This shipworm enters the timber in an early stage of life and remains there for the rest of its life. Teredos reach a length of 15 inches and a diameter of 3/8 inch, although some species of shipworm grow to a length of 6 feet. The teredo maintains a small opening in the surface of the wood to obtain nourishment from the sea water.

Another type of marine borer is the crustacean borer. The most commonly encountered crustacean borer is the limnoria or wood louse. It bores into the surface of the wood to a shallow depth. Wave action or floating debris breaks down the thin shell of timber outside the borers' burrows, causing the limnoria to burrow deeper. The continuous burrowing results in a progressive deterioration of the timber pile cross section which will be noticeable by an hourglass shape developed between the tide levels.

Figure 4-6 Marine Borer Damage to Timber Piling

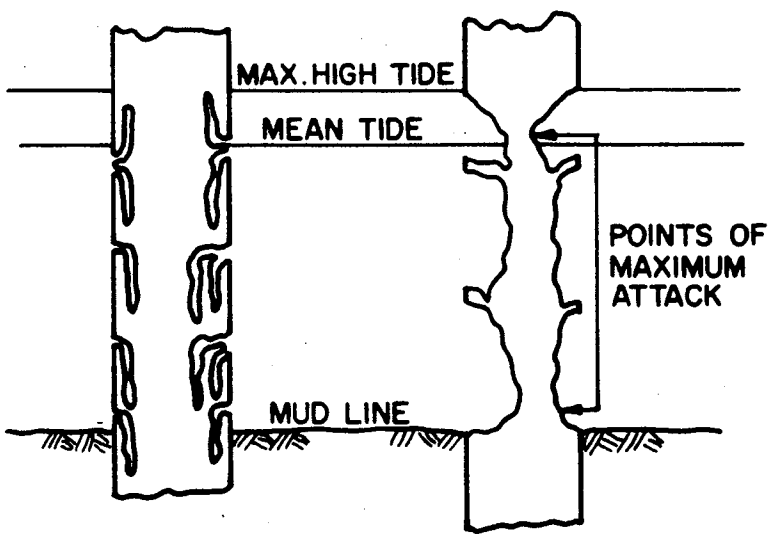


Figure 4-7 Drawing of Typical Borer Damage

Caddisflies

The caddisfly is another insect that can damage timber piles. It is generally found in fresh water but can also be found in brackish water. Bacterial and fungal decay make the timber attractive to the caddisfly.

The caddisfly is an aquatic insect that is closely related to the moth and butterfly. In water during the larva and pupa stage of their life cycle, they can dig small holes in the timber for protection. The larvae do not feed on the timber, but rather use it as a foundation for their silken shelters (see Figure 4-8). Caddisfly larvae have been known to exist on creosote-treated timber.

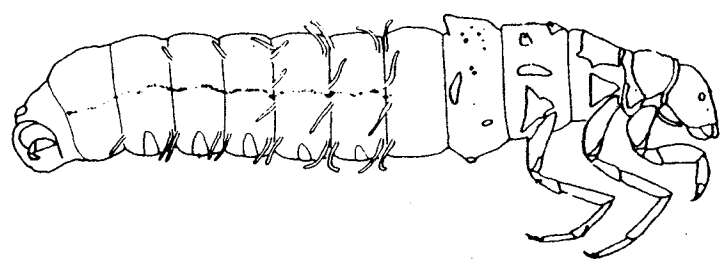


Figure 4-8 Caddisfly Larva

The combination of bacterial and fungal decay, aquatic insect infestation, and the abrasive action of tidal currents can significantly weaken timber piles by reducing their functional cross section.

Chemical Attack

Chemicals do not cause structural degradation to wood. However, animal waste can cause damage to wood, and strong alkalis will destroy wood fairly rapidly. Highway bridges are seldom exposed to these substances. Petroleum products are harmless to wood.

Damage From Other Sources

Deterioration of wood can also be caused by:

- Fire
- Impact or collisions
- Abrasion or mechanical wear
- Overstress
- Weathering or warping

4.2.3 Examination of Timber

Visual Examination

Timber bridge members can be inspected by both visual examination and by physical examination.

A visual examination can detect the following:

- **Fungus decay** - generally appears as a moist area with stain or discoloration (see Figure 4-9); fungi produce conks, which are fruiting bodies, usually fan-like in shape and growing horizontally from the wood; they shed spores which propagate the fungus; conks are a sure sign of advanced decay, and they vary from a fraction of an inch to several inches in length; sapstain fungi have small black, globular fruiting bodies which smear like soft carbon when brushed with the hand
- **Damage by parasites** - damage is generally inside the surfaces of the wood and is therefore not visible, but sagging, crushing, small holes, or the accumulation of sawdust may be observed
- **Deflection** - excessive deflection under live load or significant permanent sagging is a sign of structural weakness
- **Checks** - separations of the wood fibers, normally occurring across the annual growth rings
- **Splits** - similar to checks except the separations of the wood fibers extend completely through the piece of wood
- **Shakes** - separations along the grain which usually occur between the annual growth rings
- **Loose connections** - may be due to shrinkage of the wood, decay, or crushing of the wood around the fastener
- **Surface depressions** - indicate internal collapse which could be caused by decay

Figure 4-9 Advanced Decay in Timber Superstructure

Physical Examination

Deterioration of timber can also be detected using sounding methods. Rapping on the outside surface of the member with a hammer detects hollow areas, indicating internal decay. In a marine environment, the diameter of timber piles should be noted at various locations with each inspection.

Advanced Inspection Techniques

In addition, several advanced techniques are available for timber inspection. Nondestructive methods, described in Section 15.2.1, include:

- Pol-Tek
- Spectral analysis
- Ultrasonic testing

Destructive methods, described in Section 15.2.2, include:

- Boring or drilling
- Moisture content
- Probing
- Shigometer

4.3 Concrete

A large percentage of the bridge structures in the nation's highway network are constructed of reinforced concrete or prestressed concrete. Therefore it is important that the bridge inspector understand the basic characteristics of concrete in order to efficiently inspect bridge components made of this material.

4.3.1 Properties of Concrete

Concrete as a construction material is generally associated with roadway pavement, driveways, sidewalks, and even porch steps. It is also a material that is commonly mislabeled as cement. Concrete is a mixture of various ingredients, of which cement is merely one. When these ingredients are mixed together in the proper proportions, they chemically react to form a strong, durable construction material ideally suited for certain bridge components.

Basic Ingredients

Concrete is made up of four basic ingredients:

- Cement
- Water
- Air
- Aggregates

The first ingredient of concrete is cement. Portland Cement is one of the most common types of cement, and it is made with the following raw materials:

- Limestone - provides lime
- Cement rock - provides silica
- Claystone - provides aluminum oxide
- Iron ore - provides iron oxide

The second ingredient of concrete is water. While almost any potable water is satisfactory for making concrete, drinking water with a noticeable taste or odor may be suspect. Impurities in water, such as dissolved chemicals, salt, sugar, or algae, produce a variety of undesirable effects on the quality of the concrete mix.

The third ingredient of concrete is air. Small evenly distributed amounts of entrapped air provide:

- Increased durability
- Reduced cracking
- Improved workability
- Reduced water segregation

The fourth ingredient of concrete is aggregates. Aggregates comprise approximately 75% of a typical concrete mix by volume. Some aggregate qualities which result in a strong and durable concrete are:

- Abrasion resistance
- Weather resistance
- Chemical stability
- Chunky compact shape
- Smooth, non-porous surface texture
- Cleanliness and even gradation

Normal weight concrete has a unit weight of about 140 to 150 pcf.

Typical aggregate materials for normal weight concrete are sand, gravel, crushed stone, and air-cooled, blast-furnace slag.

Physical Properties

The major physical properties of concrete are:

- Thermal expansion - concrete expands as temperature increases and contracts as temperature decreases
- Porosity - because of entrapped air, the cement paste never completely fills the spaces between the aggregate particles, permitting absorption of water and the passage of water under pressure
- Volume changes due to moisture - concrete expands with an increase in moisture and contracts with a decrease in moisture
- Fire resistance - quality concrete is highly resistant to the effects of heat; however, temperatures over 700°F may cause damage

Mechanical Properties

The major mechanical properties of concrete are:

- Strength - plain, unreinforced concrete has a compressive strength ranging from about 2500 pounds per square inch (psi) to about 6000 psi; however, its tensile strength is only about 10% of its compressive strength, its shear strength is about 12% to 13% of its compressive strength, and its flexural strength is about 14% of its compressive strength (see Table 4-1); higher strength concretes, with compressive strength ranging from 6000 psi to about 11,000 psi, are also available
- Elasticity - within the range of normal use, concrete is able to deform under load and then return to its original orientation when the load is removed (elastic deformation); modulus of elasticity varies as the square root of compressive strength
- Creep - in addition to elastic deformation, concrete exhibits long-term, irreversible, continuing deformation under application of a sustained load ranging from 100% to 200% of initial elastic deformation, depending on time
- Isotropy - plain, unreinforced concrete has the same mechanical properties regardless of which direction it is loaded

Compressive Strength	100%
Flexural Strength	14%
Shear Strength	12-13%
Tensile Strength	10%

Note: Percentages represent a comparison of various concrete strength properties with the compressive strength of concrete.

Table 4-1 Strength Properties of Concrete

Five principal factors which increase concrete strength are:

- Increased cement content
- Sound aggregate
- Decreased water to cement ratio
- Decreased entrapped air
- Increased curing time (extent of hydration)

Reinforced Concrete

Concrete is commonly used in bridge applications due to its compressive strength properties. However, in order to supplement the limited tensile strength of concrete, tensile steel reinforcement is generally used (see Figure 4-10).

Steel reinforcement has approximately 100 times the tensile strength of concrete. Therefore, in reinforced concrete members, the concrete resists the compressive forces and the steel reinforcement resists the tensile forces. Steel reinforcement for reinforced concrete is often referred to as "mild steel." The steel reinforcement is located close to the tension face.

Reinforcing bars are also perpendicular to the primary tension steel to resist stresses resulting from temperature changes and volumetric changes of concrete. This steel is referred to as temperature and shrinkage steel.

Steel reinforcing bars can be "plain" or smooth surfaced, or they can be "deformed" with a raised gripping pattern protruding from the surface of the bar (see Figure 4-11). The gripping pattern improves the bond with the surrounding concrete. Modern reinforced concrete bridges are generally constructed with "deformed" reinforcing steel.

Reinforcing bars are identified by numbers which correspond to their nominal diameter in eighths of an inch. For example, a #4 bar has a 1/2 inch nominal diameter (or 4 times 1/8 inch). Reinforcing bars can also be used to increase the compressive strength of a concrete member. When reinforcing bars are properly cast into a concrete member, the steel and concrete acting together provide a strong, durable construction material.

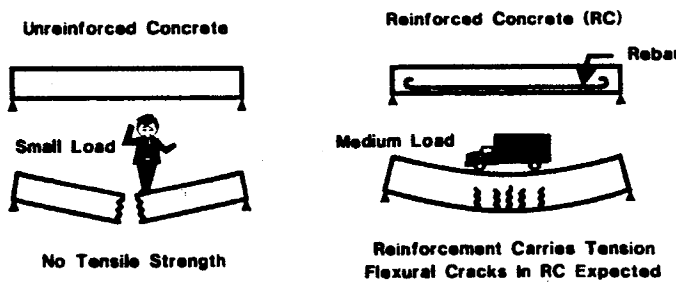


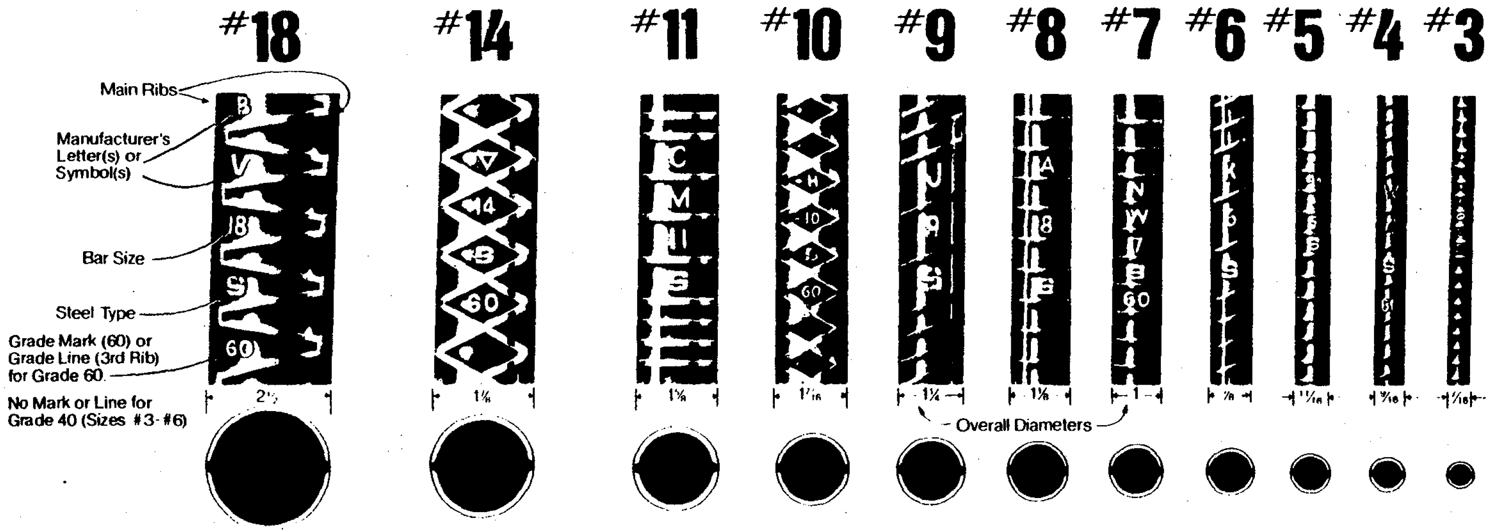
Figure 4-10 Reinforced Concrete

Prestressed Concrete

In addition to reinforced concrete, prestressed concrete, using high strength steel wires, can be used in bridge applications. To reduce the tensile forces in a concrete member, internal compressive forces are induced through prestressing steel tendons or wires. When loads are applied to the member, any tensile forces developed are counterbalanced by the internal compressive forces induced by the prestressing steel. By prestressing the concrete in this manner, the final tensile forces are typically within the tensile strength limits of plain concrete. Therefore, properly designed prestressed concrete members do not develop flexure cracks under service loads (see Figure 4-12).

There are three methods of prestressing concrete:

- Pretensioning - during fabrication of the member, prestressing steel is placed and tensioned prior to casting and curing of the concrete (see Figure 4-13)
- Posttensioning - during fabrication of the member, ducts are cast-in-place so that after curing, the prestressing steel can be passed through the ducts and tensioned (see Figure 4-14)
- Combination method - this is used for long members for which the required prestressing force cannot safely be applied using pretensioning only



	#18			#14			#11		#10		#9		#8		#7		#6		#5		#4		#3	
TENSION SPLICES AND ANCHORAGE (GRADE 60)	4.00		AREA - SQ. IN. (NOMINAL)	2.25		SPECIFIED CONCRETE STRENGTH	1.56		1.27		1.00		0.79		0.60		0.44		0.31		0.20		0.11	
	13.600		WT. - LBS./FT. (NOMINAL)	7.650			5.313		4.303		3.400		2.670		2.044		1.502		1.043		0.668		0.376	
	2.257		DIAM. - IN (NOMINAL)	1.693			1.410		1.270		1.128		1.000		0.875		0.750		0.625		0.500		0.375	
	TOP	OTHER	GRADE 60	TOP	OTHER	f'c psi	TOP	OTHER	TOP	OTHER	TOP	OTHER	TOP	OTHER	TOP	OTHER	TOP	OTHER	TOP	OTHER	TOP	OTHER	TOP	OTHER
CLASS A	169	120	Class A Tension Lap Splices = ℓ_d, (in.)	130	93	3000	96	68	78	56	61	44	48	35	37	26	27	19	21	15	17	12	13	12
	146	104		113	81	4000	83	59	67	48	53	38	42	30	32	23	25	18	21	15	17	12	13	12
	131	93		101	72	5000	74	53	60	43	48	34	38	27	29	21	25	18	21	15	17	12	13	12
	119	85		92	66	6000	68	48	55	39	43	31	34	24	29	21	25	18	21	15	17	12	13	12
	103	74		80	57	8000	59	42	48	34	38	27	34	24	29	21	25	18	21	15	17	12	13	12
CLASS B	Tension Lap Splices of #18 not permitted		Class B Tension Lap Splices = 1.3ℓ_d, (in.)	Tension Lap Splices of #14 not permitted		3000	124	89	101	72	80	57	63	45	48	34	35	25	27	20	22	16	16	12
						4000	108	77	88	63	69	49	55	39	41	30	33	23	27	20	22	16	16	12
						5000	96	69	78	56	62	44	49	35	38	27	33	23	27	20	22	16	16	12
						6000	88	63	72	51	56	40	45	32	38	27	33	23	27	20	22	16	16	12
						8000	76	54	62	44	49	35	44	31	38	27	33	23	27	20	22	16	16	12
CLASS C	Use tension couplers or butt weld		Class C Tension Lap Splices = 1.7ℓ_d, (in.)	Use tension couplers or butt weld		3000	163	116	132	95	104	74	82	59	62	45	46	33	36	26	29	20	21	15
						4000	141	101	115	82	90	65	71	51	54	39	43	31	36	26	29	20	21	15
						5000	126	90	103	73	81	58	64	46	50	36	43	31	36	26	29	20	21	15
						6000	115	82	94	67	74	53	58	42	50	36	43	31	36	26	29	20	21	15
						8000	100	71	81	58	64	46	57	41	50	36	43	31	36	26	29	20	21	15

Figure 4-11 Standard Deformed Reinforcing Bars (Source: Concrete Reinforcing Steel Institute)

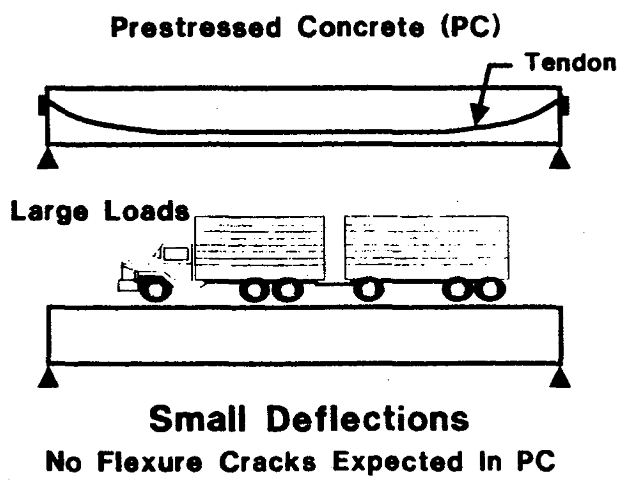


Figure 4-12 Prestressed Concrete

Figure 4-13 Pretensioned Concrete

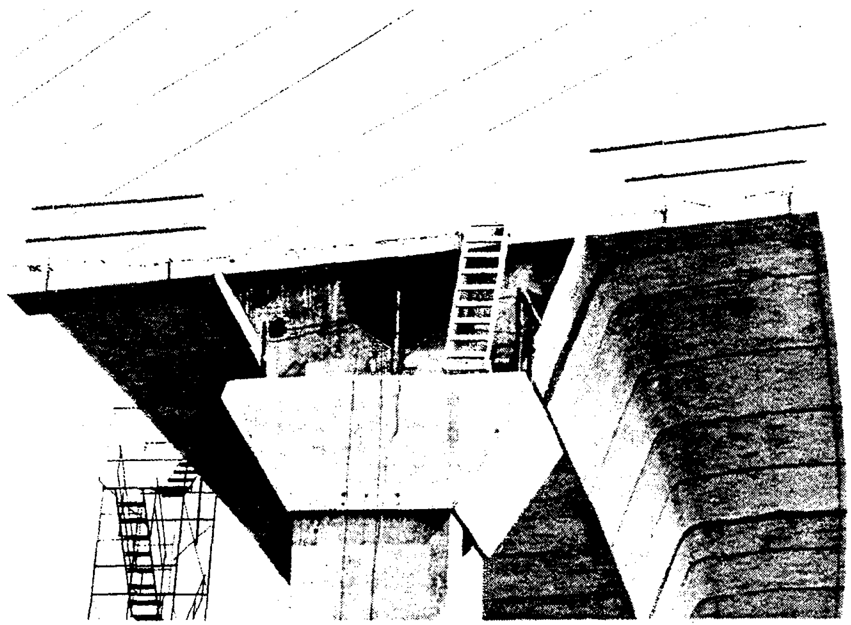


Figure 4-14 Posttensioned Concrete

Steel for prestressing is high tensile strength steel and comes in three basic forms:

- Wires (ASTM A421) - single wires or parallel wire cables; the parallel wire cables are commonly used in posttensioning operations; the most popular wire size is 1/4 inch diameter

- Strands (ASTM A416) - fabricated by twisting wires together; the seven wire strand is the most common type of prestressing steel used in United States and the 270 ksi grade is most commonly used today

- Bars (ASTM A322 and A29) - high tensile bars typically have a minimum ultimate stress of 145 ksi; the bars have full length deformations that also serve as threads to receive couplers and anchorage hardware

In pretensioned members, transfer of tendon tensile stress occurs through bonding, which is the secure interaction of the prestressing steel with the surrounding concrete.

In posttensioned members, transfer of tendon tensile stress is accomplished by mechanical end anchorages and locking devices. If bonding is also desired, special ducts are used which are pressure injected with grout after the tendons are tensioned and locked off.

This is accomplished by casting the concrete in direct contact with the prestressed steel. In posttensioned members, bonding is accomplished by injecting grout into the ducts after the high tensile steel is stressed.

For purposes of crack control in end sections of pretensioned members, the prestressing steel is sometimes unbonded. This is accomplished by providing a protective cover on the steel, preventing it from contacting the concrete. For posttensioned members, when bonding is not desirable, grouting of tendon ducts is not performed and corrosion protection in the form of galvanizing, greasing, or some other means must be provided.

4.3.2 Types and Causes of Concrete Deterioration

There are many common defects that occur on concrete bridges:

- Cracking
- Scaling
- Delamination
- Spalling
- Efflorescence
- Honeycombs
- Pop-outs
- Wear
- Collision damage
- Abrasion
- Overload damage
- Reinforcing steel corrosion
- Prestressed concrete deterioration

Cracking

A crack is a linear fracture in concrete. Cracks may extend partially or completely through the concrete member. On reinforced concrete, cracking will usually be large enough to be seen with the naked eye. However, on prestressed concrete, a crack gauge is the proper instrument needed to measure and differentiate cracks. Rust and efflorescence stains often appear at cracks. Both large and small cracks in main members, especially in prestressed members, should be carefully recorded.

Cracks can be classified as hairline, medium, or wide cracks. Hairline cracks are usually cracks that can not be measured with normal equipment, such as a six foot rule. On conventionally reinforced structures, these hairline cracks are usually insignificant to the structural capacity of the structure (refer to Section 14.2 for a discussion of structural capacity). Medium and wide cracks are cracks that can be measured by simple means. These cracks can be very significant and should be monitored and recorded in the inspection notes. On prestressed structures, all cracks are significant. When reporting cracks, the length, width, location, and orientation (horizontal, vertical, or diagonal) should be noted. The presence of rust stains or efflorescence or evidence of differential movement on either side of the crack should be indicated.

On concrete beams, the two basic types of cracks are structural cracks and nonstructural cracks.

Structural cracks are caused by dead load and live load stresses and are divided into two categories (see Figure 4-15):

- Flexure cracks
- Shear cracks

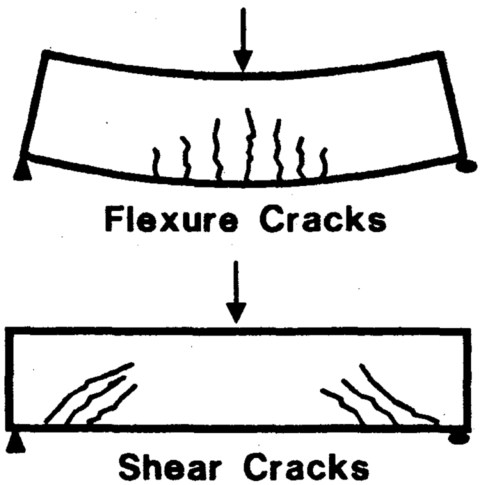


Figure 4-15 Structural Cracks

Flexure cracks are vertical and start in the maximum tension zone or the maximum moment region and proceed toward the compression zone. At the mid-span of members, flexure cracks can sometimes be found at the bottom of the member where bending or flexure stress is greatest. Also look for flexure cracks at the top of continuous members near the piers.

Shear cracks are diagonal cracks that usually occur in the web of a member. Normally, these cracks are found near the bearing area and begin at the bottom of the member and extend diagonally upward toward the center of the member.

Nonstructural cracks are divided into three categories:

- Temperature cracks
- Shrinkage cracks
- Mass concrete cracks

These cracks are relatively minor and generally do not affect the load-carrying capacity of the member. They can, however, provide openings for water and contaminants which can lead to serious problems.

Temperature cracks are caused by the thermal expansion and contraction of the concrete. Shrinkage cracks are due to the contraction of concrete caused by the curing process. Mass concrete cracks occur due to thermal gradients (differences between interior and exterior) in massive sections immediately after placement and for a period of time thereafter.

In concrete bridge decks, temperature and shrinkage cracks can occur in both the transverse and longitudinal directions. In retaining walls and abutments, these cracks are usually vertical, and in concrete beams, these cracks occur vertically or transversely on the member. However, since temperature and shrinkage stresses exist in all directions, the cracks could have other orientations.

Scaling

Scaling is the gradual and continuing loss of surface mortar and aggregate over an area. Scaling is classified in the following four categories:

- Light scale - loss of surface mortar up to 1/4 inch deep, with surface exposure of coarse aggregates
- Medium scale - loss of surface mortar from 1/4 inch to 1/2 inch deep, with mortar loss between the coarse aggregates
- Heavy scale - loss of surface mortar from 1/2 inch to 1 inch deep; coarse aggregates are clearly exposed
- Severe scale - loss of coarse aggregate particles, as well as surface mortar and the mortar surrounding the aggregates; depth of the loss exceeds 1 inch; reinforcing steel is usually exposed

When reporting scaling, the inspector should note the location of the defect, the size of the area, and the depth of penetration of the defect.

Delamination

Delamination occurs when layers of concrete separate at or near the level of the top or outermost layer of reinforcing steel. The major cause of delamination is expansion of corroding reinforcing steel. This is commonly caused by intrusion of chlorides or salt. The corrosion product (rust) occupies up to 10 times the volume of the corroded steel which it replaces. Delaminated areas give off a hollow sound when tapped with a hammer. When a delaminated area completely separates from the member, the resulting depression is called a spall.

When reporting delamination, the inspector should note the location and the size of the area of the defect.

Spalling

A spall is a roughly circular or oval depression in the concrete. Spalls result from the separation and removal of a portion of the surface concrete, revealing a fracture roughly parallel to the surface. Spalls can be caused by corroding reinforcement and friction from thermal movement. Reinforcing steel is often exposed. Spalls are classified as follows:

- Small spalls are not more than 1 inch deep or approximately 6 inches in diameter
- Large spalls are more than 1 inch deep or greater than 6 inches in diameter

When reporting spalls, the inspector should note the location of the defect, the size of the area, and the depth of the defect.

Efflorescence

Efflorescence is a white deposit on concrete caused by crystallization of soluble salts (calcium chloride) brought to the surface by moisture in the concrete. Efflorescence is caused by moisture absorption and flow. Efflorescence indicates that the concrete is contaminated.

Honeycombs

Honeycombs are hollow spaces or voids that may be present within the concrete. Honeycombs are caused by improper vibration during construction, resulting in the segregation of the coarse aggregates from the fine aggregates and cement paste.

Pop-Outs

Pop-outs are conical fragments that break out of the surface of the concrete leaving small holes. Generally, a shattered aggregate particle will be found at the bottom of the hole, with a part of the fragment still adhering to the small end of the pop-out cone. Pop-outs are caused by reactive aggregates and high alkali cement. They are also caused by aggregates, such as shale, which expand with moisture.

Wear

Wear occurs to concrete surfaces when exposed to traffic. The scraping action of snow plows and street sweepers also damage curbs, parapets, and piers.

Collision Damage

Trucks, over-height loads, derailed railroad cars, or marine traffic may strike and damage concrete bridge components. Prestressed beams are particularly sensitive to collision damage.

Abrasion

Abrasion damage is the result of external forces acting on the surface of the concrete member. Erosive action of silt-laden water running over a concrete surface and ice flow in rivers and streams can cause considerable abrasion damage to concrete piers and pilings. In addition, concrete surfaces in surf zones may be damaged by the abrasive action of sand and silt in the water.

Overload Damage

Overload damage or serious cracking may occur when concrete members are overstressed. Note any excessive vibration or deflection.

Reinforcing Steel Corrosion

Due to the chemistry of the concrete mix, reinforcing steel embedded in concrete is normally protected from corrosion. In the high alkaline environment of the concrete, a tightly adhering film forms on the steel which protects it from corrosion.

However, this protection is eliminated by the intrusion of chlorides, which enables water and oxygen to attack the reinforcing steel, forming iron oxide (i.e., rust). Chloride ions are introduced into the concrete by marine spray, industrial brine, or deicing agents. These chloride irons can reach the reinforcing steel by diffusing through the concrete or by penetrating cracks in the concrete.

Prestressed Concrete Deterioration

Prestressed concrete sections can lose their strength through several forms of concrete deterioration. Prestressed concrete members are especially sensitive to corrosion and fatigue in isolated cracks. The corrosion of prestressing wire can lead to a failure of the member. Loss of bond between the prestressing steel and the concrete can result in member failure. Unbonded members are subject to zipper effects. Relaxation of prestressing steel due to high, sustained tensile stress can cause a gradual decrease in strength over time. Shrinkage of the concrete causes a further relaxation in the prestressing steel, thereby lowering the strength of the member. In addition, creep in the concrete will cause the member to shorten, causing further relaxation in the steel tendons, which results in additional strength loss.

4.3.3 Examination of Concrete

When examining the deterioration conditions of a concrete member, access to the previous inspection report is desirable. This allows the inspector to note the progression of concrete deterioration and provides a more meaningful evaluation and inspection report.

The inspection of concrete should include both a visual examination and a physical examination.

Visual Examination

One of the primary forms of deterioration observed during the visual examination is cracking (see Figure 4-16). All cracking should be described and recorded. Future inspections will detect changes in the crack patterns or sizes which indicate active distress.

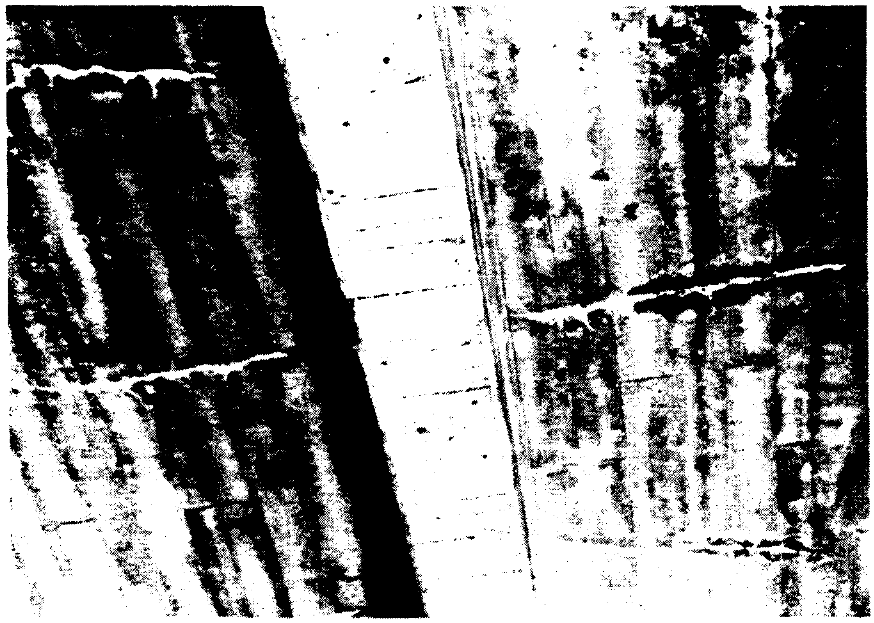


Figure 4-16 Cracking in Concrete (Note Efflorescence)

When recording cracks, it is important for the inspector to describe the:

- Type
- Size
- Length
- Direction
- Location
- Appearance or color

Since cracks are one of the most reliable indications of future problems, it is important to determine their cause and extent. If previous inspection reports are available, an assessment of whether the crack formation is continuing or halted may also be made.

Another indication of deterioration that may be observed during the visual inspection is rust stains. It is important to report rust stains on concrete members since they are produced by corroding reinforcing steel. Corroded reinforcing steel produces a loss of strength within the concrete due to reduced reinforcing steel section, concrete cracking, and bond loss between the concrete and the reinforcing steel. The location and extent of the rust stain should be measured and recorded in the inspection notes.

Additional forms of deterioration that may be visually inspected include:

- Scaling (see Figures 4-17 through 4-20)
- Delamination (see Figure 4-21)
- Spalling (see Figure 4-22)
- Efflorescence (see Figure 4-23)
- Honeycombs (see Figure 4-24)
- Pop-outs
- Wear (see Figure 4-25)
- Collision damage
- Abrasion
- Overload damage
- Reinforcing steel corrosion
- Prestressed concrete deterioration

Figure 4-17 Light Scaling

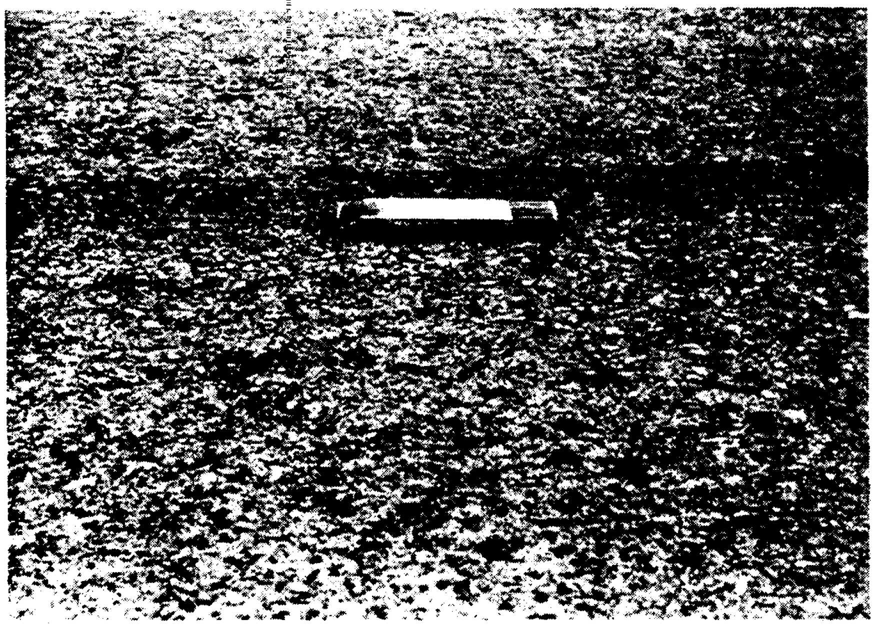


Figure 4-18 Medium Scaling

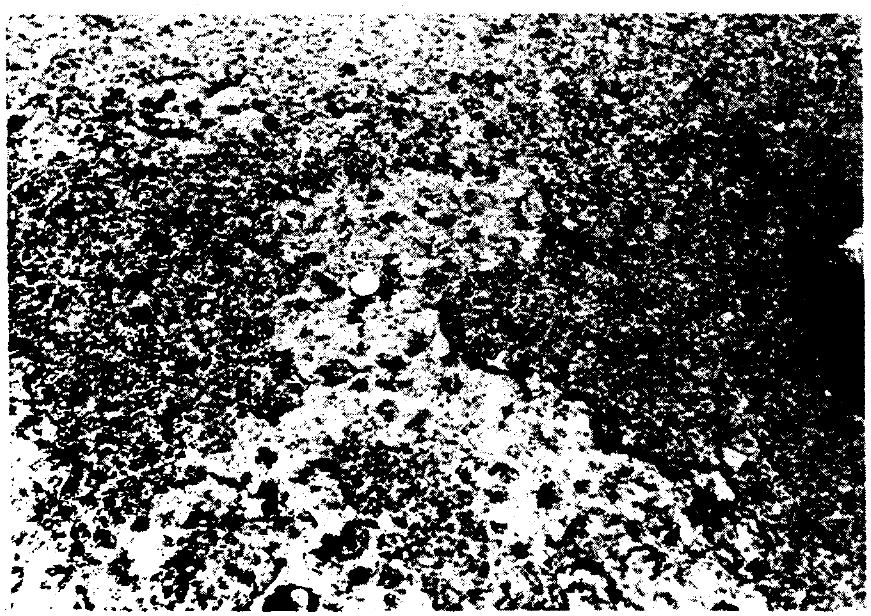


Figure 4-19 Heavy Scaling

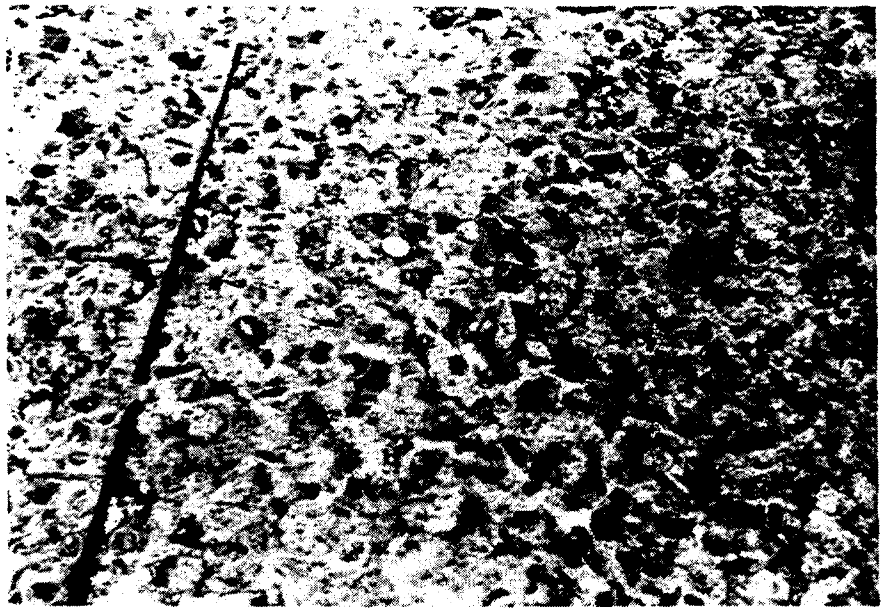


Figure 4-20 Severe Scaling

Figure 4-21 Delamination and Spall

Figure 4-22 Spall (Pothole)

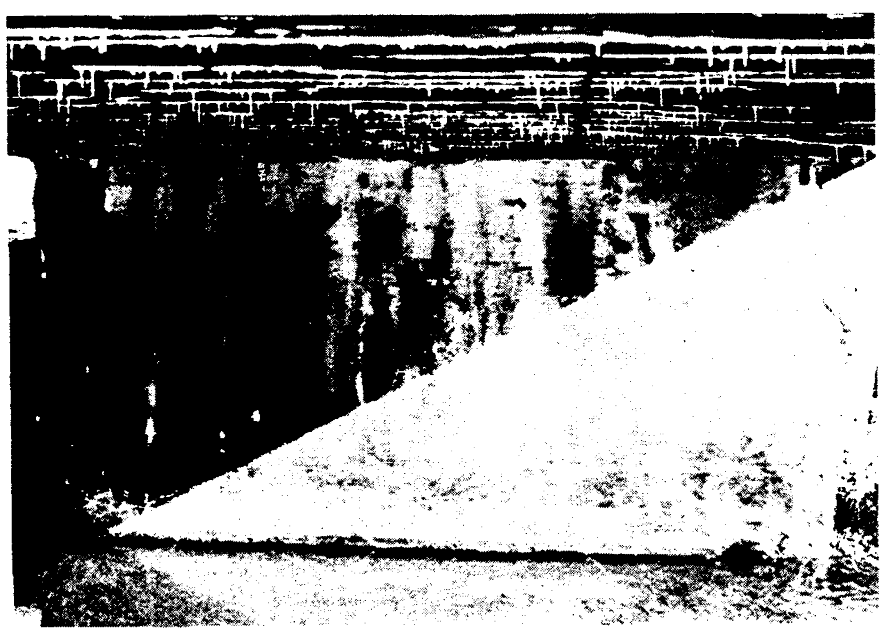


Figure 4-23 Efflorescence

Figure 4-24 Honeycombs

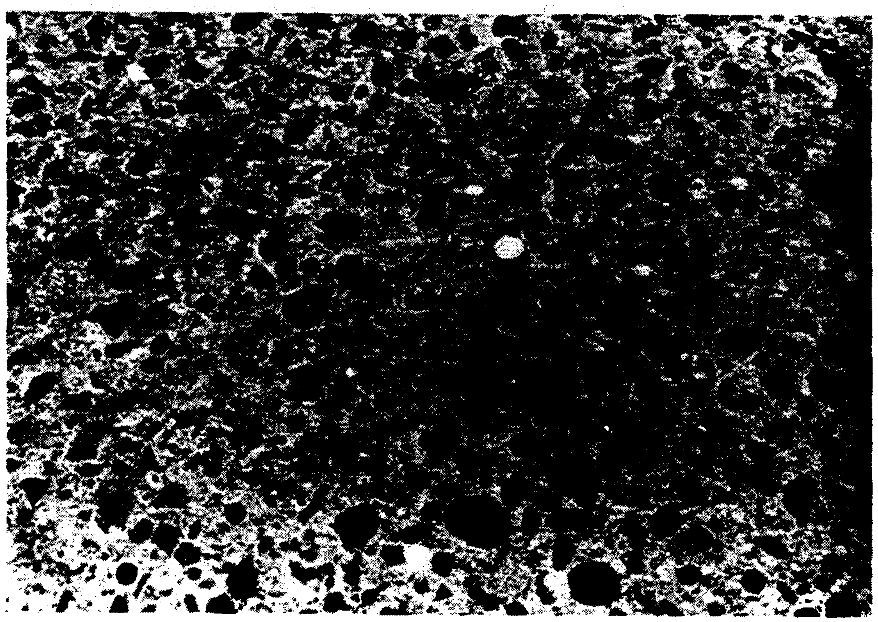


Figure 4-25 Wear

Physical Examination

The deteriorated conditions of concrete can be evaluated by physical examination as well as visual examination. Some common forms of physical examination are hammer sounding and chain-drag surveys.

Hammer sounding is used to detect areas of unsound concrete, and it is frequently used to detect delaminations. Tapping surfaces of concrete with a hammer produces a resonant sound that can be used to indicate concrete integrity. This technique is impractical in evaluating large surface areas such as concrete decks. Several advanced techniques are available for rapid survey of large horizontal surface areas (refer to Section 15.3). However, on vertical surfaces there is currently no practical or reliable alternative to hammer sounding.

A chain drag can be used to quickly inspect a large, exposed concrete deck area. Areas of delamination can be determined by listening for hollow sounds. Chain-drag surveys of concrete decks are not totally accurate. However, they are quick and inexpensive, and they can be used as an initial test to determine the need for more extensive investigation.

Advanced Inspection Techniques

Several advanced techniques are available for concrete inspection. Nondestructive methods, described in Section 15.3.1, include:

- Acoustic wave sonic/ultrasonic velocity measurements
- Delamination detection machinery
- Electrical methods
- Flat jack testing
- Ground-penetrating radar
- Impact-echo testing
- Infrared thermography
- Laser ultrasonic testing
- Magnetic field disturbance
- Neutron probe for detection of chlorides
- Nuclear methods
- Pachometer
- Rebound and penetration methods
- Ultrasonic testing

Destructive methods, described in Section 15.3.2, include:

- Carbonation
- Concrete permeability
- Concrete strength
- Endoscopes
- Moisture content
- Reinforcing steel strength

4.4 Steel

Steel is a widely used construction material for bridges due to its strength, relative ductility, and reliability. It is also a versatile construction material since it is available as wire, cable, plates, bars, and rolled shapes. It is found in a variety of members on a large number of bridges. Therefore, the bridge inspector should be familiar with the various properties and types of steel.

4.4.1
Properties of Steel

Physical Properties

Many of the nation's largest bridges are constructed primarily of steel. When compared with iron, steel has greater strength characteristics, it is more elastic, and it can better withstand the effects of impact and vibration.

Although iron has some carbon chemically dissolved in it, when the carbon content is greater than 0.1%, the material is classified as steel. Steel has a unit weight of about 490 pcf.

ASTM has defined the required properties for various steel types and classified each type with an "A" designation.

Low carbon steel, steel with carbon content less than approximately 0.3%, defines some of the most common steel types:

- A7 steel - the most widely used bridge steel up to about 1967; obsolete due to poor weldability characteristics
- A373 steel - similar to A7 steel but has improved weldability characteristics due to controlled carbon content
- A36 steel - the latest of the low carbon steels (first used in 1960); it features good weldability and improved strength

Structural nickel steel (A8) was used widely prior to the 1960's in bridge construction, but welding problems occurred due to relatively high carbon content.

Structural silicon steel (A94) was used extensively in riveted or bolted bridge structures prior to the development of low alloy steels in the 1950's. This steel also has poor weldability characteristics due to high carbon content.

Quenched and tempered alloy steel plate (A514) was developed primarily for use in welded bridges.

High strength, low alloy steel is used where weight reduction is required, where increased durability is important, and where atmospheric corrosion resistance is desired; examples include:

- A242 steel
- A441 steel - manganese vanadium steel
- A572 steel - columbium-vanadium steel (replaced A441 in 1989)
- A588 steel - a "weathering steel," was developed to be left unpainted, which develops a protective oxide coating upon exposure to the atmosphere under proper design and service conditions (refer to Section 16.4.6 for a further description of weathering steel)

These steels are also copper bearing, which provides increased resistance to atmospheric corrosion and a slight increase in strength.

Some of the steel types listed above were used widely in the past but are no longer being manufactured. A new ASTM designation (A709) was developed in 1974. This designation covers carbon and high-strength low-alloy steel structural shapes, plates, and bars, and quenched and tempered alloy steel for structural plates intended for use in bridges. Six grades are available in four yield strength levels (36, 50, 70, and 100). Grades 36, 50, 50W, 70W, and 100/100W are also included in ASTM Specifications A36, A572, A588, A852, and A514, respectively. Grades 50W, 70W, and 100W have enhanced atmospheric corrosion resistance.

In addition to the ASTM steel designations, the American Association of State Highway and Transportation Officials (AASHTO) also publishes its own steel designation (M270). For each ASTM steel designation, there is generally a corresponding AASHTO steel designation. For a summary of the various ASTM and AASHTO steel designations, refer to the table at the beginning of Chapter 10.

Mechanical Properties

Some of the mechanical properties of steel include:

- Strength - steel is isotropic and possesses tremendous compressive and tensile strength, which varies widely with type of steel
- Elasticity - the modulus of elasticity is nearly independent of steel type and is commonly assigned as 29,000,000 psi
- Ductility - both the low carbon and low alloy steels normally used in bridge construction are quite ductile; however, brittleness may occur because of heat treatment, welding, or metal fatigue
- Fire resistance - steel is subject to a loss of strength when exposed to high temperatures such as those resulting from fire
- Corrosion resistance - unprotected carbon steel corrodes (i.e., rusts) readily; however, steel can be readily protected
- Weldability - steel is weldable, but it is necessary to select a suitable welding procedure based on the chemistry of the steel
- Fatigue - fatigue problems in steel members and connections can occur in bridges due to numerous live load stress cycles combined with poor weld or connection details

4.4.2 Types and Causes of Steel Deterioration

The most recognizable type of steel deterioration is corrosion, or rust. Bridge inspectors should be familiar with corrosion since it can lead to a substantial reduction in member capacity.

Corrosion

Some of the many different types of corrosion include:

- Environmental corrosion - primarily affects metal in contact with soil or water and is caused by formation of a corrosion cell due to deicing salt concentrations, moisture content, oxygen content, and accumulated foreign matter such as roadway debris and bird droppings
- Stray current corrosion - caused by electric railways, railway signal systems, cathodic protection systems for pipelines or foundation pilings, DC industrial generators, DC welding equipment, central power stations, and large substations

- Bacteriological corrosion - organisms found in swamps, bogs, heavy clay, stagnant waters, and contaminated waters can contribute to corrosion of metals
- Stress corrosion - occurs when tensile forces expose an increased portion of the metal at the grain boundaries, leading to corrosion and ultimately cracking
- Fretting corrosion - takes place on closely fitted parts which are under vibration, such as machinery and metal fittings, and can be identified by pitting and a red deposit at the interface

Fatigue Cracking

Fatigue cracks develop in bridge structures due to repeated loadings. Since this type of cracking can lead to sudden and catastrophic failure, the bridge inspector should be able to identify fatigue cracks.

Some factors leading to the development of fatigue cracks are:

- Frequency of truck traffic
- Age or load history of the bridge
- Magnitude of stress range
- Type of detail
- Quality of the fabricated detail
- Material fracture toughness (base metal and weld metal)
- Quality of welds

There are two basic types of bending in bridge members: in-plane and out-of-plane. When in-plane bending occurs, the cross section of the member resists the load according to the design and undergoes nominal elastic deformation. Out-of-plane bending implies that the cross section of the member is loaded in a plane other than that for which it was designed and undergoes significant elastic deformation or distortion. More correctly, out-of-plane bending should be referred to as out-of-plane distortion. Out-of-plane distortion is common in beam webs where transverse members connect and can lead to fatigue cracking (see Figure 4-26).

Overloads

Overloads are loads which exceed that for which the member or structure was designed.

Steel is elastic (i.e., it returns to its original shape when a load is removed) up to a certain point, known as the yield point. After this point is reached, steel will deform or elongate and remain in this condition even after the load has been removed. This type of deformation is called plastic deformation.

Plastic deformations due to overload conditions may be encountered in both tension and compression members. The symptoms in tension members are:

- Elongation
- Decrease in cross section, commonly called "necking down"

The symptoms in compression members are:

- Buckling in the form of a single bow
- Buckling in the form of a double bow or "S" type, usually occurring where the section under compression is pinned or braced at the center point

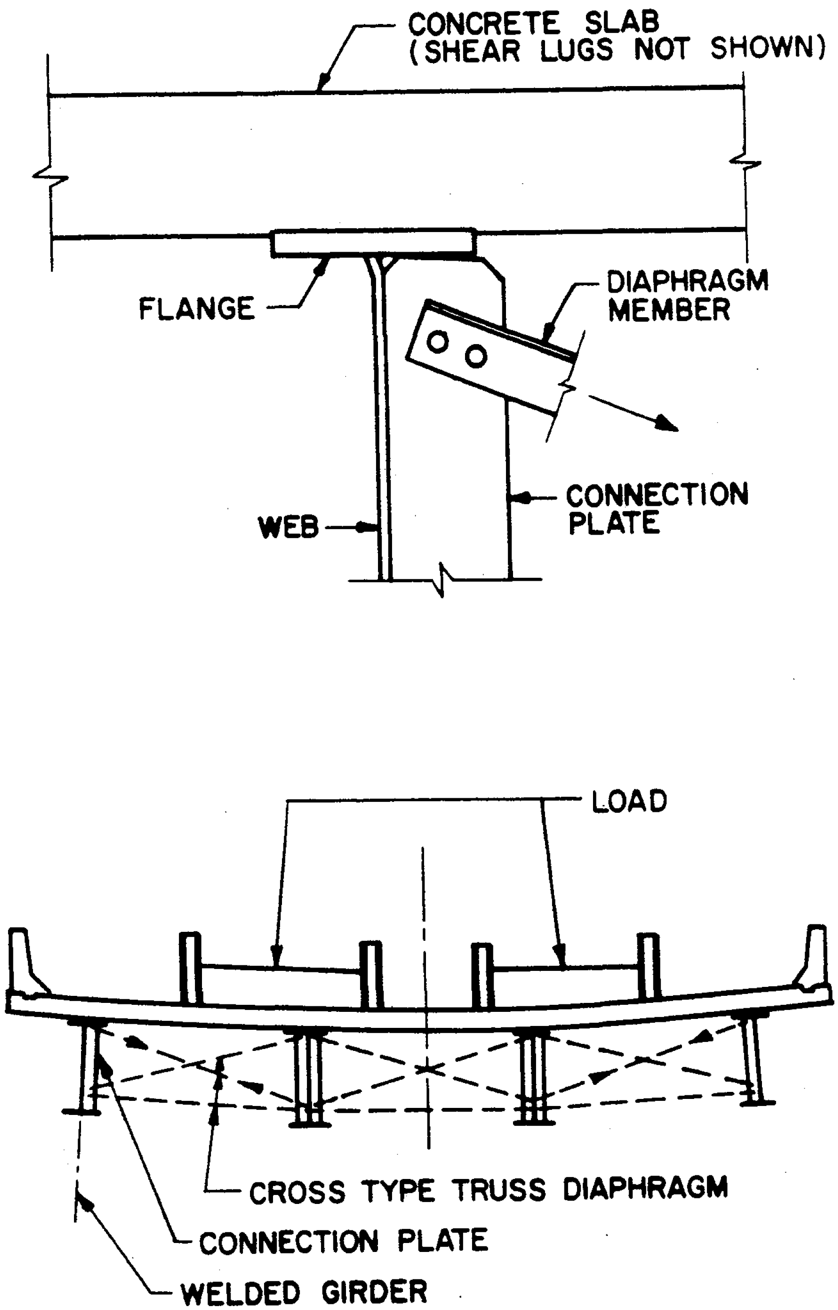


Figure 4-26 Out-of-Plane Distortion

An overload situation can lead not only to plastic deformation, but also to complete failure of the member. This occurs when a tension member breaks or when a compression member exhibits gross buckling distortion at the point of failure.

Vehicular Damage

Members of a bridge which are within reach of a moving vehicle are subject to damage by impact. Indications of vehicular damage include dislocated and distorted members.

4.4.3 Examination of Steel

The bridge inspector should not mistakenly assume that dirt or debris forms a protective coating for the steel surface. The inspector should remove all dirt and debris when possible to examine the steel surface.

Visual Examination

Some common signs of distress include:

- Bent or damaged members - determine the type of damage (e.g., collision, overload, or fire), measure the variance from proper alignment, and check for cracks, tears, and gouges near the damaged location (see Figure 4-27)
- Corrosion - since rust continually flakes off of a member, the severity of corrosion can not always be determined based simply on the amount of rust; therefore, corroded members must be examined by physical as well as visual means (see Figure 4-28)
- Fatigue cracks - fatigue cracks are common at certain locations on a bridge (see Table 4-2), and certain inspection procedures should be followed when fatigue cracks are observed (see Table 4-3 and Figure 4-29)
- Other stress-related cracks - determine the length, size, and location of the crack

Physical Examination

It is important for analysis purposes that the members reported in the plans or inspection report correspond properly with the members actually used on the bridge. If incorrect member sizes are used, then any analysis of the safety of the bridge is worthless. Therefore, the inspector should measure the bridge members to verify that the sizes recorded in the plans or inspection report are accurate.

Corrosion results in the loss of member material. This partial loss of cross section due to corrosion is known as section loss. Cross section loss may be measured using a straight edge and a ruler. Calipers may also be used to measure the thickness of the remaining steel. Section loss should be reported as a dimensional quantity relative to cross-sectional thickness. The inspector must remove all corrosion products (rust scale) prior to making measurements.

Figure 4-27 Collision Damage on a Steel Bridge

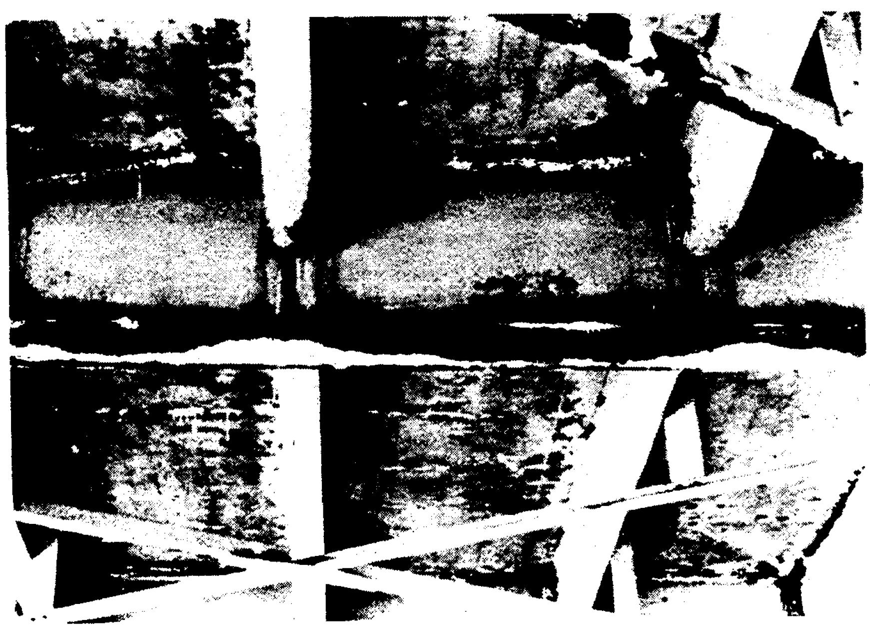


Figure 4-28 Corrosion of Steel

- Points on the structure where a discontinuity or restraint is introduced
- Loose members which could force the member or other members to carry unequal or excessive stress
- Damaged members, regardless of damage magnitude, which are misaligned, bent, or torn
- Corrosion which could reduce structural capacity through a decrease in member section and make the member less resistant to both repetitive and static stress conditions
- Welded details
- Past repairs which show indiscriminate welding or cutting procedures
- Areas of excessive vibrations or twisting

Table 4-2 Common Locations of Fatigue Cracks

- Report the fatigue crack immediately
- Determine the visual ends of the crack
- Examine other identical details on the bridge for cracks
- Examine other details for breaks in the paint and the formation of oxide (rust)
- If a suspect area is located, a more detailed examination, such as blast cleaning and using dye penetrant or ultrasonic testing, is required

Table 4-3 Inspection Procedures for Fatigue Cracks

Figure 4-29 Fatigue Crack

Advanced Inspection Techniques

In addition, several advanced techniques are available for steel inspection. Nondestructive methods, described in Section 15.4.1, include:

- Acoustic emissions testing
- Computer programs
- Computer tomography
- Corrosion sensors
- Dye penetrant
- Magnetic flux leakage
- Radiographic testing
- Robotic inspection
- Ultrasonic testing

Destructive methods, described in Section 15.4.2, include:

- Brinell hardness test
- Charpy impact test
- Chemical analysis
- Tensile strength test

4.5 Other Bridge Materials

4.5.1 Stone Masonry

Stone masonry is seldom used in bridge construction today except as facing or ornamentation. However, many old stone bridges are still in use. Granite, limestone, and sandstone are the most common types of stone used in bridges. In addition, many smaller bridges and culverts are built of locally available stones.

Properties of Stone Masonry

Stone generally has sufficient strength to be used as a load-resisting bridge member. While all stone is porous, sandstone and some limestone are more porous than granite. Most stone is absorptive, especially limestone. Stone expands and contracts with thermal variations, and it is generally a poor conductor of heat. Although stone is one of the most durable materials available, there is a wide range in durability between various types of stone. Stone is not flammable but can be damaged by fire. Stone masonry has a unit weight of about 170 pcf.

There are three general methods of finishing the surfaces of stone masonry:

- Rubble masonry
- Squared-stone masonry
- Ashlar

Rubble masonry consists of rough stones which are unsquared and used as they come from the quarry. It could be constructed to approximate regular rows or courses (coursed rubble) or could be uncoursed (random rubble). Random rubble was the least expensive type of stone masonry construction and was considered strong and durable for small spans if well constructed.

Squared-stone masonry consists of stones which are squared and dressed roughly. It could be laid randomly or in courses.

Ashlar consists of stones which are precisely squared and finely dressed. Like squared-stone masonry, it could be laid randomly or in courses.

Types and Causes of Stone Masonry Deterioration

The primary forms of deterioration in stone masonry are:

- Weathering - its hard surface degenerates into small granules, giving stones a smooth, rounded look
- Spalling - small pieces of rock break out or chip away
- Splitting - seams or cracks open up in rocks, eventually breaking them into smaller pieces (see Figure 4-30)

Some of the major causes of these forms of deterioration are:

- Chemicals - gases and solids dissolved in water often attack rocks and the cementing compounds between the rocks; oxidation and hydration of some compounds found in rock can also cause damage
- Volume changes - seasonal expansion and contraction can cause tiny seams to develop, weakening the rock
- Frost and freezing - water freezing in the seams and pores of rocks can spall or split rock
- Abrasion - due primarily to wind or waterborne particles
- Plant growth - roots and stems growing in crevices or joints can exert a wedging force, and lichen and ivy can chemically attack stone surfaces
- Marine borers - rock-boring mollusks attack rock by means of chemical secretions

Major factors contributing to the durability of stone masonry include its proper seasoning prior to use and the proper laying of the stone.

Figure 4-30 Splitting in Stone Masonry

Examination of Stone Masonry

The examination of stone masonry is similar to that of concrete. However, the joints between stones should be carefully inspected for cracks and other forms of mortar deterioration.

4.5.2 Cast Iron

Iron is an elemental metal smelted from iron ore. In general, a wide range of properties can be obtained depending upon the alloying elements used.

Cast iron is the most widely used cast metal. However, it is easily fractured by shocks and has low tensile strength due to a large percentage of free carbon and slag. Consequently, it is basically a poor bridge construction material and is not used in new bridge construction today. It may, however, be found in compression members on old bridges.

Cast iron is gray in color due to the presence of tiny flake-like particles of graphite on the surface. It has a unit weight of about 450 pcf.

Properties of Cast Iron

Some of the mechanical properties of cast iron include:

- Strength - its tensile strength varies from 25,000 psi to 50,000 psi, while its compressive strength varies from 65,000 psi to 150,000 psi
- Elasticity - cast iron has an elastic modulus of 13,000,000 psi to 30,000,000 psi, which is somewhat less than that of steel; elasticity increases with a decrease in graphite content
- Workability - cast iron possesses good machinability, and casting is relatively easy and inexpensive
- Weldability - cast iron is not effectively welded due to its high free carbon content
- Corrosion resistance - cast iron is generally more corrosion resistant than the other ferrous metals
- Brittleness - cast iron is very brittle and prone to fatigue-related failure when subjected to bending or tension stresses

Types and Causes of Cast Iron Deterioration

The primary forms of deterioration in cast iron are similar to those in steel (refer to Section 4.4.2).

Examination of Cast Iron

The examination of cast iron is similar to that of steel (refer to Section 4.4.3). Inspect for bent or damaged members, corrosion, fatigue cracks, and other stress-related cracks. Cast iron was used primarily for compression members in early iron bridges.

4.5.3 Wrought Iron

When iron is mechanically worked or rolled into a specific shape, it is classified as wrought iron. This process results in slag inclusions that are embedded between the microscopic grains of iron. This results in a fibrous material with properties in the worked direction similar to steel.

Wrought iron is no longer made in the United States. However, wrought iron tension members still exist on some older bridges, and it was well-suited for use in the early suspension bridges.

Properties of Wrought Iron

Some of the mechanical properties of wrought iron include:

- Strength - wrought iron is anisotropic (i.e., its strength varies with the orientation of its grain) due to the presence of slag inclusions; its compressive strength is about 35,000 psi, while its tensile strength varies between 36,000 psi and 50,000 psi
- Elasticity - its modulus of elasticity ranges from 24,000,000 psi to 29,000,000 psi, nearly as high as that of steel
- Impact resistance - wrought iron is tough and is noted for impact and shock resistance
- Workability - wrought iron possesses good machinability
- Weldability - wrought iron can be welded but care should be exercised when planning to weld the metal of any existing bridge
- Corrosion resistance - the fibrous nature of wrought iron produces a tight rust which is less likely to progress to flaking and scaling than is rust on carbon steel
- Ductility - wrought iron is generally ductile; reworking the wrought iron causes a finer and more thread-like distribution of the slag, thereby increasing ductility

Types and Causes of Wrought Iron Deterioration

The primary forms of deterioration in wrought iron are similar to those in steel (refer to Section 4.4.2).

Examination of Wrought Iron

The examination of wrought iron is similar to that of steel (refer to Section 4.4.3). Inspect for bent or damaged members, corrosion, fatigue cracks, and other stress-related cracks. Wrought iron was used primarily for tension members in early iron bridges.

4.5.4 Aluminum

Aluminum is widely used for signs, light standards, railings, and sign bridges. However, it is seldom used as a primary material in the construction of vehicular bridges.

Properties of Aluminum

The properties of aluminum are generally similar to those of steel (refer to Section 4.4.1). However, a few notable differences exist:

- Lightness - aluminum weighs about one third as much as steel
- Strength - aluminum is not as strong as steel, but alloying can increase its strength to that of steel
- Corrosion resistance - aluminum is highly resistant to atmospheric corrosion
- Workability - aluminum is easily fabricated, but welding of aluminum requires special procedures
- Durability - aluminum is durable

Aluminum alloy has a unit weight of about 175 pcf.

Types and Causes of Aluminum Deterioration

The primary forms of deterioration in aluminum are:

- Fatigue cracking - the combination of high stresses and vibration caused by wind produces fatigue
- Pitting - aluminum can pit slightly, but this condition rarely becomes serious

Examination of Aluminum

The examination of aluminum is similar to that of steel (refer to Section 4.4.3). Aluminum members should be examined in areas near the bases of cantilever arms and in areas near complex welded and bolted connections. Weld cracking often occurs on sign bridges near those joints which are subject to high stresses because of the misalignment of prefabricated sections.

5

Fundamentals of Bridge Inspection

Checklist of Standard Bridge Inspection Tools

Tools for Cleaning:

- ________ Wisk broom
- ________ Wire brush
- ________ Scrapers
- ________ Flat bladed screwdriver
- ________ Shovel

Tools for Inspection:

- ________ Pocket knife
- ________ Ice pick
- ________ Hand brace and bits
- ________ Increment borer
- ________ Chipping hammer with leather holder
- ________ Plumb bob
- ________ Tool belt with tool pouch

Tools for Visual Aid:

- ________ Binoculars
- ________ Flashlight
- ________ Lighted magnifying glass
- ________ Inspection mirrors
- ________ Dye penetrant

Tools for Measuring:

- ________ Pocket tape
- ________ 100 foot tape
- ________ Calipers
- ________ Optical check gauge
- ________ Paint film gauge
- ________ Tiltmeter and protractor
- ________ Thermometer
- ________ 4 foot carpenter's level

Tools for Documentation:

- ________ Inspection forms, clipboard, and pencil
- ________ Field books
- ________ Straight edge
- ________ 35 mm camera
- ________ Polaroid camera
- ________ Chalk or markers
- ________ Center punch
- ________ "P-K" nails

Miscellaneous Equipment:

- ________ "C"-clamps
- ________ Penetrating oil
- ________ Insect repellent
- ________ Wasp and hornet killer
- ________ First-aid kit
- ________ Toilet paper

5

Fundamentals of Bridge Inspection

5.1 Introduction

Bridge inspection is playing an increasingly important role in providing a safe infrastructure for our nation. As our nation's bridges continue to age and deteriorate, an accurate and thorough assessment of each bridge's condition is critical in maintaining a trustworthy highway system.

This chapter presents the responsibilities and duties of the bridge inspector. It also describes how the inspector can prepare for the inspection and some of the major inspection procedures. Bridge inspection equipment is described, and finally, important safety practices for the bridge inspector are presented.

5.2 Responsibilities and Duties of the Bridge Inspector

5.2.1 Responsibilities

There are five basic responsibilities of the bridge inspector:

- Maintain public safety and confidence
- Protect public investment
- Provide bridge inspection program support
- Provide accurate bridge records
- Fulfill legal responsibilities

Maintain Public Safety and Confidence

The primary responsibility of the bridge inspector is to maintain public safety and confidence. The general public travels our highways and bridges without hesitation. However, when a bridge fails, the public's confidence in our bridge system is violated (see Figure 5-1). The design engineer's role in assuring bridge safety is:

- To incorporate safety factors
- To design conservatively when appropriate

The inspector's role is:

- To provide thorough inspections identifying bridge conditions and defects
- To prepare condition reports documenting these deficiencies and presenting recommendations

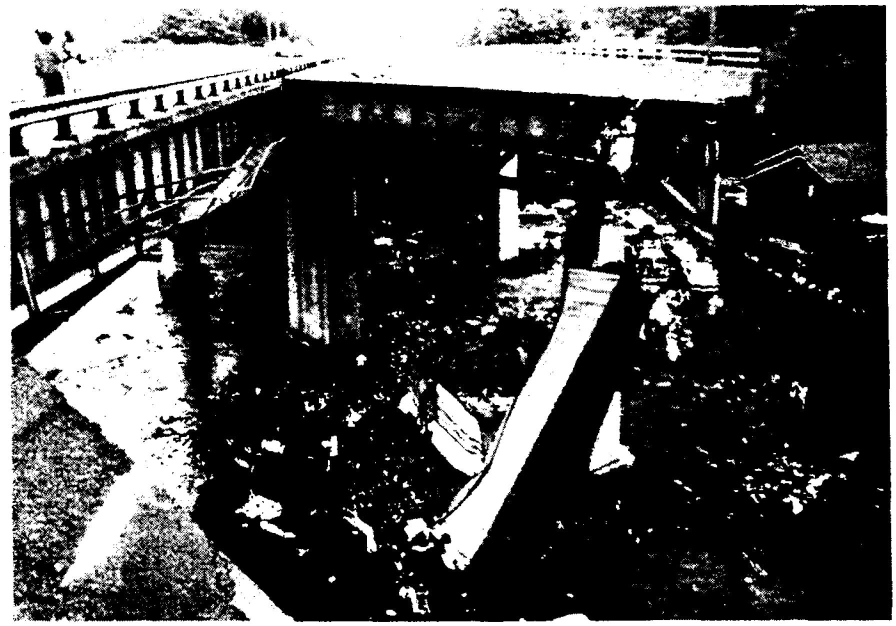


Figure 5-1 Bridge Failure

Protect Public Investment

Another responsibility is to protect public investment in bridges. The inspector must be on guard for minor problems which can be corrected before they lead to costly major repairs. The inspector must also be able to recognize bridge elements which need repair in order to maintain bridge safety and avoid replacement costs.

Provide Bridge Inspection Program Support

The National Bridge Inspection Standards (NBIS), part of the Code of Federal Regulations, mandates:

- Inspection procedures
- Frequency of inspections
- Qualifications of personnel
- Reporting
- Inventory

Bridge inspection programs are funded by public tax dollars. Therefore, the bridge inspector is financially responsible to the public.

Provide Accurate Bridge Records

There are three major reasons why accurate bridge records are required:

- To establish and maintain a structure history file
- To identify and assess bridge repair requirements
- To identify and assess bridge maintenance needs

Fulfill Legal Responsibilities

A bridge inspection report is a legal document. Descriptions must be concise, specific, detailed, quantitative (where possible), and complete.

Example of inspection descriptions: "Fair beams" is a poor description, while "Stringers in fair condition with light scaling on bottom flanges of Beams B and D for their full length" is a better description. "Deck in poor condition" is a poor description, while "Deck in poor condition with 30% chloride contamination and numerous spalls as indicated on field sketch, page 42" is a better description.

Original inspection notes should not be altered without consultation with the inspector who wrote the notes. A bridge inspection should be performed in accordance with NBIS, unless specifically stated otherwise in the report.

NBIS is very specific with regard to the qualifications of bridge inspectors. These requirements can be found in the Code of Federal Regulations, Title 23, Chapter 1, Section 650.307, (23 CFR 1.650.307), which is presented in Appendix A.

Consequence of Irresponsibility

In the event of negligence in carrying out the basic responsibilities described above, individuals, including department heads, engineers, and inspectors, are subject to personal liability. An inspector should strive to be as objective and complete as possible. Accidents that result in litigations are generally related, but not necessarily limited, to the following:

- Deficient safety features
- Failed fracture critical members
- Failed scour critical substructure elements
- Failed expansion joints, portions of decks, potholes, or other hazards to the traveling public
- Improper or deficient load posting procedures

Example of liability: In a recent case, a consulting firm was found liable when a truck driver was burned to death in a bridge-related accident. The tractor-trailer hit a large hole in a bridge deck, swerved, went through the guard rail, and fell 30 feet to the ground. Ten years prior to the accident, the consulting firm had noted severe deterioration of the deck and had recommended tests to determine the need for replacement. Two years prior to the accident, their annual inspection report did not show the deterioration or recommend repairs. One year before the accident, inspectors from the consultant checked 345 bridges in five days, including the bridge on which the accident occurred. The court found that the consulting firm had been negligent in its inspection, and assessed the firm 75% of the ensuing settlement.

5.2.2 Duties

There are five basic duties of the bridge inspector:

- Planning the inspection
- Preparing for the inspection
- Performing the inspection
- Preparing the report
- Identifying items for repairs and maintenance

Planning the Inspection

In order to make the inspection as orderly and systematic as possible, the inspector should make plans in advance. These plans should include determining the inspection sequence, establishing a time schedule, preparing for special inspection requirements (e.g., nondestructive testing and underwater inspection), organizing the field notes, anticipating the effects of traffic control procedures, and any other measures to facilitate a thorough and complete inspection.

Preparing for the Inspection

Preparation measures needed prior to the inspection include organizing the proper tools and equipment, reviewing the bridge structure files, and locating plans for the structure.

Performing the Inspection

Duties associated with the inspection include maintaining the proper structure orientation and member numbering system, developing an inspection sequence, and following proper inspection procedures.

Preparing the Report

Documentation is essential for an in-depth inspection. The inspector must gather enough information to ensure a comprehensive and complete report.

Identifying Items for Repairs and Maintenance

The final basic duty is to identify items for repairs and maintenance. The inspector must identify such items to ensure public safety and maximize longevity of the bridge.

5.3 Preparation for Inspection

The success of the on-site field inspection is largely dependent on the effort spent in preparing for the inspection. The major preparation activities include:

- Reviewing the bridge structure file
- Identifying the components and elements
- Developing an inspection sequence
- Preparing notes, forms, and sketches
- Arranging for traffic control
- Accounting for special considerations
- Organizing the tools and equipment
- Making arrangements for required methods of access
- Reviewing safety precautions

5.3.1 Review Bridge Structure File

The first step in preparing for a bridge inspection is to review the many available sources of information about the bridge, such as:

- "As-built" bridge plans
- Previous inspection reports
- Maintenance and repair records
- Geotechnical data
- Hydrologic data
- Utility plans
- Right-of-way plans

Bridge Plans

The bridge plans contain information about the bridge type, the number of spans, the use of simple or continuous spans, and the materials of construction (see Figure 5-2). They also contain information about the presence of composite action between the deck and girders, the use of framing action at the substructure members, and the kind of connection details used. The year of construction and the design loading are also generally contained in the bridge plans.

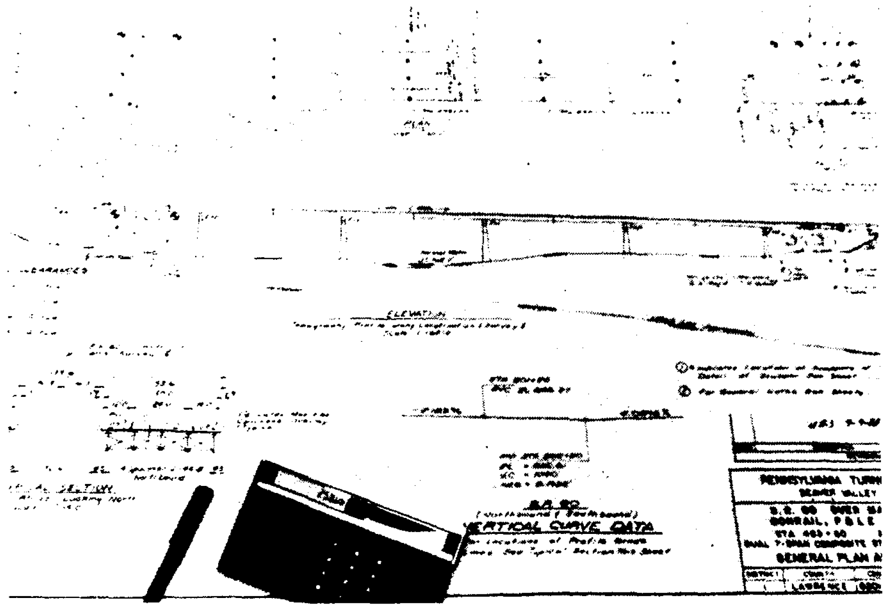


Figure 5-2 Bridge Plans

Previous Inspection Reports

Previous inspection reports provide valuable information about the history of the bridge, documenting its condition in previous years. This information can be used to determine which components and elements of the bridge warrant special attention. It also allows the inspector to compare the current levels of deterioration with those noted during previous inspections.

Maintenance and Repair Records

Maintenance and repair records allow the inspector to report all subsequent repairs during the inspection phase, noting the types, extent, and dates of the repairs.

Geotechnical Data

Geotechnical data provides information about the foundation material below the structure. Sand, silt, or clay is more susceptible to settlement and scour problems than is rock. Therefore, structures founded on these materials should generally be given more attention than those founded on rock.

Hydrologic Data

Hydrologic data provides information about the shape and location of the channel, the presence of protection devices, flood frequencies, and water elevations for various flood intervals. Using this information, the inspector can note any changes in the channel configuration and in the water elevation.

Additional Data

Utility plans can be used to determine the types and numbers of utility attachments, and right-of-way plans can be used to determine the limits of the right-of-way.

5.3.2 Identify Components and Elements

Another important activity in preparing for the inspection is to establish the structure orientation, as well as a system for identifying the various components and elements of the bridge (see Figure 5-3). If drawings or previous inspection reports are available, the identification system used during the inspection should be the same as that used in these sources.

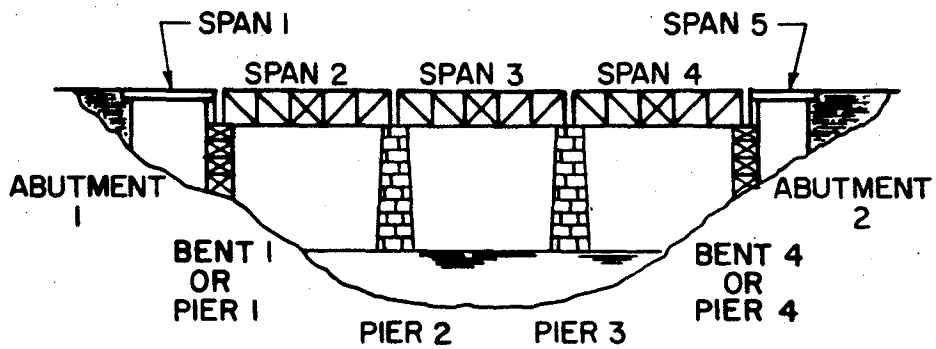


Figure 5-3 Sample Bridge Numbering Scheme

If no previous records are available, then the inspector should establish an identification system. The numbering system presented in this section is one possible system, but some states may use a different numbering system.

The route direction can be determined based on mile markers or stationing, and this direction should be used to identify the beginning and the end of the bridge.

Deck Element Numbering System

The deck element numbering system should include the deck sections (between construction joints), expansion joints, railing, parapets, and light standards. These elements should be numbered consecutively, from the beginning to the end of the bridge.

Superstructure Element Numbering System

The superstructure element numbering system should include the spans, the beams, and, in the case of a truss, panel points. The spans should be numbered consecutively, with Span 1 located at the beginning of the bridge. Multiple beams should be numbered consecutively from left to right facing in the route direction. Similar to spans, floorbeams should be numbered consecutively from the beginning of the bridge, but the first floorbeam should be labeled as Floorbeam 0. This will coordinate the floorbeam and the bay numbers such that a given floorbeam number will be located at the end of its corresponding bay.

For trusses, the panel numbers should be numbered similarly to the floorbeams, beginning with Panel Point 0. Label both the upstream and downstream trusses. Points in the same vertical line have the same number. If there is no lower panel point in a particular vertical line, the numbers of the lower chord will skip a number (see Figure 5-4). Some design plans number to a midpoint on the truss and then number backwards to zero using prime numbers. However, this numbering system is not recommended for field inspection use since the prime designations in the field notes may be obscured by dirt.

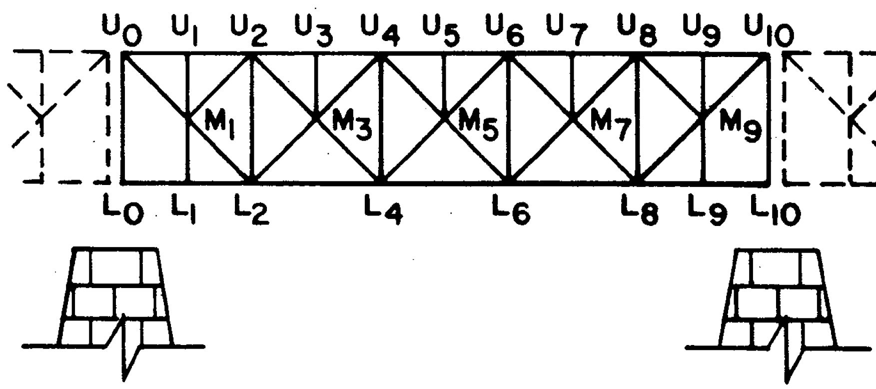


Figure 5-4 Sample Truss Numbering Scheme

Substructure Element Numbering System

The substructure element numbering system should include the abutments and the piers. Abutment 1 is located at the beginning of the bridge, and Abutment 2 is located at the end. The piers should be numbered consecutively, with Pier 1 located closest to the beginning of the bridge.

5.3.3 Develop Inspection Sequence

An inspection normally begins with the deck and superstructure elements and proceeds to the substructure. However, there are many factors that must be considered when planning a sequence of inspection for a bridge, including:

- Type of bridge
- Condition of the bridge components
- Overall condition
- Inspection agency requirements
- Size and complexity of the bridge
- Traffic conditions
- Special procedures

A sample inspection sequence for a bridge of average length and complexity is presented in Table 5-1. While developing an inspection sequence is important, it is of value only if following it ensures a complete and thorough inspection of the bridge.

1. Roadway and Deck Elements	3. Substructure Elements
• Approach roadways • Traffic safety features • Bridge deck • Expansion joints • Sidewalks and railings • Drainage • Signing • Electrical/lighting • Barriers, gates, and other traffic control devices	• Abutments • Skewbacks (arches) • Slope protection • Piers • Footings • Piles • Curtain walls
2. Superstructure Elements	**4. Channel and Waterway Elements**
• Bearings • Main supporting members • Secondary members and bracings • Utilities • Anchorages	• Channel profile and alignment • Channel streambed • Channel embankment • Channel embankment protection • Fenders • Dolphins • Hydraulic opening • Water depth scales • Navigational lights and aids

Table 5-1 Sample Inspection Sequence

5.3.4 Prepare Notes

Preparing notes, forms, and sketches prior to the on-site inspection eliminates unnecessary work in the field. Copies of the agency's standard inspection form should be obtained for use in recordkeeping.

Photocopy sketches from previous inspection reports so that defects previously documented can simply be updated. Preparing extra copies provides a contingency for sheets that may be lost or damaged in the field.

If previous sketches are not available, pre-made, generic sketches may be used for repetitive features or members. Possible applications of this timesaving procedure include deck sections, floor systems, bracing members, abutments, piers, and retaining walls.

5.3.5 Traffic Control

Bridge inspection, like construction and maintenance activities on bridges, often presents motorists with unexpected and unusual situations (see Figure 5-5). Most state agencies have adopted the federal *Manual on Uniform Traffic Control Devices for Streets and Highways* (*MUTCD*). Some state and local jurisdictions, however, issue their own manuals. When working in an area exposed to traffic, the bridge inspector should check and follow the existing standards. These standards will prescribe the minimum procedures for a number of typical applications and the proper use of standard traffic control devices, such as cones, signs, and flashing arrow boards.

Figure 5-5 Traffic Control Operation (Source: American Traffic Safety Services Association)

Principles and procedures which may enhance the safety of motorists and bridge inspectors in work areas include the following:

- Traffic safety should be a high priority element on every bridge inspection project where the inspectors' activities are exposed to traffic or likely to affect normal traffic movements.
- Traffic should be routed through work areas with geometrics and traffic control devices comparable to those employed by other highway situations.
- Traffic movement should be inhibited as little as practicable.
- Approaching motorists should be guided in a clear and positive manner throughout the bridge inspection site.
- On long duration inspections, routine inspection of traffic control devices should be performed.
- All persons responsible for the performance of traffic control operations should be adequately trained.

In addition, schedules may have to be adjusted to accommodate traffic control needs. For example, the number of lanes that can be closed at one time may require conducting the inspection operation with less than optimum efficiency. While it might be most efficient to inspect a floor system from left to right, traffic control may dictate working full length, a few beams at a time.

5.3.6 Special Considerations

Time Requirements

The inspection report or the bridge record file should state the amount of time required for the inspection. The inspection time requirements should be broken down into office preparation, travel time, field time, and report preparation.

Peak Travel Times

In populated areas, an inspection requiring traffic restrictions may be limited to certain hours of the day, such as 10:00 am to 2:00 pm. Some days may be banned for inspection work altogether. Actual inspection time may be less than a 40 hour work week in these situations, and schedules should be adjusted accordingly.

Set-Up Time

Set-up time must be considered both before and during the inspection. For example, rigging efforts may require several days before the inspectors arrive on the site. Also, other equipment, such as compressors and cleaning equipment, may require daily set-up time. Adequate time should be provided in the schedule for set-up and take-down time requirements.

Access

Access requirements must also be considered when preparing for an inspection. Bridge members may be very similar to each other, but they may require different amounts of time to gain access to them. For example, it may take longer to maneuver a lift device to gain access to a floor system near utility lines than for one that is free of obstructions. On some structures, access hatches may need to be opened to gain access to a portion of the bridge.

Overall Condition

The overall condition of the bridge will play a major role in determining how long an inspection will take. Previous inspection reports provide an indication of the bridge's overall condition. It generally takes more time to inspect and document a deteriorated element (e.g., measuring, sketching, and photographing) than it does to simply observe that an element is in good condition.

Weather

Adverse weather conditions may not halt an inspection entirely, but may play a significant role in the inspection process. During adverse weather conditions, climbing should generally be avoided. There must be an increased awareness of safety hazards, and keeping notes dry can be difficult. During seasons of poor weather, a less aggressive schedule should be adopted than during the good weather months.

Permits

When inspecting a bridge owned by or crossing a railroad, an access permit generally must be obtained before proceeding with the field inspection. A permit must also be obtained when inspecting bridges passing over navigable waterways.

5.3.7 Additional Preparation

Additional preparation for inspection includes:

- Organizing tools and equipment (refer to Section 5.5)
- Making arrangements for required methods of access (refer to Section 5.6)
- Reviewing safety precautions (refer to Section 5.7)

5.4 Inspection Procedures

The procedures used to inspect a bridge depend largely on the bridge type, the materials used, and the general condition of the bridge. Therefore, the inspector must be familiar with the basic inspection procedures for a wide variety of bridges.

A first step in the inspection procedure is to establish the orientation of the site and of the bridge. The orientation should include the compass directions, the direction of waterway flow, and the direction of the inventory route. Numbers or letters should be crayoned or painted on the bridge to identify and code components and elements of the structure. The purpose of these marks is to keep track of the inspector's location and to guard against overlooking any portion of the structure.

After the site orientation has been established, the inspector is ready to begin the on-site inspection. The inspector must be careful and attentive to the work at hand, and no portion of the bridge should be overlooked. Those portions that are most critical to the structural integrity of the bridge should be given special attention. (Refer to Chapter 18 for a description of fracture critical members.)

The prudence used during the inspection must be combined with thorough and complete recordkeeping. Observations should be careful and attentive, and every defect should be recorded. A very careful inspection is worth no more than the records kept during that inspection.

5.4.1 Basic Guidelines

Decks

The inspector should check the approach pavement for unevenness, settlement, or roughness. Also check the condition of the shoulders, slopes, drainage, and approach guardrail.

The deck and any sidewalk should be examined for various defects, noting size, type, extent, and location of each defect. The location should be referenced using the centerline or curb line, the span number, and the distance from a specific pier or joint.

Examine the expansion joints for sufficient clearance and for adequate seal. Record the width of the joint opening at both curb lines, noting the air temperature and the general weather conditions at the time of the inspection.

Finally, check that safety features, signs, and lighting are present and identify their condition.

Superstructures

The superstructure must be inspected thoroughly, since the failure of a main supporting member could result in the collapse of the bridge. The most common forms of main supporting members are:

- Beams and girders
- Floor beams and stringers
- Trusses
- Catenary and suspender cables
- Eyebar chains
- Arch ribs

- Frames
- Pins and hanger plates

The bearings must also be inspected thoroughly, since they provide the critical link between the superstructure and the substructure. Record the difference between the rocker tilt and a fixed reference line, noting the direction of tilt, the air temperature, and the general weather conditions at the time of the inspection.

Substructures

The substructure, which supports the superstructure, is made up of abutments, piers, and bents. If "as-built" plans are available, the dimensions of the substructure units should be compared with those presented on the plans. Since the primary method of bridge inspection is visual, all dirt, leaves, animal waste, and debris should be removed to allow close observation and evaluation. Substructure units should be checked for settlement by sighting along the superstructure and plumbing vertical faces. In conjunction with the scour inspection of the waterway, the substructure units should be checked for undermining, noting both its extent and location.

Waterways

Waterways are dynamic in nature, with their volume of flow and their path continually changing. Therefore, bridges passing over them must be carefully inspected for the effects of these changes.

A record should be maintained of the channel profile and alignment, noting any meandering of the channel both upstream and downstream. Report any skew or improper location of the piers or abutments.

Scour is the primary concern when evaluating the effects of waterways on bridges (see Figure 5-6). The existence and extent of scour must be determined using a grid system and noting the depth of the channel bottom at each grid point.

Figure 5-6 Inspection for Scour and Undermining

Embankment erosion should be noted both upstream and downstream of the bridge, as should debris and excessive vegetation. Record their type, size, extent, and location. Note also the high water mark, referencing it to a fixed elevation such as the bottom of the superstructure.

5.4.2 Inspection of Bridge Elements

The inspector must be familiar with several general terms used to describe bridge defects:

- Corrosion - rusting
- Cracking - breaking away without separating into parts
- Splitting - separating into parts
- Connection slippage - connections coming apart
- Overstress - deformation due to overload
- Collision damage - damage caused when a bridge is struck by vehicles or vessels

Refer to Chapter 4 for a more detailed list and description of types and causes of deterioration. As described in Chapter 4, each material is subject to unique defects. Therefore, the inspector should be familiar with the different inspection procedures used with each material.

Timber Inspection

When inspecting timber structures, determine the extent and severity of weathering and wear, being specific about dimensions, depths, and locations. Probe the timber to detect any hidden deterioration due to decay, insects, or marine borers.

Note any large cracks, splits, or crushed areas. While these may be caused by collision or overload damage, the inspector should be factual, avoiding speculation as to the causes. Note any fire damage, recording the measurements of the remaining sound material. Document any exposed untreated portions of the wood, indicating the type, size, and location.

Concrete Inspection

When inspecting concrete structures, note all visible cracks, recording their type, width, length, and location. Any rust or efflorescence stains should also be recorded. Concrete scaling can occur on any exposed face of the concrete surface, and its area, location, depth, and general characteristics should be recorded. Inspect concrete surfaces for delamination or hollow zones, which are areas of incipient spalling, using a hammer or a chain drag. Delamination should be carefully documented using sketches showing the location and pertinent dimensions.

Unlike delamination, spalling is readily visible. Spalling should also be documented using sketches, noting the depth of the spalling, the presence of exposed reinforcing steel, and any deterioration or section loss that may be present on the exposed bars.

Steel and Iron Inspection

When inspecting steel or iron structures, determine the extent and severity of corrosion, carefully measuring the amount of cross section loss. All cracks should be noted, recording their length, size, and location. Bent or damaged members should be documented, noting the type of damage and amount of deflection.

Loose rivets or bolts can be detected by striking them with a hammer while holding a thumb on the opposite end of the rivet or bolt. Movement will be felt if it is loose. In addition, any missing rivets or bolts should also be noted.

Note any frozen pins, hangers, or expansion devices. One indication of this is if the hangers or expansion rockers are inclined or rotated in a direction opposite to that expected for the current temperature. In cold weather, a rocker bearing should lean towards the fixed end of the bridge, while in hot weather, it should lean away from the fixed end. A locked bearing is generally caused by heavy rust on the bearing elements.

5.5 Inspection Equipment

5.5.1 Standard Tools

In order for the inspector to perform an accurate and comprehensive inspection, the proper tools must be used. Standard tools that an inspector should have available at the bridge site can be grouped into six basic categories:

- Tools for cleaning (see Figure 5-7)
- Tools for inspection (see Figure 5-8)
- Tools for visual aid (see Figure 5-9)
- Tools for measuring (see Figure 5-10)
- Tools for documentation
- Miscellaneous equipment

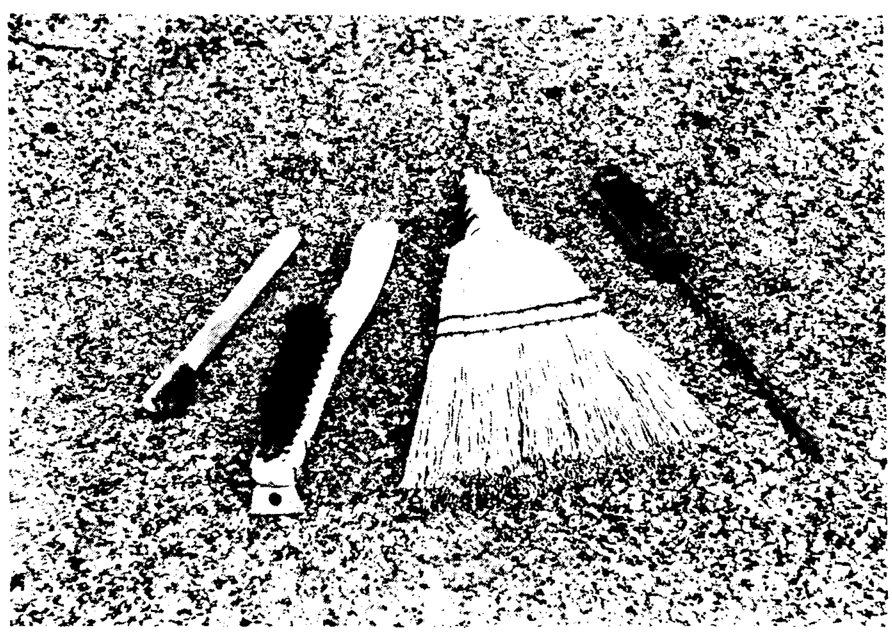


Figure 5-7 Tools for Cleaning

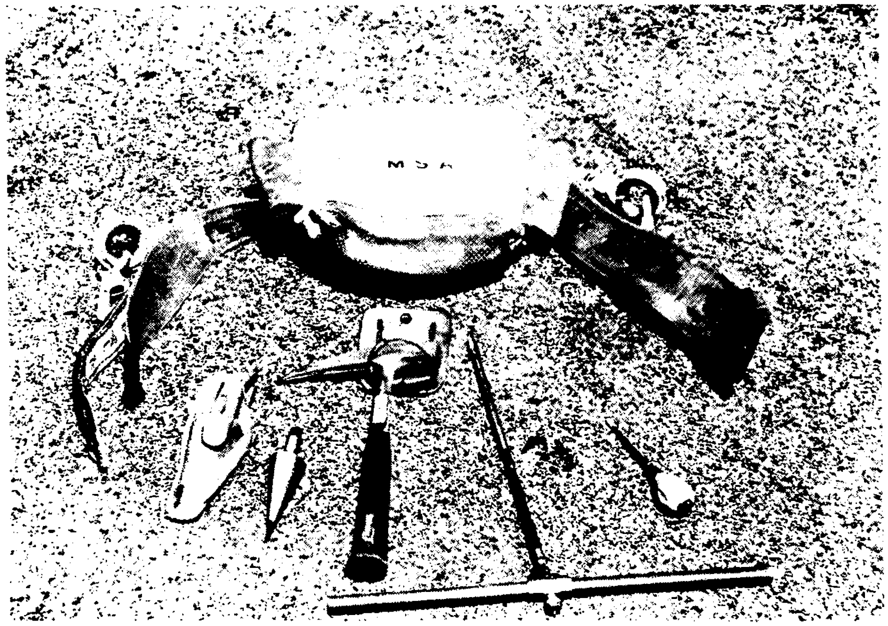


Figure 5-8 Tools for Inspection

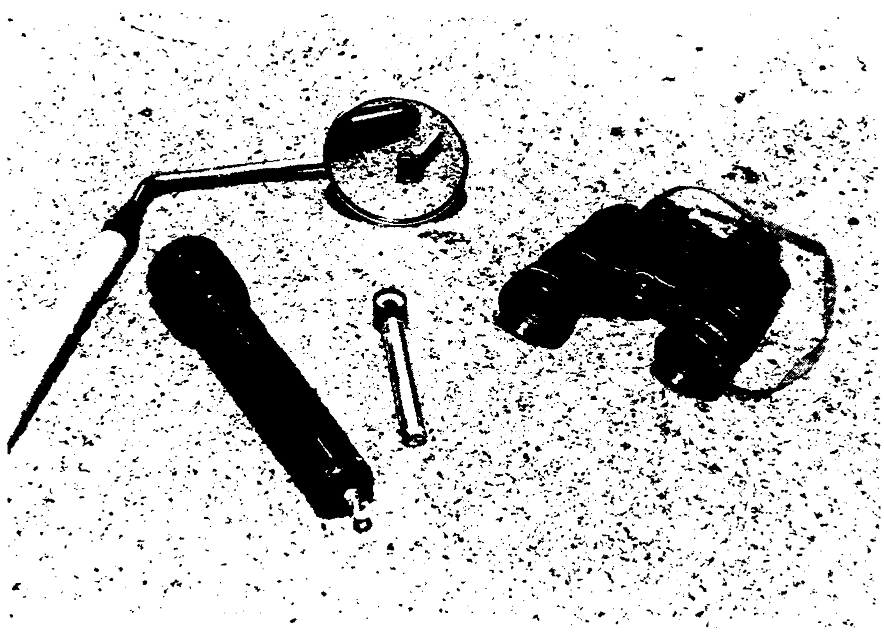


Figure 5-9 Tools for Visual Aid

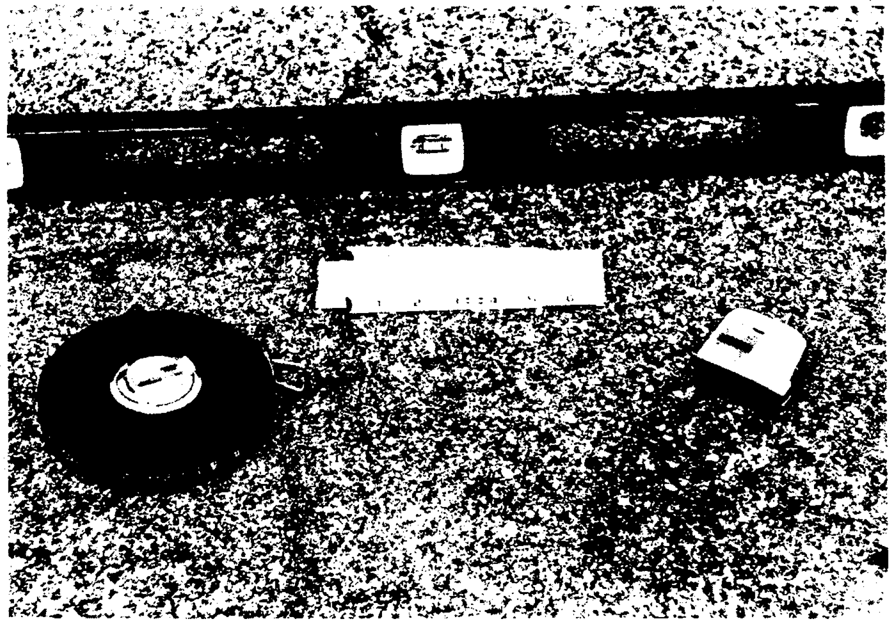


Figure 5-10 Tools for Measuring

Tools for Cleaning

Tools for cleaning should include:

- Wisk broom - used for removing loose dirt and debris
- Wire brush - used for removing loose paint and corrosion from steel elements
- Scrapers (2 inch) - used for removing corrosion or growth from element surfaces
- Flat bladed screwdriver - used for general cleaning and probing
- Shovel - used for removing dirt and debris from bearing areas

Tools for Inspection

Tools for inspection should include:

- Pocket knife - used for general duty
- Ice pick - used for surface examination of timber elements
- Hand brace and bits - used for boring suspect areas of timber elements
- Increment borer - used for internal examination of timber elements
- Chipping hammer with leather holder (6 ounce geologist's pick) - used for loosening dirt and rust scale, sounding concrete, and checking for sheared or loose fasteners
- Plumb bob - used to measure vertical alignment of a superstructure or substructure element
- Tool belt with tool pouch - used for convenient holding and access of small tools

Tools for Visual Aid

Tools for visual aid should include:

- Binoculars - used to preview areas prior to inspection activity and for examination at distances
- Flashlight - used for the examination of dark areas

- Lighted magnifying glass (e.g., five times and 10 times) - used for close examination of cracks and areas prone to cracking
- Inspection mirrors - used for inspection of inaccessible areas (e.g., underside of deck joints)
- Dye penetrant - used for identifying cracks and their lengths

Tools for Measuring

Tools for measuring should include:

- Pocket tape (6 foot rule) - used to measure defects and element and joint dimensions
- 100 foot tape - used for measuring component dimensions
- Calipers - used for measuring the thickness of an element beyond an exposed edge
- Optical crack gauge - used for precise measurements of crack widths
- Paint film gauge - used for checking paint thickness
- Tiltmeter and protractor - used for determining tilting substructures and for measuring the angle of bearing tilt
- Thermometer - used for measuring ambient air temperature and superstructure temperature
- 4 foot carpenter's level - used for measuring deck cross-slopes and approach pavement settlement

Tools for Documentation

Tools for documentation should include:

- Inspection forms, clipboard, and pencil - used for recordkeeping for an average bridge
- Field books - used for additional recordkeeping for complex structures
- Straight edge - used for drawing concise sketches
- 35 mm camera - used for visual documentation of the bridge site and conditions
- Polaroid camera - used to provide instant documentation for serious conditions which require immediate review by office personnel
- Chalk or markers - used for element and defect identification for improved organization and photo documentation
- Center punch - used for applying reference marks to steel elements for movement documentation (e.g., bearing tilt and joint openings)
- "P-K" nails - Parker Kalon masonry survey nails used for establishing a reference point necessary for movement documentation of substructures and large cracks

Miscellaneous Equipment

Miscellaneous equipment should include:

- "C"-clamps - used to provide a "third hand" when taking difficult measurements
- Penetrating oil - aids removal of fasteners, lock nuts, and pin caps when necessary
- Insect repellent - reduces attack by mosquitoes, ticks, and chiggers
- Wasp and hornet killer - used to eliminate nests, and hives to permit inspection
- First-aid kit - used for small cuts, snake bites, and bee stings
- Toilet paper - used for "emergencies" (better safe than sorry)

5.5.2 Special Equipment

For the routine inspection of an average bridge, special equipment is usually not necessary. However, with some structures, special inspection activities require special tools. These special activities are often subcontracted by the agency responsible for the bridge. The inspector should be familiar with special equipment and its application.

Survey Equipment

Special circumstances may require the use of a transit, a level, an incremental rod, or other survey equipment. This equipment establishes a component's exact location relative to other components, as well as an established reference point.

Nondestructive Testing Equipment

Nondestructive testing (NDT) is the in-place examination of a material for structural integrity without damaging the material. NDT equipment allows the inspector to "see" inside a bridge element and assess deficiencies that may not be visible with the naked eye. Generally, a trained technician is necessary to conduct NDT and interpret their results. Refer to Chapter 15 for a more detailed description of NDT.

Underwater Inspection Equipment

Underwater inspection is the examination of substructure units and the channel below the water line. When the waterway is shallow, underwater inspection can be performed above water with a simple probe. Probing can be performed using a piece of reinforcing steel, a survey rod, a folding rule, or even a tree limb.

When the waterway is deep, underwater inspection must be performed under the water by trained divers. This requires special diving equipment that includes a working platform, fathometer, ground penetrating radar, air supply systems, radio communication, and sounding equipment. Refer to Chapter 17 for a more detailed description of underwater inspection equipment.

Other Special Equipment

An inspection may require special equipment to prepare the bridge prior to the inspection. Such special equipment includes:

- Air/water jet equipment - used to clean surfaces of dirt and debris
- Sand or shot blasting equipment - used to clean steel surfaces to bare metal
- Burning, drilling, and grinding equipment

5.6 Methods of Access

The two primary methods of gaining access to hard to reach areas of a bridge are access equipment and access vehicles. Common access equipment includes ladders, rigging, and scaffolds, while common access vehicles include manlifts, bucket trucks, and snoopers. In most cases, using a manlift or bucket truck will be less time consuming than using a ladder or rigging to inspect a structure. The time saved, however, must offset the high costs associated with operating access vehicles.

5.6.1 Access Equipment

The purpose of access equipment is to position the inspector close enough to the bridge component so that a "hands-on" inspection can be performed. The following are some of the most common forms of access equipment.

Ladders

Ladders can be used for inspecting the underside of a bridge or for inspecting substructure units. However, a ladder should be used only for those portions of the bridge that can be reached comfortably, without undue leaning.

Rigging

Rigging of a structure consists of cables and platforms (see Figure 5-11). Rigging is used to gain access to floor systems and the bottom of main load-carrying members in areas where access by other means is not feasible or where special inspection procedures are required (e.g., nondestructive testing and pin removal). Rigging is often used over water, over busy highways or railroads where sufficient clearance exists, and for bridges that are over 40 feet high.

Figure 5-11 Rigging

Scaffolds

Scaffolds are generally more mobile than rigging. They provide an efficient access alternative for structures that are less than 40 feet high and over level ground with little or no traffic.

Boats or Barges

A boat or barge may be needed for structures over water. A boat can be used for some inspection, as well as for taking photographs. A barge can be used as a work platform for underwater inspection.

Climbers

Climbers are mobile inspection platforms that "climb" steel cables. They are well suited for the inspection of high piers and other long vertical faces of bridge members. Climbers are sometimes referred to as "spiders."

Floats

A float is a wood plank work platform hung by ropes. Floats are generally used for access in situations where the inspector will be at a particular location for a relatively long period of time.

Bosun (or Boatswain) Chairs

Bosun (or boatswain) chairs are suspended with a rope and can carry only one inspector at a time. They can be raised and lowered with block and tackle devices.

Climbing

On some structures, if other methods of access are not practical, inspectors must climb the bridge elements. Safety awareness should be foremost in the inspector's mind when utilizing this technique. Climbing can be divided into two categories. The first category is free climbing, in which the inspector climbs freely, unsecured to the bridge. The second category employs rappelling techniques and safety equipment.

5.6.2 Access Vehicles

There are also many types of vehicles available to assist the inspector in gaining access to bridge elements. The following are some of the most common types of access vehicles.

Manlifts

A manlift is a vehicle with a platform or bucket capable of holding one or more inspectors. The bucket is attached to a hydraulic boom that is mounted on a carriage. An inspector "drives" the carriage using controls in the bucket. This type of vehicle is usually not licensed for use on highways. However, some manlifts are nimble and can operate on a variety of terrains.

Bucket Trucks

A bucket truck is similar to a manlift (see Figure 5-12). However, a bucket truck can be driven on a highway, and the inspector controls only the bucket. Outriggers are sometimes extended from the chassis of the vehicle to help maintain stability, allowing greater reach and turning range. Some bucket trucks can move along the bridge during inspection activities. Most bucket trucks also have multiple booms with some models providing reach of up to 60 feet.

Figure 5-12 Bucket Truck

Snoopers

A snooper is a specialized bucket truck with an articulated boom designed to reach under a structure while parked on the deck (see Figure 5-13). A rotating turret provides maximum flexibility, and outriggers with wheels allow the truck to be moved during operations. Usually the third boom has the capacity for extending and retracting, allowing for greater reach under a structure.

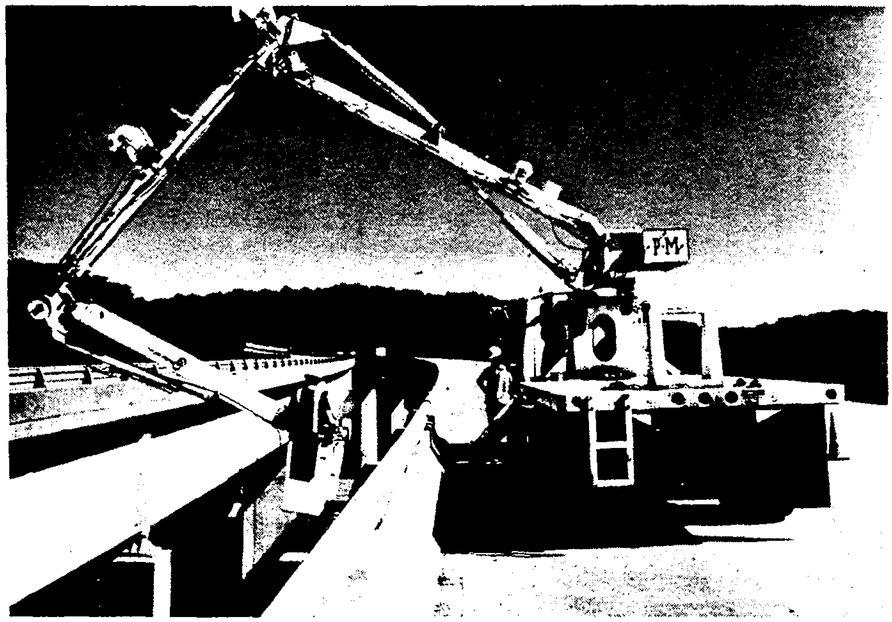


Figure 5-13 Snooper

5.7 Safety Practices

While completing the inspection in a timely and efficient manner is important, safety is also a major concern in the field. Bridge inspection is inherently dangerous and therefore requires continual watchfulness on the part of each member of the inspection team. Attitude, alertness, and common sense are three important factors in maintaining safety.

5.7.1 General Safety Awareness

Why Safety?

Accidents can cause pain, suffering, family hardship, and even death. Accidents also cost money in equipment, lost production, and medical expenses. Spending the effort to be safe pays big dividends in avoided expenses and grief.

Safety Fundamentals

The single most important consideration for inspecting bridges safely is the inspector's concern for creating a safe working environment. Good work habits which lead to a safe working environment include:

- Keeping well rested and alert
- Maintaining health and physical conditioning
- Using proper tools
- Keeping work areas neat and uncluttered

- Establishing systematic procedures concerning what to expect of one another
- Following safety rules and regulations established by the Occupational Safety and Health Administration (OSHA) in 29 CFR Chapter XVII, Article 1926.00, the agency, and your employer
- Using common sense and good judgment
- Avoiding alcohol and drugs

Safety Responsibilities

The employer is responsible for providing a safe working environment, including:

- Clear safety regulations and guidelines
- Safety training
- Proper tools and equipment

The supervisor is responsible for maintaining a safe working environment, including:

- Supervision of established job procedures
- Guidance in application of safety procedures
- Guidance in proper use of equipment
- Enforcement of safety regulations

Bridge inspectors are ultimately responsible for their own safety. The bridge inspector's responsibilities also include:

- Recognition of physical limitations
- Knowledge of rules and requirements of job
- Safety of fellow workers
- Reporting an accident (usually within 24 hours)

5.7.2 Personal Protection

Proper Inspection Attire

It is important to dress properly for the job. Field clothes should be properly sized for the individual, and they should be appropriate for the climate. For general inspection activities, the inspector should wear leather boots with traction lug soles. For climbing of bridge components, the inspector should wear boots with a steel shank (with non-slip soles without heavy lugs), as well as leather gloves. Wearing a tool pouch enables the inspector to carry tools and notes with hands free for climbing and other inspection activities.

Inspection Safety Equipment

While safety equipment is designed to prevent injury, the inspector must use this equipment to gain protection. Some common pieces of safety equipment are:

- Hard hat - provides protection from falling objects and protects the inspector's head from accidental impact with bridge components
- Reflective safety vest - essential when working near traffic conditions
- Safety goggles - eye protection is necessary when the inspector is exposed to flying particles; glasses with shatterproof lenses are not adequate since side protection is not provided; only single lens glasses should be worn when climbing (no bifocals)
- Life jacket - should always be worn when working over water or in a boat
- Dust mask - protects the lungs from harmful air pollutants

- Respirator - protects the inspector from harmful airborne contaminants from sand blasting, painting, and exposure to dust from pigeon droppings
- Safety belt and lanyard - must be worn above water, above traffic, and at excessive heights; the safety belt should be tied off to a solid structural member or to a safety line, but not to scaffolding or its supporting cable
- Gloves - protect the hands from harmful effects of deteriorated members

5.7.3 Causes of Accidents

General

The two major causes of accidents are human error and equipment failure. Human error can be reduced by acknowledging that we all make mistakes and planning ahead to minimize their effects (see Figure 5-14). Equipment failure can be reduced by providing inspection, maintenance, and update of equipment.

Specific Causes

Some specific causes of accidents include:

- Improper attitude - distraction, carelessness, and worry over personal matters
- Personal limitations - lack of knowledge or skill; exceeding physical capabilities
- Physical impairment - previous injury, illness, side effects of medication, alcohol, or drugs
- Boredom or distractions - falling into an inattentive state while performing repetitive, routine tasks
- Thoughtlessness - lack of safety awareness and not recognizing hazards
- Short-cuts - sacrificing safety for the sake of time
- Faulty equipment - damaged ladder rungs, worn ropes, and frayed cables
- Improper or loose fitting attire

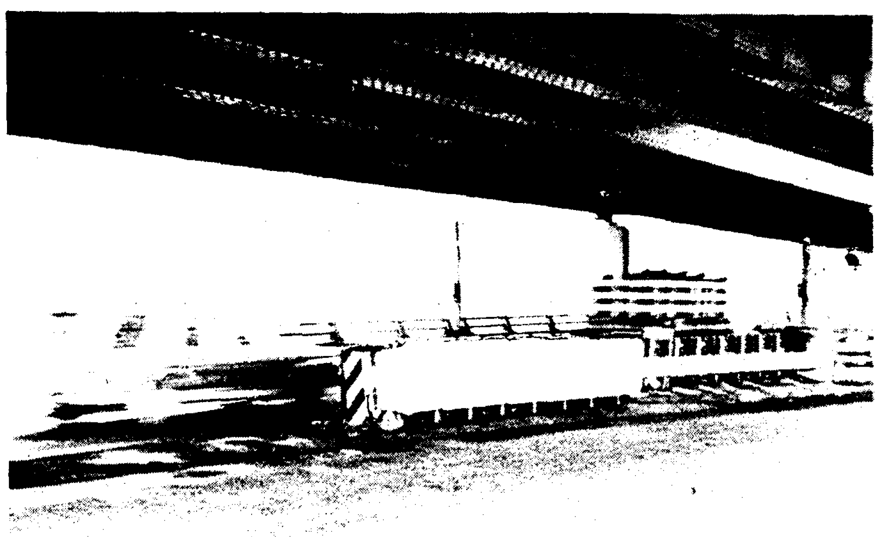


Figure 5-14 High Speed Traffic - Not a Place to be Careless

5.7.4
Safety Precautions

General Precautions

Some general guidelines for safe inspections include:

- Avoid use of intoxicants or drugs - impairs judgment, reflexes, and coordination
- Medication - prescription and over-the-counter medications can cause unwanted and dangerous side effects
- Electricity - all cables and wires should be assumed to be live; all power lines should be shut down
- Assistance - always work in pairs
- Inspection over water - a safety boat, equipped with a life ring and radio communication, must be provided when working over bodies of water
- Waders - caution should be used when wearing waders since they can fill with water, making swimming impossible
- Inspection over traffic - if working above traffic can not be avoided, then tools and notebooks should be tied off
- Entering dark areas - a flashlight should always be used; lifelines and an oxygen supply may have to be considered
- Pigeon droppings - breathing the dust of pigeon droppings may cause lung cancer

Climbing Safety

There are three basic areas of preparation necessary for a safe climbing inspection. The first basic area is the organization of the inspection:

- Climbing strategy - climbing time should be minimized
- Inspection plan - the inspector should know exactly where to go, what will need to be done, and what tools will be needed
- Weather conditions - rainy conditions warrant postponement of steel bridge inspections
- Traffic - should not be obstructed

Second, inspection equipment should be checked for proper use and conditions:

- Ladders - accidents involving ladders are the most common
- Scaffolding - should be checked for height, load capacity, cracks, loose connections, and weak areas
- Timber planks - two or more planks securely cleated together should be used; plank ends should be securely attached to their supports
- Inspection vehicles - platform trucks, bucket trucks, and snoopers should be used if possible
- Catwalks and travelers - permanent inspection access devices should be used when available (see Figure 5-15)
- Rigging - the inspector should be familiar with proper rigging techniques and should not have "blind" trust in the riggers

Figure 5-15 Inspection Catwalk

Third, the inspector must be mentally prepared for a climbing inspection (see Figure 5-16). A good safety attitude is of foremost importance. Three precautions that must be addressed are:

- Avoid emotional distress - do not climb when emotionally upset or when lacking self-control
- Self-awareness - always know where you are and what you are doing when climbing
- Confidence - do not do anything you are not confident of doing safely, and do not hide the fact that something was not inspected

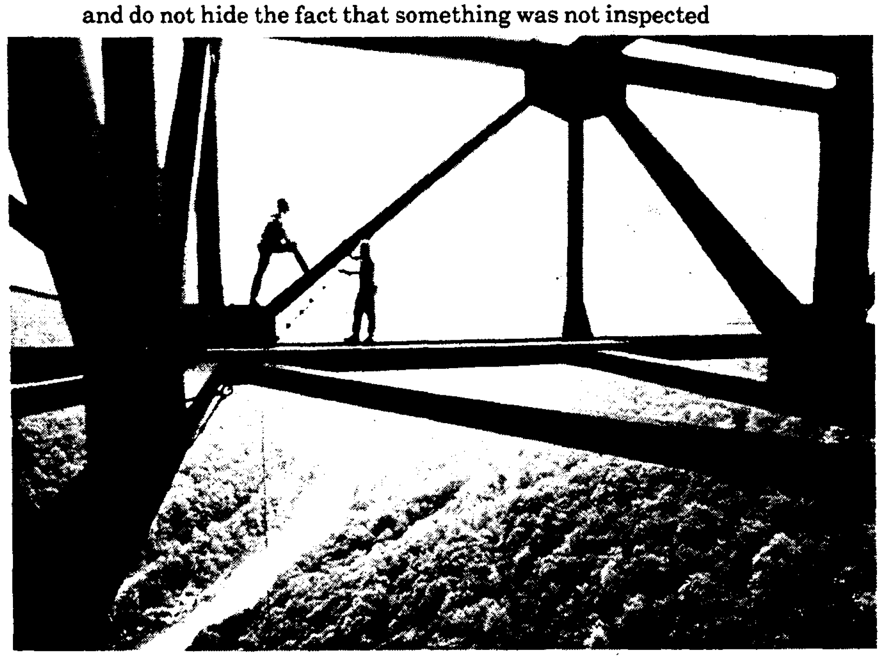


Figure 5-16 Safety Precautions During a Climbing Inspection

Confined Spaces

Inspection of box girder bridges, steel arch rings, arch ties, cellular concrete structures, and long culverts often involves confined spaces. There are three major concerns when inspecting a confined space:

- Lack of oxygen - oxygen content must remain above 19% for the inspector to remain conscious
- Toxic gases - generally produced by work processes such as painting, burning, and welding
- Explosive gases - materials such as natural gas and methane are produced by the natural oxidation of organic matter

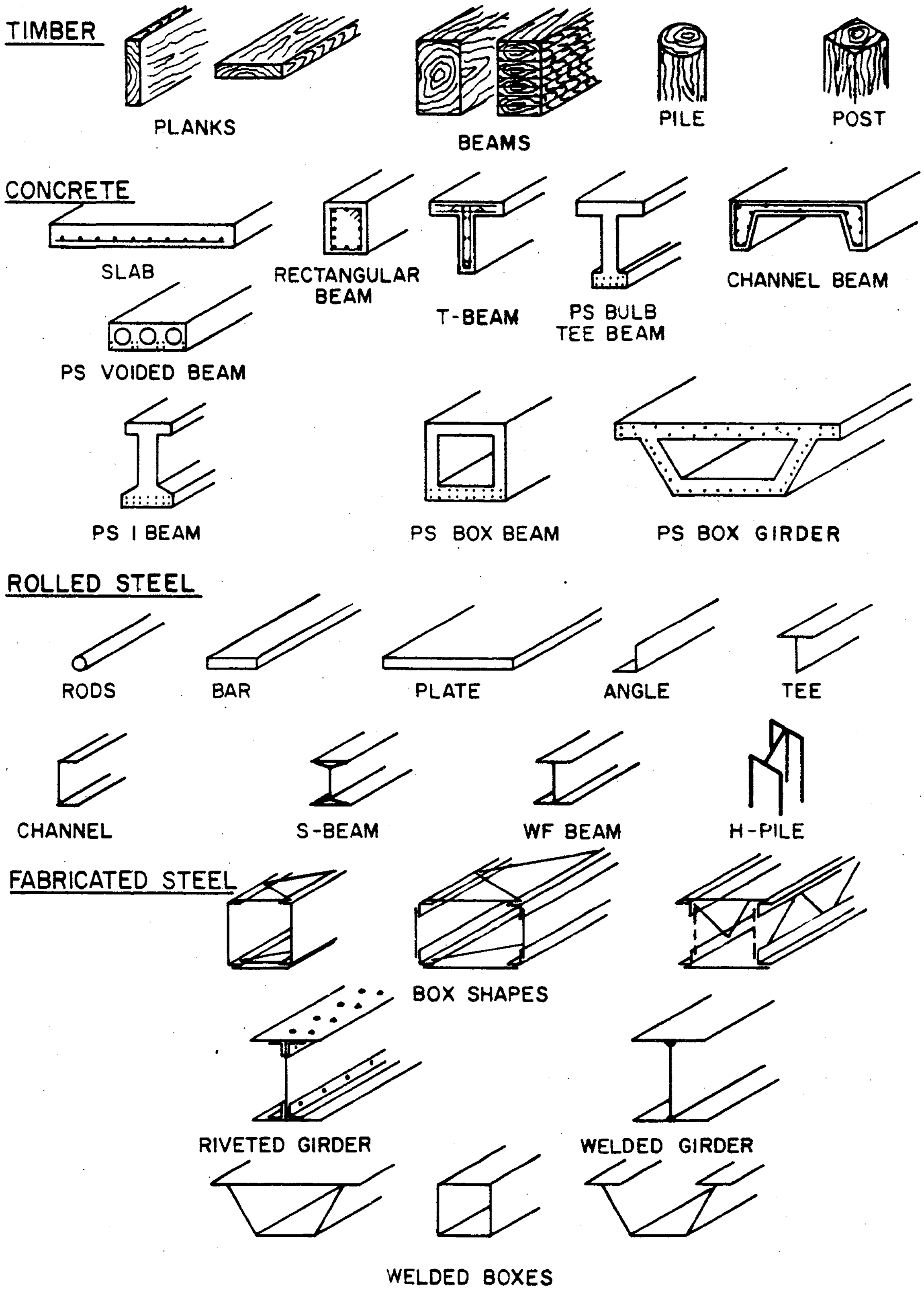
When a confined area must be inspected, some basic safety precautions should be followed:

- Test oxygen and other gases at 15 minute intervals
- Avoid use of flammable liquids
- Position inspection vehicles away from the area entrance to avoid carbon monoxide fumes
- Operations involving gasoline or toxic gases should be performed "down wind" of the operator and the inspection team
- Use approved air-breathing apparatus when ventilation is not possible or when detection equipment is not available
- Adequate lighting and lifelines are required when entering culverts
- Inspection should be performed in pairs, with a third inspector remaining outside of dark or confined areas

6

Identification and Function of Bridge Components and Elements

BASIC MEMBER SHAPES



6

Identification and Function of Bridge Components and Elements

6.1 Introduction

At this point, the bridge inspector should be familiar with the terminology and elementary theory of bridge mechanics and materials. Chapter 3 explained how various forces and loads affect bridges. Chapter 4 discussed the types of materials used in the construction of bridges and commonly encountered deterioration problems.

This chapter presents the terminology needed by inspectors to properly identify and describe the individual elements that comprise a bridge. First the major components of a bridge are described. Then the basic member shapes, the "building blocks," of the bridge are presented. Finally, the methods of connecting shapes together are discussed. Basic member shapes are connected to form the major components.

6.2 Major Bridge Components

A thorough and complete bridge inspection is dependent upon the bridge inspector's ability to identify and understand the function of the major bridge components and their elements. Most bridges can be divided into three basic parts or components (see Figure 6-1):

- Deck
- Superstructure
- Substructure

6.2.1 Deck

The deck is that component of a bridge to which the live load is directly applied.

Deck Purpose

The purpose of the deck is to provide a smooth and safe riding surface for the traffic utilizing the bridge (see Figure 6-2).

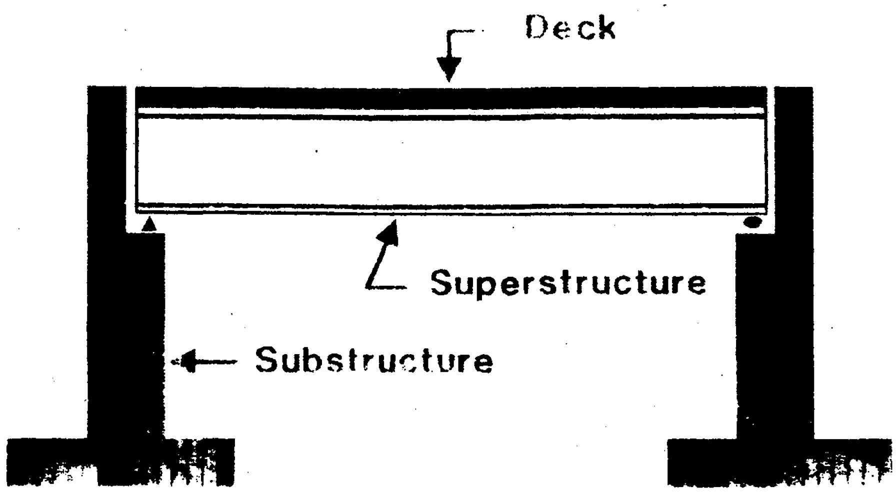


Figure 6-1 Major Bridge Components

Figure 6-2 Bridge Deck With a Smooth Riding Surface

Deck Function

The function of the deck is to transfer the live load and dead load of the deck to other bridge components. In most bridges, the deck distributes the live load to the superstructure through a floor system. However, on some bridges (e.g., a concrete slab bridge), the deck and superstructure are one unit which distributes the live load directly to the bridge supports (see Figure 6-3).

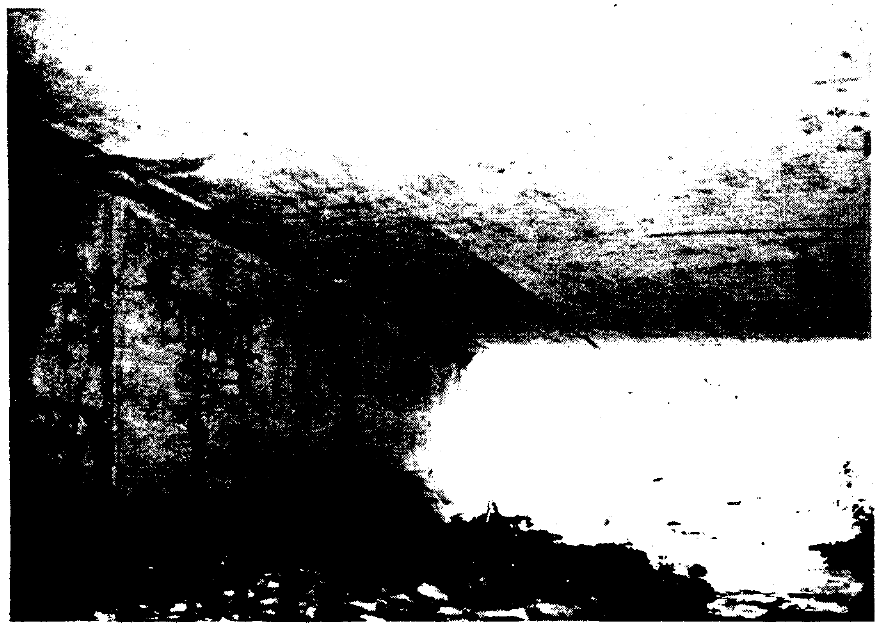


Figure 6-3 Underside View of a Slab Bridge

Deck Materials

There are three common materials used in the construction of bridge decks:

- Timber
- Concrete
- Steel

6.2.2 Superstructure

The superstructure is that component of the bridge which supports the deck or riding surface of the bridge, as well as the loads applied to the deck.

Superstructure Purpose

The basic purpose of the superstructure is to carry loads from the deck across the span and to the bridge supports.

Superstructure Function

The function of the superstructure is to transmit loads. Bridges are named for their type of superstructure. Superstructures may be characterized with regard to their function (i.e., how they transmit loads to the substructure). Loads may be transmitted through tension, compression, bending, or a combination of these three. There are three basic types of bridges (see Figure 2-1):

- Beam
- Arch
- Cable-supported

Beam Bridges

In the case of beam bridges, loads from the superstructure are transmitted vertically to the substructure. Examples of beam bridges include:

- Slabs (concrete)
- Beams (timber, concrete, or steel) (see Figure 6-4)
- Girders (concrete or steel)
- Trusses (timber or steel)

Figure 6-4 Timber Beam Bridge

Arch Bridges

In the case of arch bridges, the loads from the superstructure are transmitted diagonally to the substructure. True arches are in pure compression. Arch bridges can be constructed from timber, concrete, or steel (see Figure 6-5).

Cable-Supported Bridges

In the case of cable-supported bridges, the tension loads from the superstructure (cables) are resisted by the substructure anchorages and towers. Cable-supported bridges can be either suspension or cable-stayed (see Figure 6-6).

Superstructure Materials

In addition to the type of superstructure, a bridge is also named for the material used in the superstructure. Over the years, several common materials have been used in the construction of bridge superstructures:

- Natural stone
- Timber
- Masonry
- Iron
- Concrete
- Steel

6.2.3 Substructure

The substructure is that component of a bridge which includes all the elements which support the superstructure.

Figure 6-5 Concrete Arch Bridge

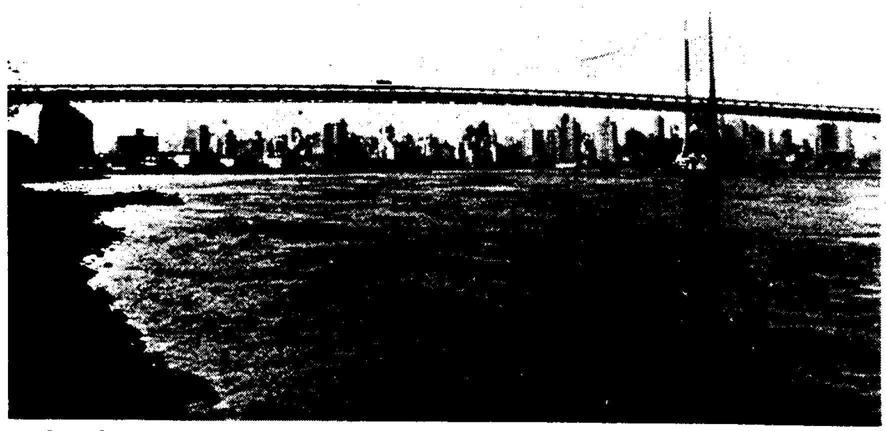


Figure 6-6 Steel Suspension Bridge

Substructure Purpose

The purpose of the substructure is to transfer the loads from the superstructure to the foundation soil or rock.

Substructure Function

Substructure units function as both axially-loaded and bending members. These units resist both vertical and horizontal loads applied from the superstructure. Substructures are divided into two basic categories:

- Abutments
- Piers and bents

Abutments provide support for the ends of the superstructure (see Figure 6-7). Piers and bents provide support for the superstructure at intermediate points along the bridge (see Figure 6-8).

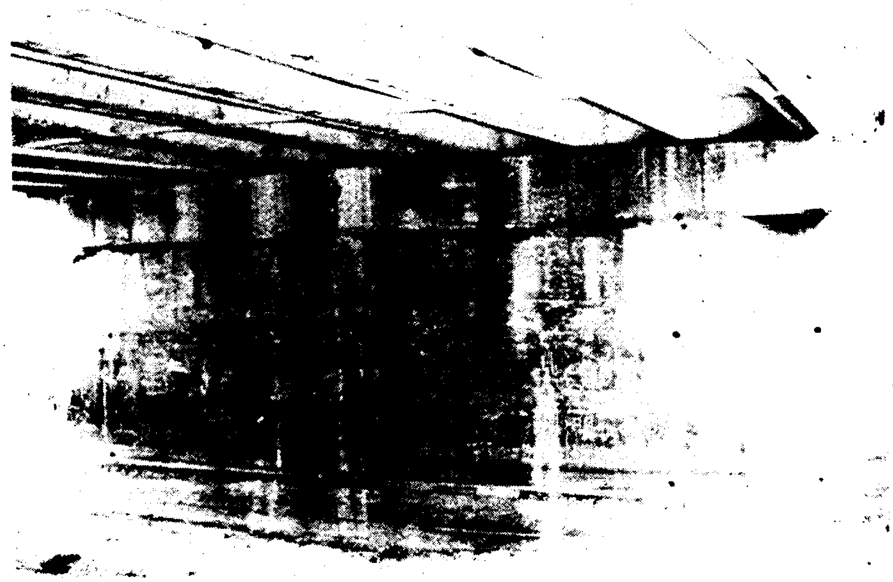


Figure 6-7 Concrete Abutment

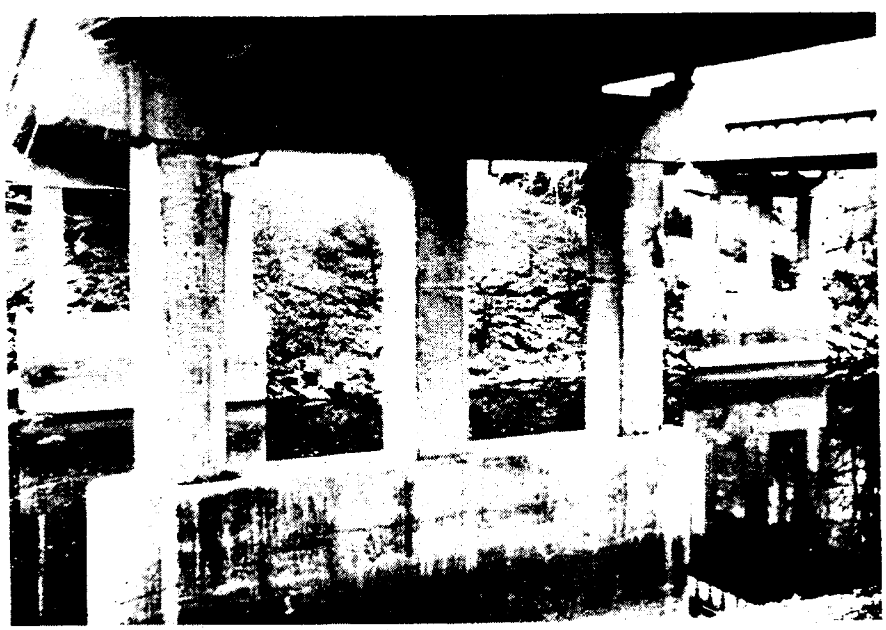


Figure 6-8 Concrete Pier

Substructure Materials Substructure elements are constructed of the following materials:

- Natural stone
- Timber
- Masonry
- Concrete
- Steel

6.3 Basic Member Shapes

The ability to recognize and identify basic member shapes requires an understanding of the timber, concrete, and steel shapes used in the construction of bridges.

Every bridge member is designed to carry a unique combination of tension, compression, and shear. These are considered the three basic kinds of member stresses. Bending loads cause a combination of tension and compression in a member. Shear stresses are caused by transverse forces exerted on a member. As such, certain shapes and materials have distinct characteristics in resisting the applied loads.

6.3.1 Timber Shapes

Timber members are found in a variety of shapes (see Figure 6-9). The sizes of timber members are generally given in nominal dimensions (such as in Figures 6-9 through 6-11). However, timber members are generally seasoned and surfaced from the rough sawn condition, making the actual dimension about 1/2 to 3/4 inches less than the nominal dimension.

The physical properties of timber enable it to resist both tensile and compressive stresses. Therefore, it can function as an axially-loaded or bending member. Timber bridge members are made into three basic shapes:

- Planks
- Beams
- Piles

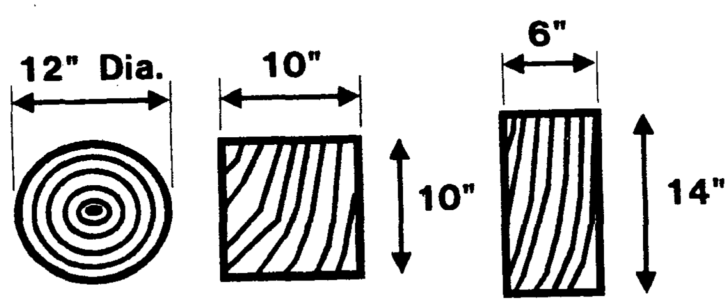


Figure 6-9 Timber Shapes

Planks

Planks are characterized by elongated, rectangular dimensions determined by the intended bridge use. Plank thickness is dependent upon the distance between the supporting points and the magnitude of the vehicle load. A common dimension for timber planks is a 2-inch (1 1/2 inch seasoned and dressed) thickness and a 12-inch (11 1/4 inch seasoned and surfaced) width (see Figure 6-10).

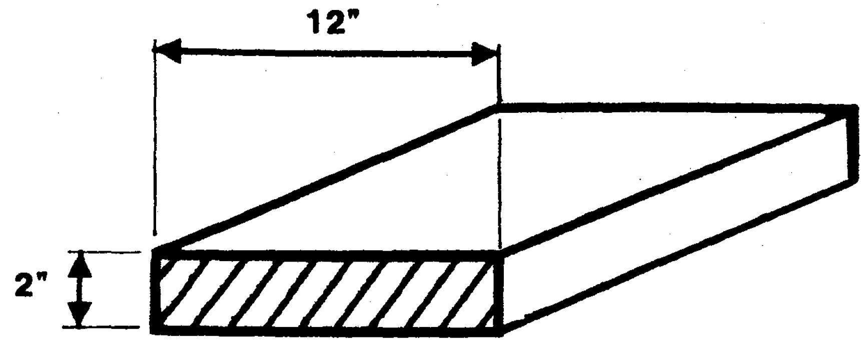


Figure 6-10 Timber Plank

Planks are most often used for bridge decks on bridges carrying light or infrequent truck traffic. While some shapes and materials are relatively new, the use of timber plank decks has existed for centuries. Timber planks are advantageous in that they are economical, light weight, readily available, and easy to erect.

Beams

Timber beams have more equal rectangular dimensions than do planks, and they are sometimes square. Common dimensions include 10 inches by 10 inches (9 1/2 inches by 9 1/2 inches dressed) square timbers, and 6 inches by 14 inches (5 1/2 inches by 13 1/2 inches dressed) rectangular timbers.

As the differences in the common dimensions of planks and timber beams indicate, beams are larger and heavier than planks and can support heavier loads, as well as span greater distances. As such, timber beams are used in bridge superstructures and substructures to carry bending and axial loads.

Timbers can either be solid sawn or glued-laminated (see Figure 6-11). Glued-laminated timbers are advantageous in that they can be fabricated from smaller, more readily available pieces. Glued lamination also allows larger rectangular members to be formed without the presence of natural defects such as knots. Glued-laminated timbers are normally manufactured from well-seasoned laminations and display very little shrinkage after they are made.

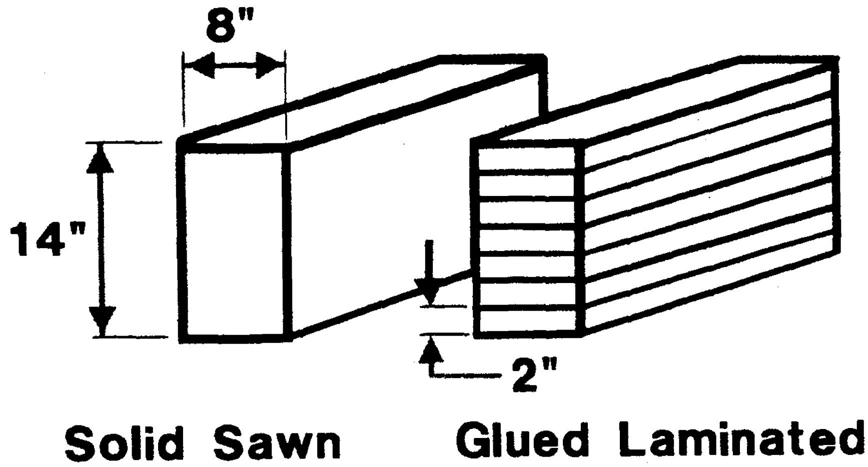


Figure 6-11 Timber Beams

Piles

Timber can also be used for piles. Piles are slender columns that support the substructure footing or partially form the substructure. Piles may be partially above ground but are usually completely buried.

6.3.2 Concrete Shapes

Concrete is a unique material for bridge members because it can be formed into an infinite variety of shapes. Concrete members are used to carry axial loads and loads in bending. Since bending is really a combination of compressive and tensile stresses, plain concrete is a poor material to resist bending. Concrete bending members are typically reinforced with either reinforcing steel (producing reinforced concrete) or with prestressing steel (producing prestressed concrete) in order to carry the tensile stresses in the member. The cost of prestressing steel is greater than that of reinforcing steel. However, because less steel is used in prestressed concrete, it is more economical to use.

Reinforced Concrete Shapes

The most common shapes of reinforced concrete members are (see Figure 6-12):

- Slabs
- Rectangular beams
- Tee beams
- Channel beams

Bridges utilizing these shapes and steel reinforcement were constructed between 1930 and 1945 and were typically cast-in-place. Many of these designs are obsolete, but the structures remain in service. Concrete members of this type are used for short and medium span bridges.

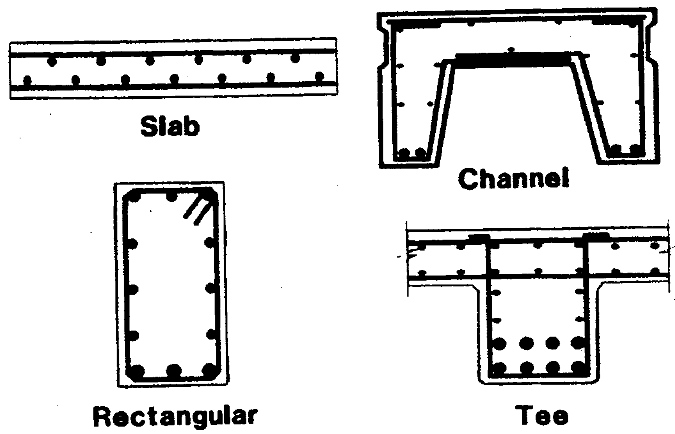


Figure 6-12 Reinforced Concrete Shapes

Concrete slabs are used for concrete decks and slab bridges. On concrete decks, the concrete slab spans the distance between superstructure members and is generally seven inches to nine inches thick. On slab bridges, the slab spans the distance between piers or abutments, forming an integral deck and superstructure. Slab bridge elements are usually 12 inches to 24 inches thick.

Rectangular beams are used for both superstructure and substructure bridge elements. Concrete pier caps are commonly rectangular beams which support the superstructure.

Bridge use for tee beams is generally limited to superstructure elements. Distinguished by a "T" shape, tee beams combine the functions of a rectangular beam and slab to form an integral deck and superstructure.

Bridge use for channel beams is limited to superstructure elements. This particular shape is precast rather than cast-in-place. Channel beams are formed in the shape of a "C" and placed legs down when erected. They function as both superstructure and deck and are typically used for shorter span bridges. A wearing course is often added to provide the riding surface.

Prestressed Concrete Shapes

The most common shapes of prestressed concrete members are (see Figure 6-13):

- I-beams
- Bulb-tees
- Box beams
- Box girders
- Voided slabs

These shapes are used for superstructure members.

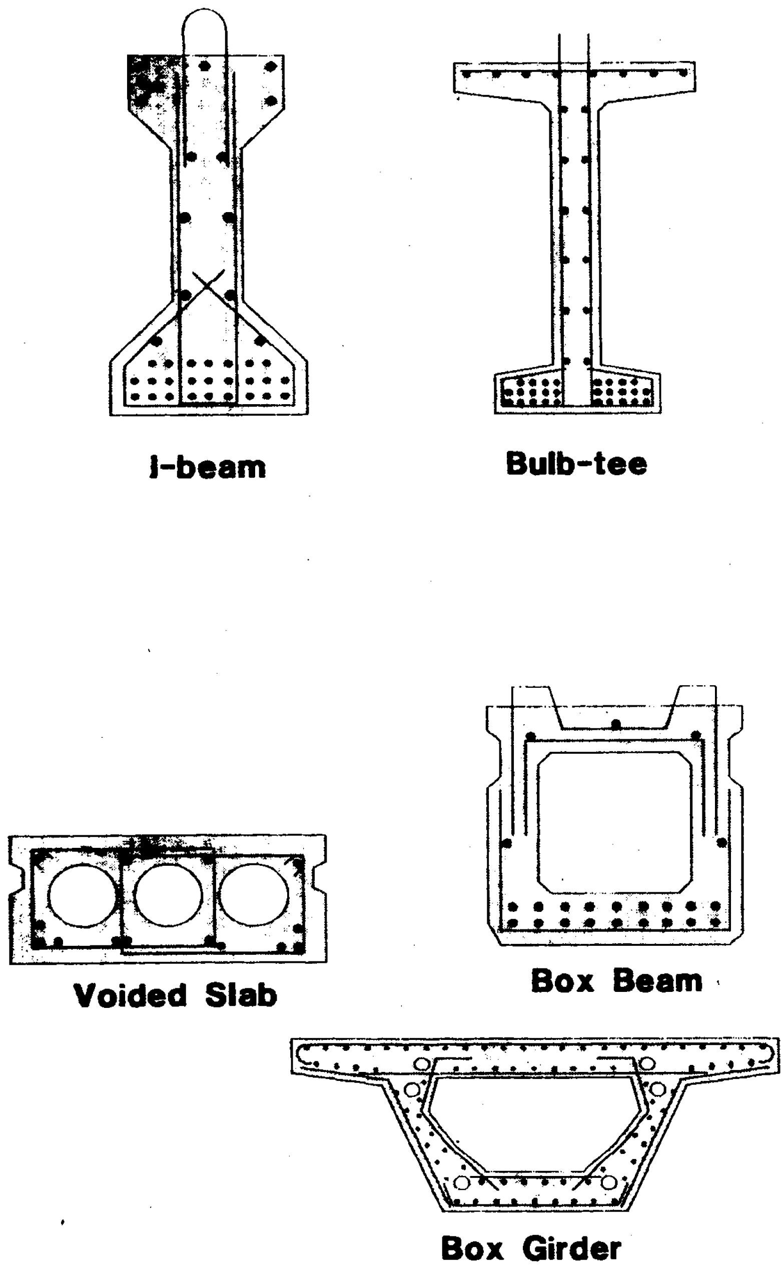


Figure 6-13 Prestressed Concrete Shapes

Prestressed concrete beams can be precast at a fabricator's plant using high strength concrete. Increased material strengths, more efficient shapes, and the prestress forces allow these members to carry greater loads. Therefore, they are capable of spanning greater distances and supporting heavier live loads. Bridges using members of this type and material have been widely used in the United States since World War II.

I-beams, distinguished by their "I" shape, function as superstructure members and support the deck. This type of beam can be used for spans as long as 150 feet.

Bulb-tee beams are distinguished by their "T" shapes, with a bulb-shaped section (similar to the bottom flange of an I-beam) at the bottom of the vertical leg of the tee. Bulb-tee beams combine the functions of an I-beam and a slab to form an integral deck and superstructure. This type of beam can be used for spans as long as 180 feet.

Box beams, distinguished by a square or rectangular shape, usually have a beam depth greater than 17 inches. Box beams can be adjacent or spread, and they are typically used for short and medium span bridges.

Box girders, distinguished by their trapezoidal box shapes, function as both deck and superstructure. Box girders are used for long span or curved bridges. They can be precast and erected in segments or cast in place.

Voided slabs, distinguished by their rectangular shape and their interior voids, are generally precast units placed parallel with the roadway alignment. The interior voids are used to reduce the dead load. Voided slabs can be used for spans of 30 to 80 feet.

Axially-Loaded Compression Members

Concrete axially-loaded compression members are used in bridges in the form of:

- Columns
- Arches
- Piles

Because these members also carry varying bending forces, they contain steel reinforcement.

Columns are straight members which can carry axial load, horizontal load, and bending and are used as substructure elements. Columns are commonly either square, rectangular, or round.

An arch can be thought of as a curved column and is commonly used as a superstructure element. Concrete superstructure arches are generally square or rectangular in cross section.

Piles are slender columns that support the substructure footing or partially form the substructure. Piles may be partially above ground but are usually completely buried (see Figure 6-14).

Figure 6-14 Concrete Pile Bent

6.3.3 Iron Shapes

Iron was used predominately as a bridge material between 1850 and 1900. Stronger and more fire resistant than wood, iron was widely used to carry the expanding railroad system during this period.

There are two types of iron members: cast iron and wrought iron. Cast iron is formed by casting, whereas wrought iron is formed by forging or rolling the iron into the desired form.

Cast Iron

Historically, cast iron preceded wrought iron as a bridge material. The method of casting molten iron to form a desired shape was more direct than that of wrought iron.

Casting allowed iron to be formed into almost any shape. However, because of cast iron's brittleness and low tensile strength, bridge members of cast iron were best used to carry axial compression loads. Therefore, cast iron members were usually cylindrical or box-shaped to efficiently resist axial loads.

Wrought Iron

In the late 1800's, wrought iron virtually replaced the use of cast iron. The two primary reasons for this were that wrought iron was better suited to carry tensile loads and advances in rolling technology made wrought iron shapes easier to obtain and more economical to use. Advances in technology made it possible to form a variety of shapes by rolling, including:

- Rods and wire
- Bars
- Plates
- Angles
- Channels
- Beams

6.3.4 Steel Shapes

Steel bridge members began to be used in the United States in the late 1800's and, by 1900, had virtually replaced iron as a bridge material. The replacement of iron by steel was the result of advances in steel making. These advances yielded a steel material which surpassed iron in both strength and elasticity. Steel could carry heavier loads and better withstand the shock and vibration of ever-increasing live loads. Since the early 1900's, the quality of steel has continued to improve. Early grades of steel, such as A7, have been replaced by stronger and more ductile A36, A572, and A588 steels.

Due to their strength, steel bridge members are used to carry axial forces as well as bending forces. Steel shapes are generally either rolled or built-up.

Rolled Shapes

Rolled steel shapes commonly used on bridges include (see Figure 6-15):

- Bars and plates
- Angles
- Channels
- Beams

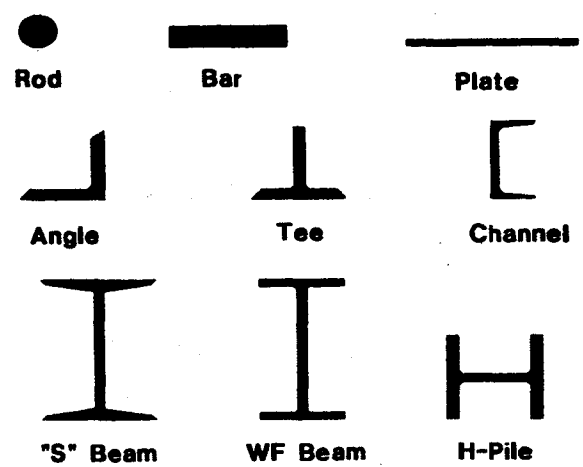


Figure 6-15 Common Rolled Steel Shapes

The standard weights and dimensions of these shapes can be found in the American Institute of Steel Construction (AISC) *Manual of Steel Construction.*

Bars and plates are formed into flat pieces of steel. Bars are normally considered to be up to 8 inches in width. Common examples of bars include lacing bars on a truss and steel eyebars. Plates are designated as flat plates if they are over 8 inches in width. A common example of a plate is the gusset plate on a truss. Bars and plates are dimensioned as follows: width (in inches) x thickness (in inches) x length (in feet and inches). Examples of bar and plate dimensions include:

- Lacing bar: 2"x3/8"x1'-3"
- Gusset plate: 21"x1/2"x4'-4"

Angles are "L"-shaped members, the sides of which are called "legs." Each angle has two legs, and the width of the legs can either be equal or unequal. When dimensioning angles, the two leg widths are given first, followed by the thickness and the length. Examples of angle dimensions include:

- L4"x4"x1/4"x3'-2"
- 2L's5"x3"x3/8"x1'-1"

Angles range in size from 1"x1"x1/4" to 8"x8"x1 1/8". Angles range in weight from less than 1 pound per foot to almost 60 pounds per foot.

Angles, bars, and plates are commonly connected to form bracing members (see Figure 6-16).

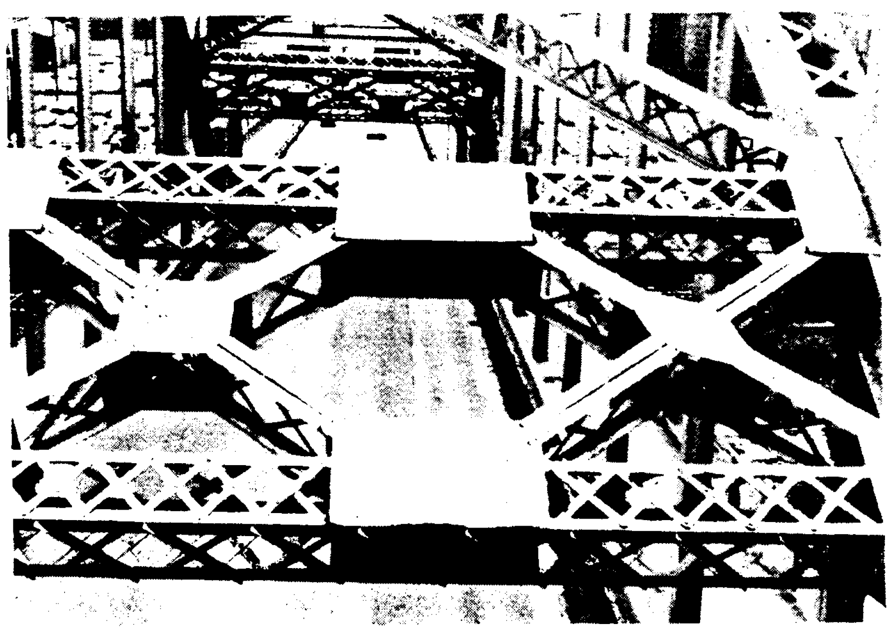


Figure 6-16 Bracing Members Made From Angles, Bars, and Plates

Channels are squared-off "C"-shaped members and are used as diaphragms, struts, or built-up members. The top and bottom parts of a channel are called the flanges. Channels are dimensioned by the depth (the distance between outside edges of the flanges) in inches, the weight in pounds per foot, and the length. Examples of channel dimensions include:

- C9x15x9'-6"
- C12x20.7x11'-2 1/2"

When measuring a channel, it is not possible for the inspector to know how much the channel section weighs. In order to determine the weight, the inspector must record the flange width and the web depth. From this information, the inspector can then determine the true channel designation through the use of reference books.

Standard channels range in depth from 3 inches to 15 inches, and weights range from less than 5 pounds per foot to 50 pounds per foot. Nonstandard sections (called miscellaneous channels or MC) are rolled to depths of up to 24 inches, weighing up to 60 pounds per foot.

Beams are "I"-shaped sections used as main load-carrying members. The load-carrying capacity generally increases as the member size increases. The early days of the iron and steel industry saw the various manufacturers rolling beams to their own standards. It was not until 1896 that beam weights and dimensions were standardized when the American Standard beam was adopted by the Association of American Steel Manufacturers. Because of this, I-beams are referred to by many designations, depending on their dimensions and the time period in which the particular shape was rolled. Today all I-beams are dimensioned according to their depth, weight, and length.

Examples of beam dimensions include:

- S15x50 - an American Standard (hence the "S") beam with a depth of 15 inches and a weight of 50 pounds per foot
- W18x76 - a wide (W) flange beam with a depth of 18 inches and a weight of 76 pounds per foot

Some of the more common designations for rolled I-beams are:

- S = American Standard beam
- W = Wide flange beam
- WF = Wide flange beam
- CB = Carnegie beam
- M = Miscellaneous beam
- HP = H-pile

When measuring an I-beam, the inspector needs to measure the depth, the flange width and thickness, and the web thickness (if possible). With this information, the inspector can then determine the beam designation from reference books.

These beams range in depth from 3 to 36 inches and range in weight from 6 to over 300 pounds per foot. Larger "jumbo" shapes are now rolled for use in building construction.

Built-Up Shapes

Built-up shapes offer a great deal of flexibility in designing member shapes. As such, they allow the bridge engineer to customize the members to their use. Built-up shapes are fabricated by either riveting or welding techniques.

The practice of riveting steel shapes began in the 1800's and continued through the 1950's. Typical riveted shapes include girders and boxes.

Riveted girders are large I-beam members fabricated from plates and angles. These girders were fabricated when the largest rolled beams were still not large enough (see Figure 6-17).

Riveted boxes are large rectangular shapes fabricated from plates, angles, or channels. These boxes are used for cross-girders, truss chord members, and substructure members (see Figure 6-18).

As technology improved, the need for riveting was replaced by high strength bolts and welding. Popular since the early 1960's, welded steel shapes also include girders and boxes.

Welded girders are large I-beam members fabricated from plates. They are referred to as welded plate girders and have replaced the riveted girder (see Figure 6-19).

Welded boxes are large, box-shaped members fabricated from plates. Welded boxes are commonly used for superstructure girders, truss members, and cross girders. Welded box shapes have replaced riveted box shapes (see Figure 6-20).

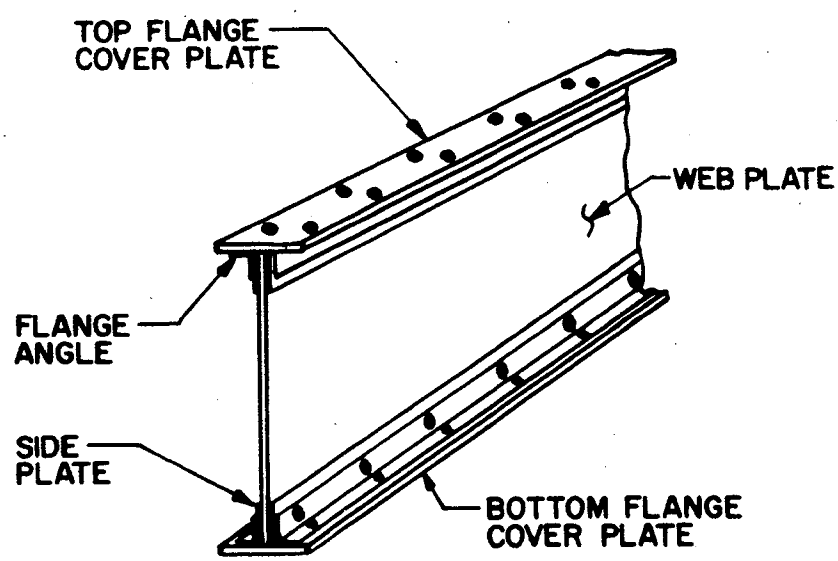


Figure 6-17 Riveted I-Beam

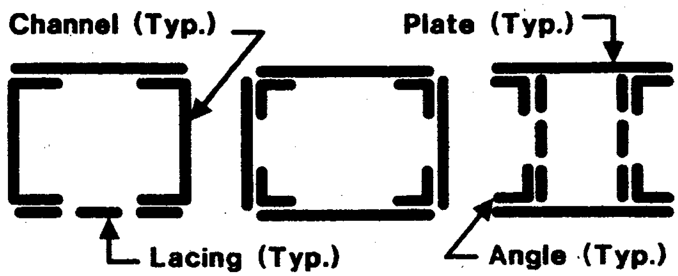


Figure 6-18 Riveted Box Shapes

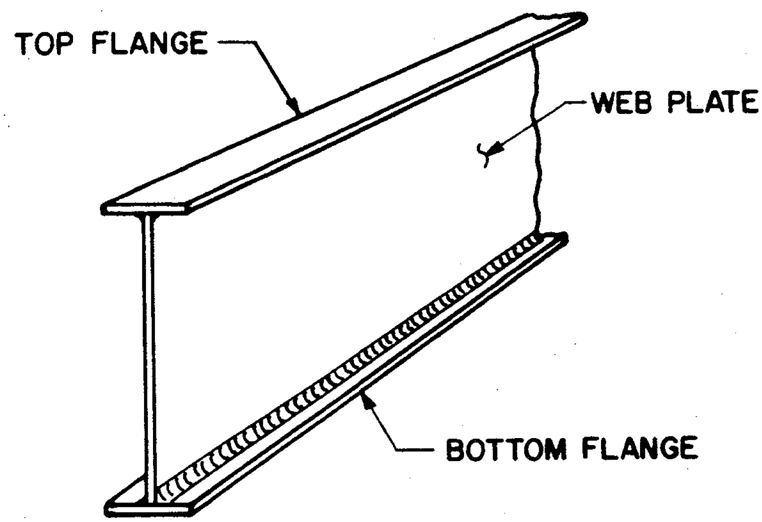


Figure 6-19 Welded I-Beam

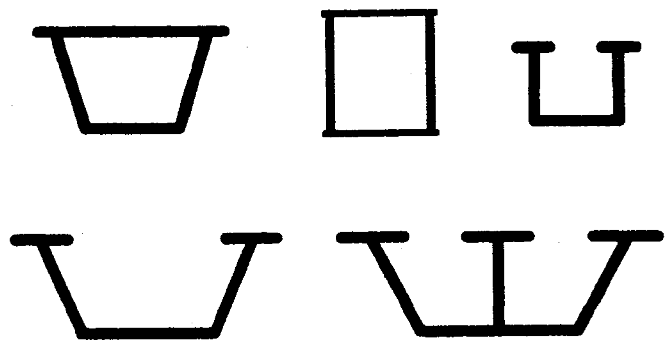


Figure 6-20 Welded Box Shapes

Cables

Steel cables are tension members and are used in suspension, tied-arch, and cable-stayed bridges. They are used as main cables and hangers of these bridge types (see Figure 6-21).

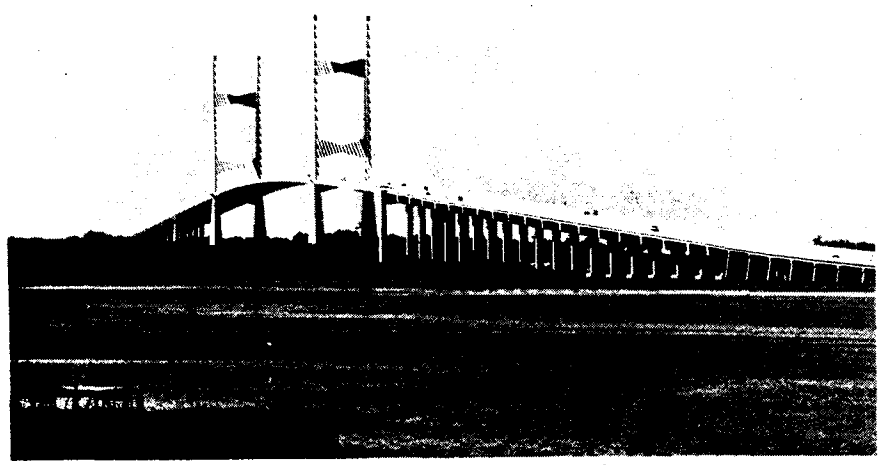


Figure 6-21 Cable-Supported Bridge

6.4 Connections

Rolled and built-up steel shapes are used to make stringers, floorbeams, girders, and truss members. These members require structural joints, or connections, to transfer loads between members. There are several different types of bridge member connections:

- Pin connections
- Riveted connections
- Bolted connections
- Welded connections
- Pin and hanger connections
- Splice connections

6.4.1 Pin Connections

Pins are cylindrical beams produced by either forging, casting, or cold-rolling. The pin sizes and configurations are as follows (see Figure 6-22):

- A small pin (1 1/4 to 4 inches in diameter) is usually made with a cotter pin hole at one or both ends
- A medium pin (up to 10 inches in diameter) usually has threaded end projections for recessed retainer nuts
- A large pin (over 10 inches in diameter) is held in place by a recessed cap at each end and is secured by a bolt passing completely through the caps and pin

Pins are often surrounded by a protective sleeve which may also act as a spacer to separate members. Pin connections are commonly used in eyebar trusses, hinged arches, and bearing supports (see Figure 6-23).

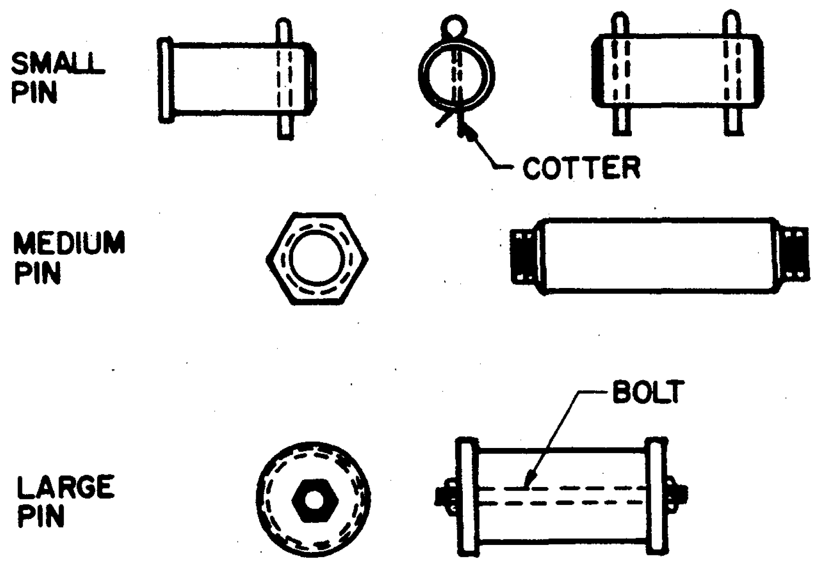


Figure 6-22 Sizes of Bridge Pins

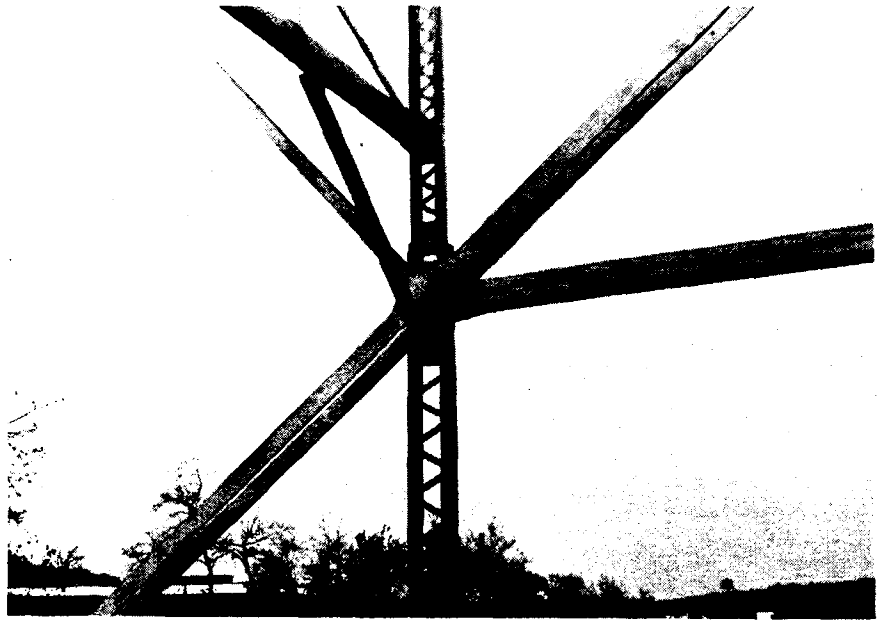


Figure 6-23 Pin-Connected Truss Members

The major advantages of using pin connection details are the design simplicity and the ability for free end rotation. The design simplicity afforded by pin connections reduces the amount and complexity of design calculations. By allowing for free end rotation, pin connections reduce the level of stress in the member.

The major disadvantages of pin connection details are the result of vibration, pin wear, unequal eyebar tension, unseen corrosion, and poor inspectability. Vibrations increase with pin connections because they allow more movement than more rigid types of connections. As a result of increased vibration, moving parts are subject to wear.

Pin connections are used both in trusses and at expansion joints. Both truss and girder suspended spans or cantilever joints that permit expansion are susceptible to freezing or fixity of the pinned joints. This results in changes in the structure and undesirable stresses when axially-loaded members become bending members.

Some pins connect multiple eyebars. Since the eyebars may have different lengths, they may experience different levels of tension. In addition, because parts of the pin surface are hidden from view by the eyebars, links, or connected parts, an alternate method of completely inspecting the pin must be used (e.g., ultrasonic or pin removal).

6.4.2 Riveted Connections

The rivet was the primary fastener used in the early days of iron and steel bridges. The use of high strength bolts replaced rivets by the early 1960's.

The standard head is called a high-button or acorn-head rivet. Flat-head and countersunk-head rivets were also used in areas of limited clearance, such as an eyebar pin connection (see Figure 6-24).

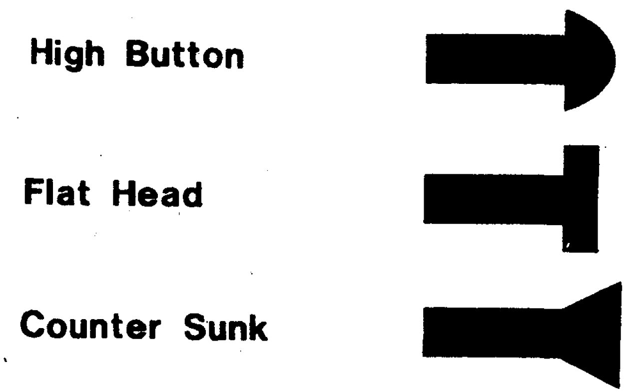


Figure 6-24 Types of Rivet Heads

There are two grades of rivets typically found on bridges:

- ASTM A502 Grade 1 (formerly ASTM A141) low carbon steel
- ASTM A502 Grade 2 (formerly ASTM A195) high strength steel

The rivet sizes most often used on bridges were 3/4, 7/8, or 1 inch shank diameters. Rivet holes were generally 1/16 inch larger than the rivet shank. While the hot rivet was being driven, the shank would increase slightly, filling the hole. As the rivet cooled, it would shrink in length, clamping together the connected element.

When the inspector can feel vibration on one head of the rivet while hitting the other head with a hammer, this generally indicates that the rivet is loose. This method may not work with sheared rivets clamped between several plates.

6.4.3 Bolted Connections

Research into the use of high strength bolts began in 1947. The first specifications for the use of bolts were subsequently published in 1951. The economic and structural advantages of bolts over rivets led to their rapid use by bridge engineers. Bridges constructed in the late 1950's may have a combination of riveted (shop) and bolted (field) connections (see Figure 6-25).

Structural bolts come in three basic types:

- ASTM A307 low carbon steel
- ASTM A325 high strength steel
- ASTM A490 high strength alloy steel

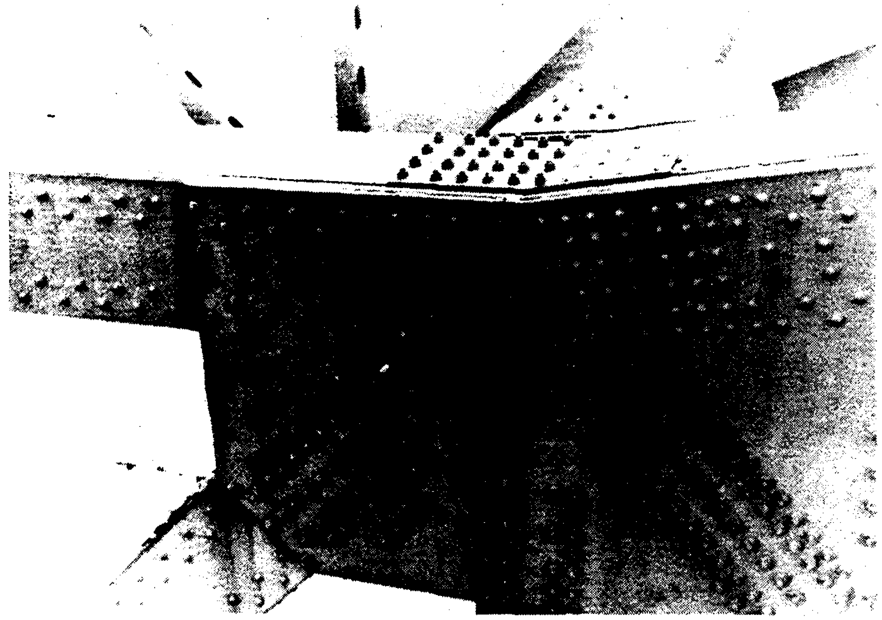


Figure 6-25 Shop Rivets and Field Bolts

The most commonly used bolts on bridges are 3/4, 7/8, and 1 inch in diameter. Larger bolts are often used to anchor the bearings. Bolt holes are typically 1/16 inch larger than the bolt. However, oversized and slotted holes are also permissible.

The strength of high strength bolts is measured in tension. However, the inspection of high strength bolts on bridges involves many variables. Although the installation inspection of new high strength bolts often requires the use of a torque wrench, this method does not have any merit when inspecting high strength bolts on in-service bridges. The torque is dependent on factors such as bolt diameter, bolt length, connection design (bearing or friction), use of washers, paint and coatings, parallelism of connected parts, dirt, rust, and corrosion.

The inspector must be cautioned that standard tables and formulas relating tension to torque are no longer considered valid.

Simple techniques, such as looking and feeling for loose bolts, are the most common methods used by inspectors when inspecting for loose bolts.

6.4.4 Welded Connections

Pins, rivets, and bolts are examples of mechanical fasteners forming non-rigid joints. A welded connection is not mechanical but rather is rigid one-piece construction. A properly welded joint, in which two pieces are fused together, is as strong as the joined materials.

Similar to mechanical fasteners, welds are used to make structural connections between members and also to connect elements of a built-up member. Welds have also been used in the fabrication and erection of bridges as a way to temporarily hold pieces together prior to field riveting, bolting, or welding. Small temporary erection welds, known as tack welds, can cause serious problems to certain bridge members (see Figure 6-26). Welding is also used as a means of sealing joints and seams from moisture.

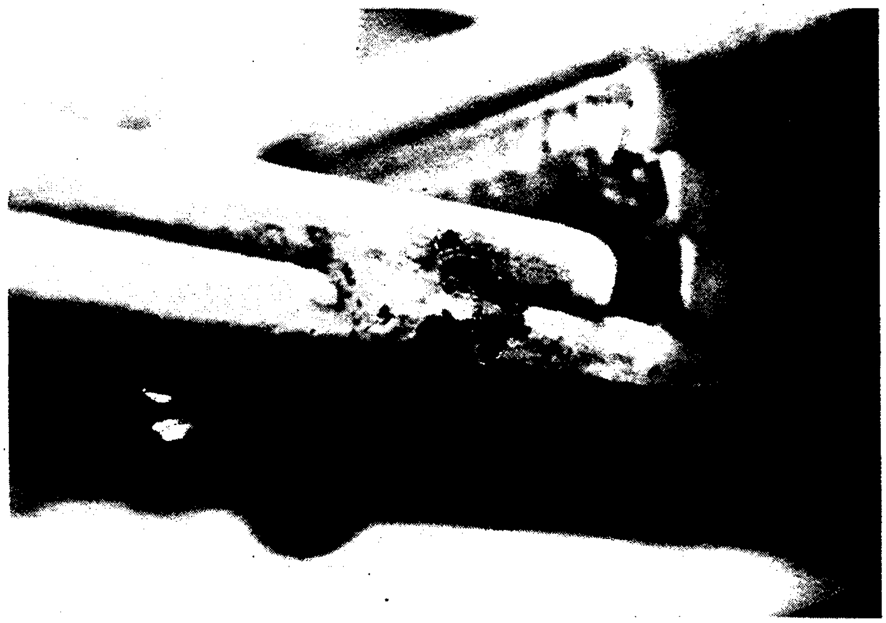


Figure 6-26 Close-Up of Tack Weld on a Riveted Built-Up Truss Member

The first specification for using welds on bridges appeared in 1936. Welding eventually replaced rivets for fabricating built-up members. Welded plate girders, hollow box-like truss members, and shear connectors for composite decks are just a few of the advances attributed to welding technology.

Welds need to be carefully inspected for cracks or signs of cracks (e.g., broken paint or rust stains) in both the welds and the adjoining base metal elements.

6.4.5 Pin and Hanger Connections

A pin and hanger connection is a type of hinge consisting of two pins and a hanger. Pin and hanger connections are used in an articulated (continuous bridge with hinges) or a suspended span configuration. The location of the connection varies depending on the type of bridge. In I-beam bridges, a hanger is located on either side of the webs (see Figure 6-27). In suspended span truss bridges, each connection has a hanger which is similar in shape to the other truss members (with the exception of the pinned ends).

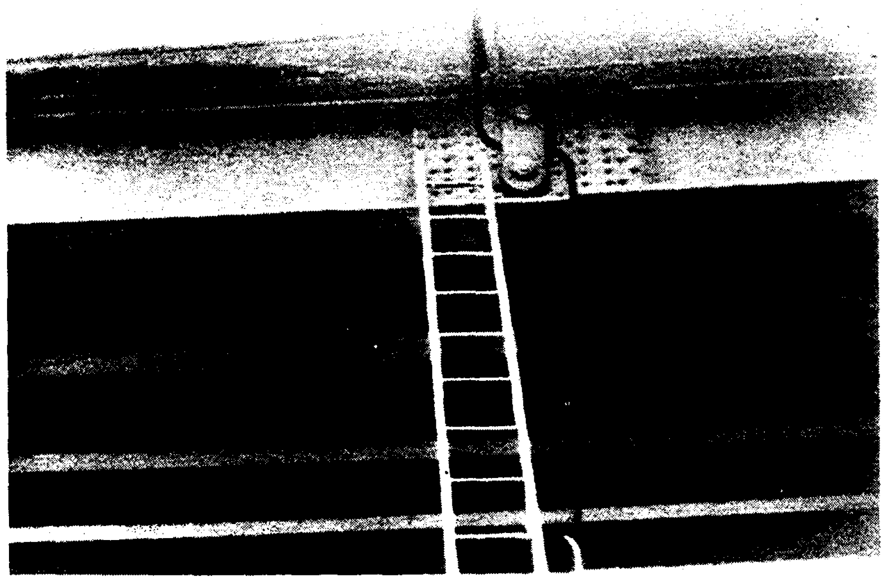


Figure 6-27 Pin and Hanger Connection

Pin and hanger connections must be carefully inspected for signs of wear and corrosion. A potential problem can occur if corrosion of the pin and hanger causes the connection to "freeze," inhibiting free rotation. This condition violates the design, resulting in additional stresses in the pin and hanger. The failure of a pin and hanger connection can cause a partial or complete failure of the bridge.

6.4.6 Splice Connections

A splice connection is the joining of two sections of the same member, either in the fabrication shop or in the field. This type of connection can be made using rivets, bolts, or welds. Bolted splices are common in multi-beam superstructures due to the limited allowable shipping lengths (see Figure 6-28). Welded flange splices are common in large welded plate girders as a means of fabricating the most economical section.

Figure 6-28 Bolted Field Splice

7

Inspection and Evaluation of Decks

7

Inspection and Evaluation of Decks

7.1 Introduction

The primary purpose of a bridge deck is to provide a roadway over which traffic can move and to distribute traffic and deck weight loads to the superstructure elements. The specific function of a deck is determined by whether the deck is composite or non-composite.

Composite Deck

A composite deck is designed to join together the deck and supporting members such that they structurally behave as one member. A composite deck spans between its supports but also functions to increase superstructure strength and allowable span length. Composite decks are often used in bridge design, and the most common application is the attachment of a concrete deck to steel beams or girders. For further details about composite action and shear connectors, refer to Section 3.5.5 and see Figure 3-17.

Non-Composite Deck

A non-composite deck does not contribute to the structural capacity of the main carrying members. A non-composite deck only functions to span between superstructure members and to provide a wearing surface for the traffic.

Deck Defects

Decks are subject to a variety of defects caused by many different factors. Since decks are exposed to traffic, they are subject to wear and abrasion, impact damage (e.g., snow plows), and overloads. Decks are also subject to damaging environmental exposure, such as seawater spray, freeze-thaw cycles, moisture from snow and rain, deicing chemicals, fungi, and parasites (see Figure 7-1). Ice melting agents and abrasive nonskid materials applied to decks include chlorides, sand mix, gravel, and cinders. Finally, design and construction deficiencies, such as improper design application, insufficient reinforcement bar cover, premature form removal, poor concrete mix, and improper vibration, can contribute to defects in a bridge deck.

Figure 7-1 Environmental Damage to a Bridge Deck

Constant exposure to the elements makes weathering a significant cause of deck deterioration. Vehicular traffic also produces damaging effects on the deck surface. For these reasons, a wearing surface is often applied to the surface of the deck. The wearing surface, also referred to as an overlay, is the topmost layer of material applied on the deck. This provides a smooth riding surface in addition to protecting the deck from the effects of weathering and traffic. Wearing surfaces differ depending on whether the deck is constructed of timber, concrete, or steel.

This chapter describes the design characteristics, the primary inspection locations, and the most common inspection procedures for bridge decks composed of timber, concrete, or steel. It also describes the inspection and evaluation of deck joints, drainage systems, safety features, signing and lighting, and approach roadways. Refer to Chapter 4 for a more detailed presentation of the most common defects found in timber, concrete, and steel, and their common causes.

7.2 Timber Decks

7.2.1 Design Characteristics

Timber decks are normally referred to as decking or timber flooring, and the term is generally limited to the roadway portion which receives vehicular loads. Timber decks are usually non-composite because of the inefficient shear transfer through the attachment devices. The four basic types of timber decks are:

- Plank decks
- Nailed laminated decks
- Glued laminated deck planks
- Prestressed laminated decks and stress timber decks

Plank Decks

Plank decks consist of timber planks laid transversely across the bridge (see Figure 7-2). The planks are individually attached to the bridge beams using spikes or bolt clamps, depending on the beam material. It is common for plank decks to have 2-inch by 2-inch strips nailed longitudinally on top of the planks to distribute load and retain the bituminous wearing surface.

Figure 7-2 Plank Deck

Nailed Laminated Decks

Nailed laminated decks consist of timber planks with the wide dimensions of the planks in the vertical position and laminated by through-nailing the adjacent planks (see Figure 7-3). On timber beams, each lamination is toenailed to the beam. On steel beams, clamp bolts are used as required. In either case, laminates are generally perpendicular to the roadway centerline.

Swelling and shrinking from wetting and drying cause a gradual loosening of the nails, displacing the laminations. This permits moisture to penetrate the deck and superstructure, eventually leading to decay and deterioration of the deck.

Glued Laminated Deck Planks

Glued laminated deck planks consist of timber planks glued together with a waterproof adhesive. Each plank is 3 to 4 feet wide. Before the planks are attached to the superstructure, they are usually clamped together with full-length, longitudinal tie rods. There are several techniques used to attach glued laminated decks to a floor system, including nailing, bolting, reverse bolting, clip angles and bolts, and nailers.

Nailing can be used to connect the glued laminated lumber to the stringers. This technique is generally not preferred due to the possibility of the nails being pried out of the deck by the vehicle traffic.

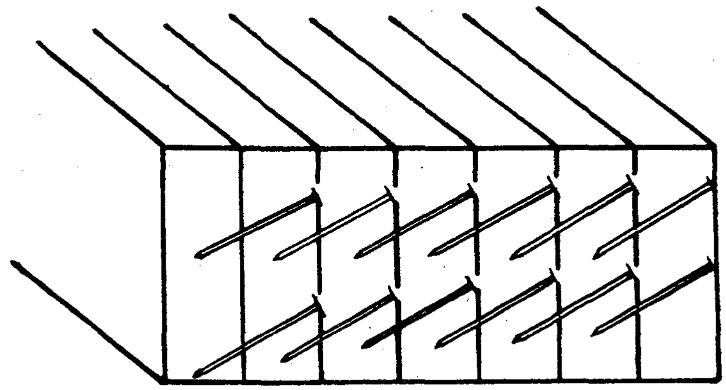


Figure 7-3 Section of a Nailed Laminated Deck

Bolting the deck to the floor system provides a greater resistance to uplift than nailing, but bolts may still be pried loose.

Reverse bolting involves fastening the bolts to the underside of the deck on either side of the stringers, thereby preventing the lateral movement of the deck. This is a rare type of connection.

Clip angles and bolts involve attaching clip angles to the stringers and then using bolts to attach the clip angles to the deck.

Nailers are planks that run along the top of steel stringers. This technique involves the bolting of the nailers to the stringers and nailing the timber planks to the nailers. This prevents the costly bolting of all planks to the steel stringers.

Prestressed Laminated Decks and Stressed Timber Decks

Prestressed laminated decks and stressed timber decks consist of thick, laminated timber planks which usually run longitudinally in the direction of the bridge span. The timber planks vary in length and size. The laminations are squeezed together by prestressing (posttensioning) high strength steel bars, spaced approximately 24 inches on center. With a hydraulic jacking system tensioning the bars, they are passed through predrilled holes in the laminations. Steel channel bulkheads and anchorage plates are then used to anchor the prestressing bars. This prestressing operation creates friction connections between the laminations, thereby enabling the laminated planks to span longer distances.

Prestressed laminated decks are used on a variety of bridge superstructures, such as trusses and multi-beam bridges, and they can be used as the superstructure itself for shorter span bridges.

7.2.2

Wearing Surfaces for Timber Decks

The wearing surface of a timber deck is constructed of either timber, bituminous materials, or concrete.

Timber

A timber wearing surface may consist of longitudinal timbers placed over the transverse decking. Runner planks or "running boards" are planks placed longitudinally only in the strips where the wheels of vehicles ride.

Bituminous

Bituminous generally consists of a coarse aggregate. The aggregate is mixed with a binder substance which binds the aggregate together and binds the surfacing to the deck. Asphalt is a popular bituminous wearing surface for timber decks. However, it is not commonly used on plank decks due to the fact that deflection of the planks will cause the asphalt to break apart.

Concrete

While concrete may be used as a wearing surface on timber decks, it is not frequently used for this purpose.

7.2.3

Inspection Locations and Procedures

The primary locations for timber deck inspection include:

- Areas exposed to traffic - examine for wear, weathering, and impact damage (see Figure 7-4)
- Bearing and shear areas where the timber deck contacts the supporting floor system - inspect for crushing, decay, and fastener deficiencies
- Tension areas between the support points - investigate for flexure damage, such as splitting, sagging, and cracks
- Deck surface - check for decay, particularly in areas exposed to drainage
- Outside edges of deck - inspect for decay

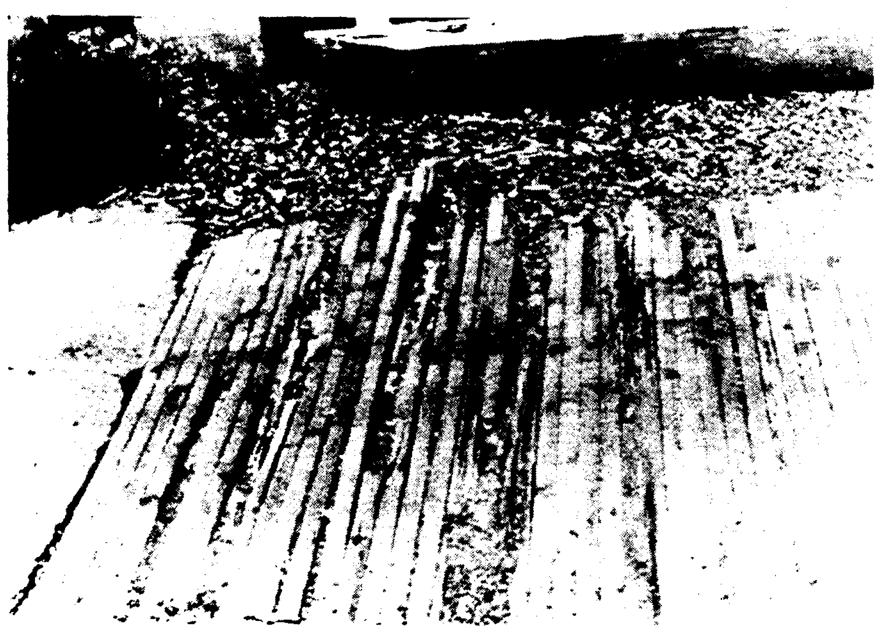


Figure 7-4 Wear and Weathering on a Timber Deck

The inspection of timber decks for deterioration and decay is primarily a visual activity. All surfaces of the deck planks should receive a close visual inspection.

However, physical examinations must also be used for suspect areas. The most common physical inspection techniques for timber include sounding and probing, drilling, core sampling, and electrical testing. An inspection hammer should be used initially to evaluate the subsurface condition of the planks and the tightness of the fasteners. In suspect areas, probing can be used to reveal decayed planks using a pick test or penetration test. If the deck planks are over 2 inches thick, suspect planks should be drilled to determine the extent of decay.

7.3 Concrete Decks

7.3.1 Design Characteristics

The most common bridge deck material is concrete. The physical properties of concrete permit casting in various shapes and sizes, providing the bridge designer and the bridge builder with a variety of construction methods.

Composite Action

A concrete deck is generally used when composite action is desired in the superstructure (refer to Sections 3.5.5 and 7.1 and see Figures 2-12 and 3-17). An example of composite action is a cast-in-place concrete deck joined to steel or prestressed concrete beams or a steel floor system using shear connectors. A precast deck can provide composite action through grout pockets which engage shear connectors.

In addition to distributing wheel loads, a composite concrete deck also contributes to the superstructure capacity. However, a non-composite deck is assumed not to contribute to the structural capacity of the superstructure.

Steel Reinforcement

Because concrete is weak in tension, it is used together with reinforcement to resist the tensile stresses. The most common reinforcement is steel reinforcing bars, commonly referred to as "rebars." These bars are basically round in cross section with lugs or deformations rolled into the surface to create a mechanical bond between the bars and the concrete. Because the corrosion of the reinforcing steel is the primary factor in deck deterioration, rebars have been commonly galvanized or coated with epoxy since about 1970.

The inspector must be able to identify the direction of the primary, or tension, steel reinforcement to properly evaluate any cracks in the deck. Primary reinforcement is placed perpendicular to the deck's support points. For example, the support points on a multi-beam bridge and on a floorbeam and stringer type floor system are parallel with the direction of traffic. Therefore, the primary deck reinforcement on these deck types is perpendicular to the direction of traffic (see Figure 7-5). The support points on a floorbeam only type floor system are perpendicular with the traffic flow, and the primary deck reinforcement is therefore parallel with the traffic flow.

Figure 7-5 Pothole Showing Primary Deck Reinforcing Steel Perpendicular to Traffic

Primary reinforcement is generally a larger bar size than the temperature and shrinkage steel. However, to improve design and construction efficiencies, concrete decks may be reinforced with the same size bar in both the top and bottom rebar mats. Reinforcement cover is generally 2 inches minimum for cast-in-place concrete decks and 1 inch minimum for precast decks.

The three basic types of concrete decks are:

- Reinforced cast-in-place (CIP)
- Precast
- Precast prestressed deck panels with cast-in-place (CIP) topping

Reinforced Cast-in-Place (CIP)

Concrete decks can be cast in place on the bridge. Forms are used to contain the concrete so that when the concrete is cured, it will be in the correct position and shape. There are two types of forms used when pouring concrete: removable and stay-in-place.

Removable forms are usually wood planking or plywood but can also be fiberglass reinforced plastic. These forms are removed from the deck after the concrete has cured.

Concrete decks which are cast in place are often supported from below by prefabricated stay-in-place (SIP) forms. These forms are corrugated metal sheets permanently installed above or within the floor system. After the concrete has cured, these forms, as the name indicates, remain in place as permanent nonworking members of the bridge.

Precast

Precast decks are reinforced concrete slabs that are poured and cured somewhere other than on the bridge. Precast decks can be either reinforced with conventional mild reinforcement or with prestressing strands. The slabs are then placed on the bridge and attached to the floor system.

Precast decks can be attached to the floor system by mechanical clips which bolt the deck panels to the stringers. An alternate method involves leaving block-out holes in the precast panels as an opening for shear connectors. The deck panels are positioned over the shear connectors and the block-out holes are then filled with concrete or grout.

Precast Prestressed Deck Panels With Cast-in-Place Topping

Partial depth precast prestressed deck panels can also be used as forms for a cast-in-place concrete overlay. The precast panels are placed across the stringers and act as forms. After the cast-in-place topping has cured, it will work compositely with the precast deck panels.

7.3.2 Wearing Surfaces for Concrete Decks

The wearing surface materials for concrete decks are generally either concrete or asphalt.

Concrete

There are two types of concrete wearing surfaces: integral and overlays. An integral concrete wearing surface is cast with the deck slab, typically adding an extra 1/2 inch of thickness to the slab. A concrete overlay wearing surface is cast separately over the previously cast deck slab. Some concrete wearing surfaces may have transverse grooves cut into them as a means of improving traction. The grooves can be tined while the concrete is still plastic or they can be diamond-sawed after the concrete has cured. There are three types of concrete overlays:

- Low slump dense concrete
- Polymer modified concrete
- Internally sealed concrete

Low slump dense concrete (LSDC) overlay was first used in the early 1960's for patches and overlays on bridges in Iowa and Kansas (hence the common term "Iowa Method"). The original overlays were 1 1/4 inches thick, but now a 2-inch minimum is specified. LSDC uses a dense concrete with a very low water-cement ratio.

Polymer modified concrete overlay involves the incorporation into the fresh concrete of polymer emulsions which have been polymerized prior to being added to the mixture. This is commonly known as latex-modified concrete (LMC). LMC is conventional Portland cement concrete with the addition of approximately 15 percent latex solids by weight of the cement.

The primary difference between the LSDC and the LMC overlays is that low slump concrete uses inexpensive materials but is difficult to place and requires special finishing equipment. Conversely, latex-modified concrete utilizes expensive materials but requires less manpower and is placed by conventional equipment. The performance of LMC has generally been satisfactory, although, in some cases, extensive map cracking and debonding have been reported. The causes for this are likely the improper application of the curing method, application under high temperature, or shrinkage due to high slump.

Internally sealed concrete overlays consist of the incorporation of fusible polymeric particles into a concrete mix. After the concrete has cured, the additive is then fused to it. This system, in effect, seals the concrete from moisture and chemicals.

Asphalt

Concrete decks may also have a layer of asphalt to act as the wearing surface. When asphalt is placed on concrete, a waterproof membrane may be placed on the concrete to protect the reinforced concrete from the adverse effects of water which passes through the permeable asphalt concrete layer. Not all attempts at providing a waterproof membrane are successful.

7.3.3 Inspection Locations and Procedures

Both the top and bottom surfaces of concrete decks should be inspected for cracking, scaling, spalling, corroding reinforcement, chloride contamination, delamination, and full or partial depth failures (refer to Section 4.3). The primary locations for concrete deck inspection include:

- Areas exposed to traffic - examine for wear, scaling, delamination, and spalls (see Figure 7-5)
- Areas exposed to drainage - investigate for general deterioration of the concrete
- Bearing and shear areas where the concrete deck is supported - check for spalls and crushing
- Shear key joints between precast deck panels - inspect for cracks and other signs of independent action
- Top of the slab over the supports - examine for flexure cracks
- Bottom of the slab between the supports - check for flexure cracks
- Top and bottom of the slab in negative moment regions of the superstructure - check for transverse flexure cracks
- Stay-in-place forms - investigate for deterioration and corrosion of the forms, often indicating contamination of the concrete deck; these forms can retain moisture and chlorides which penetrate full depth cracks in the deck
- Anchorage zones of precast slab tie rods - check for deteriorating grout pockets or loose lock-off devices; if a previous inspection report is available, this should be used by the inspector so that the progression of any deterioration can be noted

The inspection of concrete decks for cracks, spalls, and other defects is primarily a visual activity. However, hammers and chain drags can be used to detect areas of delamination. In addition, core samples can be taken from the deck and sent to a laboratory to determine the extent of any chloride contamination. Advanced equipment is also available for checking for delamination and rebar corrosion (refer to Section 15.3).

7.4 Steel Decks

7.4.1 Design Characteristics

The four basic types of steel decks are:

- Orthotropic decks
- Buckle plate decks
- Corrugated steel flooring
- Grid decks

Orthotropic Decks

An orthotropic deck consists of a flat, thin steel plate stiffened by a series of closely spaced longitudinal ribs at right angles to the floor beams. The deck acts integrally with the steel superstructure. An orthotropic deck becomes the top flange of the entire floor system. Orthotropic decks are occasionally used on large bridges.

Buckle Plate Decks

Buckle plate deck is found on older bridges. It consists of steel plates attached to the floor system which supports a layer of reinforced concrete. The plates are concave or "dished" with drain holes in the center. All four sides are typically riveted to the floor system. Buckle plate decks serve as part of the structural deck and as the deck form. They are obsolete, however, and are no longer used today.

Corrugated Steel Flooring

Corrugated steel flooring is popular because of its light weight and high strength. This deck consists of corrugated steel planks covered by a layer of asphalt. The planks are set upon the stringers so that the corrugations run perpendicular to the length of the bridge. The steel planks are welded in place to steel stringers. In the case of timber stringers, the planks are attached by lag bolts. The corrugations are filled with bituminous pavement, and then a wearing surface is applied. This deck is used primarily for the rehabilitation of small bridge decks.

Grid Decks

Grid decks are probably the most common type of steel deck because of their light weight and high strength. They are commonly welded units which may be open or filled with concrete.

Open decks are lighter than concrete-filled decks, but they are vulnerable to corrosion since they are continually exposed to weather, debris, and traffic. Another disadvantage of open decks is that they allow dirt and debris to fall onto the supporting members.

Fully-filled decks are grid decks which have been completely filled with concrete. These decks provide the maximum load carrying capacity. Form pans are welded within the grid to hold the concrete. Filled decks often contain rebars for extra strength.

Partially-filled decks are grid decks which have been partially filled with lightweight concrete. This provides the strength of a concrete deck with a reduction of the dead load and the protection of the floor system. Grid decks are often found on rehabilitated bridges. Their low weight reduces the dead load on a rehabilitated bridge, and their easy installation reduces the time that the bridge must be closed for repairs.

The three types of grid decks include:

- Welded grid decks
- Riveted grate decks
- Exodermic decks

Welded Grid Decks

Welded grid decks have their components welded together. These components consist of bearing bars, cross bars, and supplementary bars.

The bearing bars support the grating. Bearing bars are laid on top of the stringers perpendicularly and are then field-welded or bolted to the stringers. These bars are also referred to as the primary or main bars.

The cross bars are grating bars that are laid perpendicular on top of the bearing bars. They may be either shop- or field-welded to the grating system. Cross bars, also referred to as secondary bars or distribution bars, are generally serrated for improved traction.

The supplementary bars are grating bars that run parallel to the bearing bars. They are also shop- or field-welded to the grating system. Not all grating systems have supplementary bars. These bars are also referred to as tertiary bars.

Riveted Grate Decks

A riveted grate deck is made up of bearing bars, crimp bars, and intermediate bars and can either be fully or partially filled with concrete to improve the load carrying capacity of the deck.

Bearing bars run perpendicular to the stringers and are attached to the stringers by either welds or bolts. They are similar to the bearing bars in welded grates.

Crimp bars are riveted to the bearing bars to form the grating.

Intermediate bars run parallel to the bearing bars, but, in order to reduce the weight of the deck, are not as long. The crimp bars are riveted to intermediate bars and may not be present on all riveted grate decks.

Exodermic Decks

Exodermic decks are a newer type of bridge deck in which a reinforced concrete slab is placed on top of, and is made composite with, a steel grid.

7.4.2 Wearing Surfaces for Steel Decks

Wearing surfaces for steel decks can consist of:

- Serrated steel
- Concrete
- Asphalt

Studs can be welded to steel decks for skid resistance.

Serrated Steel

Open grid decks usually have serrated edges on the grating. Designed not to wear, these serrations make up the riding surface of an open grid deck.

Concrete

Acting as the wearing surface, fully and partially filled grid decks have a layer of concrete flush with the top of the grids. This concrete and the concrete used to fill the grids are generally poured at the same time.

Asphalt

Steel plate decks, such as orthotropic decks, typically have a layer of asphalt as the wearing surface. Corrugated steel plank decks also have asphalt wearing surfaces.

7.4.3 Inspection Locations and Procedures

Steel decks should be visually inspected for broken welds, failed fasteners, broken grids, and section loss (see Figure 7-6). The primary locations for steel deck inspection include:

- Bearing areas - check for cracked welds or broken fasteners which connect the steel deck to the supporting floor system
- Primary bearing bars - inspect for broken, cracked, or missing bars
- Areas where water can be trapped - investigate for corrosion
- Steel grid decks - check for slipperiness caused by excessive wear
- Connections - examine for broken connections and listen for rattles as traffic passes over the deck
- Filled grid decks - inspect for grid expansion at joints and bridge ends, often caused by corrosion

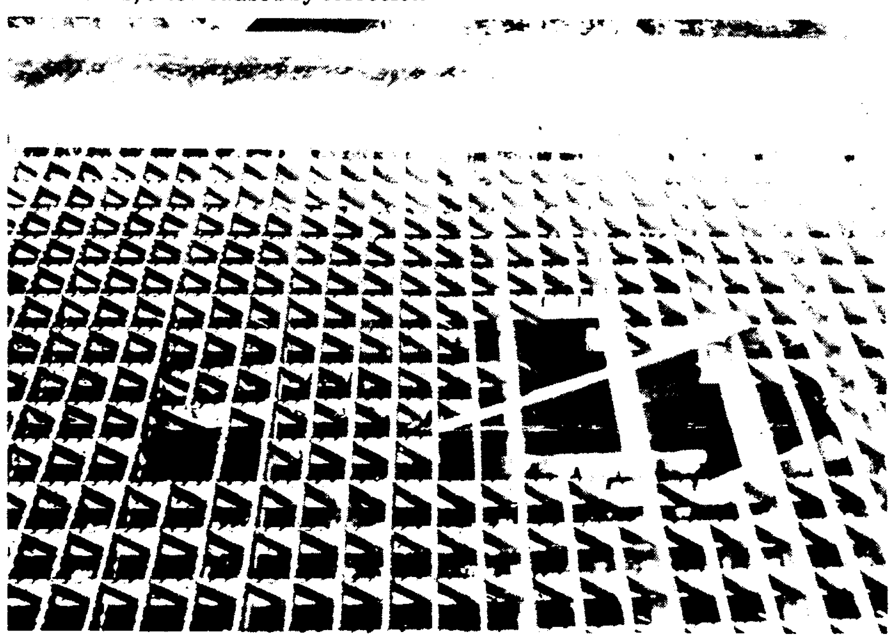


Figure 7-6 Broken Members on an Open Steel Grid Deck

On corrugated flooring, check between the support points for section loss due to corrosion. In areas where corrosion is evident, all scale should be removed with an inspection hammer in order to evaluate the amount of remaining material. Document the location and condition of any repair plates.

7.5 Deck Joints

The deck joint is a very important part of a bridge. Its primary function is to accommodate the expansion and contraction of the deck. It also fills the gap between the deck sections and the abutment backwall. In addition, the deck joint provides a smooth transition from the approach roadway to the bridge deck. The deck joint must be able to withstand all possible weather extremes in a given area. It must do all of this without compromising the ride quality of vehicles crossing the bridge. The inspector must be able to recognize deck joints that are not functioning properly.

Deck joints allow a bridge deck to be divided into sections. The joints are located at each abutment and, in the case of multiple span structures, can be located above piers or on a drop-in span. Deck joints should not be confused with construction joints. The construction joint marks the beginning or end of a concrete pour during the construction of the bridge deck. The two major categories of deck joints are open joints and closed joints.

7.5.1 Open Joints

Open joints allow water and debris to pass through the joints. The two types of open joints are as follows:

- Formed joints
- Finger plate joints

Formed Joints

Formed joints are little more than a gap between the bridge deck and the abutment backwall or, in the case of a multiple span structure, between adjacent deck sections. They are usually found on very short span bridges where expansion is minimal. The formed joint is usually unprotected, but the deck slab and backwall can be armored with steel angles. Formed joints are common on short span bridges with concrete decks (see Figure 7-7).

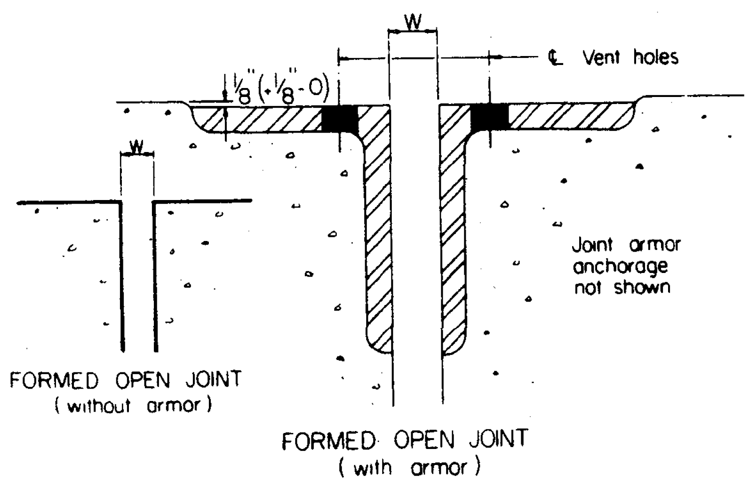


Figure 7-7 Formed Joint

Finger Plate Joints

A finger plate joint, also known as a tooth plate joint or a tooth dam, consists of two steel plates with interlocking fingers. These joints are usually found on longer span bridges where greater expansion is required. The two types of finger plate joints are cantilever finger plate joints and supported finger plate joints.

The cantilever finger plate joint is used when less expansion is required. The fingers on this joint cantilever out from the deck side plate and the abutment side plate (see Figure 7-8).

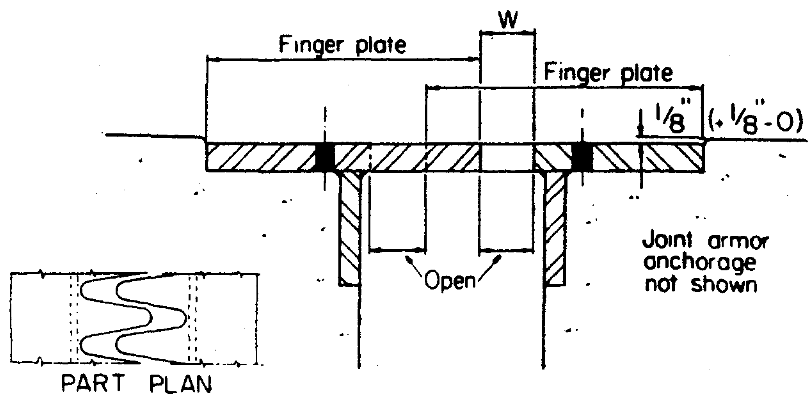


Figure 7-8 Cantilever Finger Plate Joint

The supported finger plate joint is used on longer spans. The fingers on this joint have their own support system in the form of transverse beams under the joint. Some types of finger plate joints are segmental allowing for maintenance and replacement if necessary.

7.5.2 Closed Joints

Closed joints are designed so that water and debris do not pass through them. There are six types of closed joints, including:

- Poured joint seal
- Compression seal
- Cellular seal
- Sliding plate joint
- Prefabricated elastomeric seal
- Modular elastomeric seal

Poured Joint Seal

A poured joint seal is made of two materials: a base and a poured sealant. The base consists of a preformed expansion joint filler. The top of this material is 1 to 2 inches from the top of the deck. The remaining joint space consists of the poured sealant which is separated from the base by a backer rod or a bond breaker. Since the poured joint seal can only accommodate a movement of about 1/4 inch, it is usually found on short span structures.

Compression Seal

A compression seal consists of a rectangle of neoprene with a honeycomb cross section (see Figure 7-9). The honeycomb design allows the compression seal to fully recover after being distorted during bridge expansion and contraction. It is called a compression seal because it functions in a partially compressed state at all times. Compression seals usually have steel angle armoring of the deck and backwall. In some cases, the deck joint is saw cut to accept the installation of the compression seal. In such cases, no armoring is provided. These seals come in a variety of sizes and are often classified by their maximum movement capacity. A large compression seal can accommodate a maximum movement of approximately 2 inches.

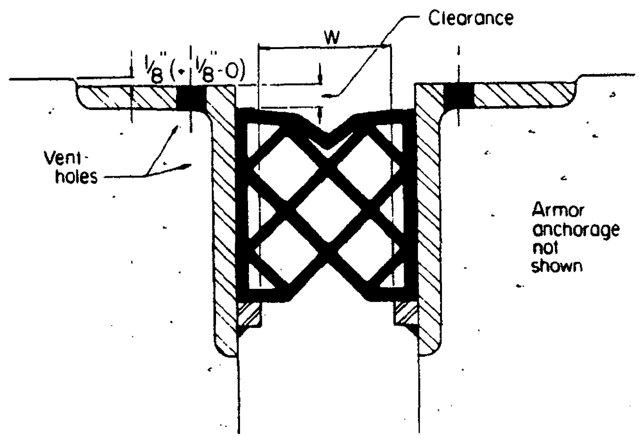


Figure 7-9 Compression Seal

Cellular Seal

The cellular seal is similar to the compression seal and its armoring is almost identical. They differ in the type of material used to seal the joint. Unlike the compression seal, the cellular seal is made of a closed-cell foam that allows the joint to move in different directions without losing the seal. This foam allows for expansion and contraction both parallel and perpendicular to the joint. The parallel movement is referred to as racking and occurs during normal expansion and contraction of a curved structure or a bridge on a skew.

Sliding Plate Joint

A sliding plate joint is composed of two plates sliding on top of each other. Although classified as a closed joint, the sliding plate joint is usually not watertight. In an attempt to seal the joint, an elastomeric sheet is sometimes used. This sheet is attached between the plates and the joint armoring. The resulting trough serves to carry water away to the sides of the deck (see Figure 7-10). The sliding plate joint can accommodate a maximum movement of approximately 4 inches.

Prefabricated Elastomeric Seal

Prefabricated elastomeric seals are frequently proprietary products and include three basic types:

- Plank seal
- Sheet seal
- Strip seal

A plank seal consists of steel reinforced neoprene that supports vehicular wheel loads over the joint. This type of seal is bolted to the deck and is capable of accommodating movement ranges from 2 to 13 inches.

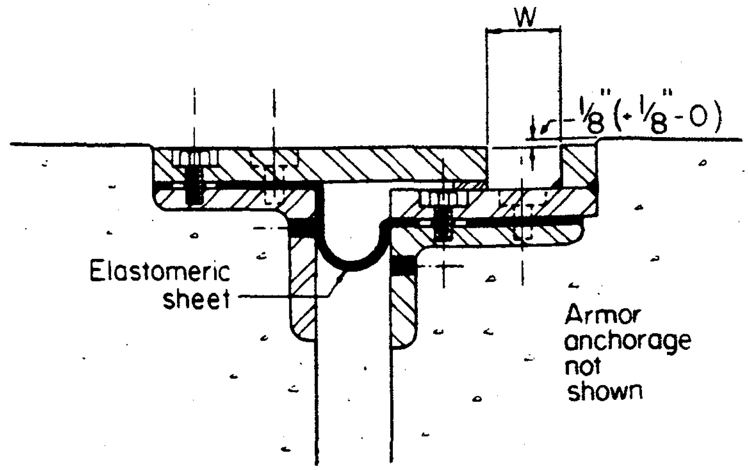


Figure 7-10 Sliding Plate Joint

A sheet seal consists of two blocks of steel reinforced neoprene. A thin sheet of neoprene spans the joint and connects the two blocks. This joint can accommodate a maximum movement of approximately 4 inches.

A strip seal consists of two slotted steel anchorages cast into the deck and backwall. A neoprene seal fits into the grooves to span the joint. This joint can accommodate a maximum movement of approximately 4 inches.

Modular Elastomeric Seal

The modular elastomeric seal is another neoprene type seal which can support vehicular wheel loads. It consists of hollow, rectangular neoprene block seals, interconnected with steel and supported by its own stringer system (see Figure 7-11). The normal range of operation for movement is between 4 and 24 inches. It can, however, be fabricated to accommodate movements up to 48 inches.

7.5.3 Inspection Locations and Procedures

There is not a separate item on the Structure Inventory and Appraisal (SI&A) Sheet to code the serviceability of deck joints, and deck joint conditions are not considered in the rating of the bridge. However, it is important for the inspector to note their condition since deck joint problems are often related to problems elsewhere on the bridge.

Deck joints should be inspected for:

- Dirt and debris accumulation
- Proper alignment
- Damage to seals
- Indiscriminate overlays
- Joint supports
- Joint anchorage devices

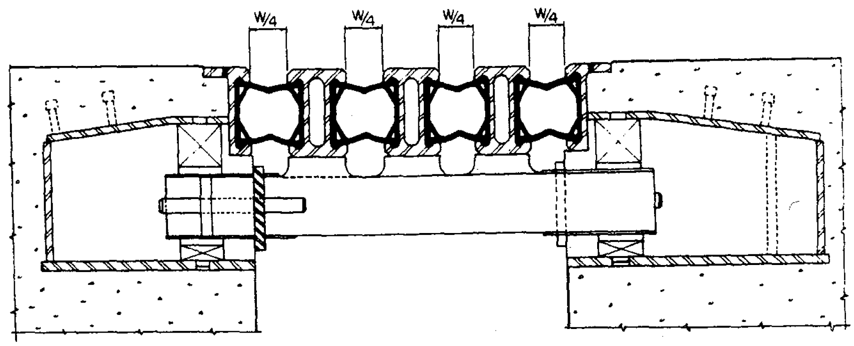


Figure 7-11 Modular Elastomeric Seal

Dirt and Debris Accumulation

Debris lodged in the joint may prevent normal expansion and contraction, causing cracking in the deck, the backwall, or both. In addition, as dirt and debris is continually driven into a joint, the joint material can eventually fail.

Proper Alignment

Both sides of the joint should be at the same level with no vertical displacement between the two. On straight bridges, the joint opening should be parallel across the deck.

In a finger plate joint, the individual fingers should mesh together properly, and they should be in the same plane as the deck surface.

It is important that the relative movements of the joint are consistent with the temperature. During the coldest and the warmest times of the day, the air temperature and the superstructure temperature should be recorded, and the deck opening should be measured. Since heat causes expansion, the joint opening should be smallest when the temperature is greatest. The superstructure temperature can be taken by placing a surface temperature thermometer or the bulb of a standard thermometer against the superstructure member itself. The superstructure temperature is generally about 3 to 5 °F lower than the air temperature.

Damage to Seals

Damage from snow plows, traffic, and debris can cause the joint seals to be torn, pulled out of the anchorage, or removed altogether (see Figure 7-12). Any of these conditions should be noted by the inspector. Also look for evidence of leakage through closed joints.

Figure 7-12 Failed Compression Seal

Indiscriminate Overlays When new pavement is applied to a bridge, it is frequently placed over the deck joints with little or no regard for their ability to function properly. This occurs most frequently on small, local bridges. Transverse cracks in the pavement may be evidence that a joint has been covered by the indiscriminate application of new overlay, and the joint function may be severely impaired (see Figure 7-13).

Figure 7-13 Asphalt Wearing Surface Over an Expansion Joint

Joint Supports

Where larger expansions and contractions must be accommodated, the joint may be fully or partially supported from beneath by transverse beams. These joint supports should be carefully inspected for proper function and for corrosion.

Joint Anchorage Devices

Deficiencies in joint anchorage devices are a common source of deck joint problems. Therefore, joint anchorage devices should be carefully inspected for proper function and for corrosion.

7.6 Drainage Systems

The purpose of a drainage system is to remove water and all hazards associated with it from the structure. There is not a separate item on the SI&A Sheet to code the serviceability of drainage systems, and drainage system conditions are not considered in the rating of the bridge. However, it is important for the inspector to note their condition, since drainage system problems can eventually lead to structural problems.

7.6.1 Deck Drainage Elements

Before it is possible to perform an inspection of a deck drainage system, it is necessary to become familiar with its various elements:

- Runoff
- Deck drains
- Outlet pipes
- Downspout pipes
- Cleanout plugs

Runoff

Runoff is the water and any contents that may run off the surface of the bridge deck.

Deck Drains

The deck drain is the first component of the drainage system that runoff encounters. A deck drain is a receptacle to receive water. Deck drains may be nothing more than openings in a filled grid deck, holes in a concrete deck, or slots in the base of a parapet. Inlet boxes and scuppers are also examples of deck drains.

Inlet boxes have a grate, which is a ribbed or perforated cover. Grates are fabricated from steel bars that are oriented with the longitudinal direction of the bridge and spaced at approximately 2 inches on center. A bicycle safety grate has steel rods placed perpendicular to the grating bars, spaced approximately 4 inches on center.

Grates keep larger debris from entering the drainage system while allowing water to pass through. They also serve to support traffic and other live loads. The drainage system may end with the deck drain.

Outlet Pipes

The outlet pipe leads water away from the drain. For bridges over roadways, the outlet pipe connects to other pipes. When the bridge is not over a roadway, the outlet pipe may simply extend a few feet down from the deck so that drainage water is not windblown onto the superstructure.

Downspout Pipes

When a bridge is located over a roadway, the deck drainage must be directed from the outlet pipe to a nearby storm sewer system or another appropriate release point. This is done with a downspout pipe network.

Cleanout Plugs

The cleanout plug is a removable plug in the piping system that allows access for cleaning.

7.6.2 Inspection Locations and Procedures

The following drainage system elements should be inspected:

- Grates
- Deck drains and inlets
- Drainage troughs
- Outlet pipes

Grates

Grates should be clear of debris (e.g., plants and grass) and free to allow deck runoff to enter. Grates that are deteriorated, broken, or missing should be reported.

Deck Drains and Inlets

Deck drains and inlets must be of sufficient size and spacing to carry the runoff away from the structure effectively. Since runoff conditions can change due to development, these drainage elements should be carefully examined with each bridge inspection. Clogged deck drains lead to accelerated deck deterioration and the undesirable condition of standing water in the traffic lanes (see Figure 7-14).

Drainage Troughs

Drainage troughs located under the joint should be carefully examined. A buildup of debris can accelerate the deterioration of the trough and allow water to drain onto structural members. If possible, use a shovel to clean as much debris as practical; report the remaining condition for appropriate maintenance work.

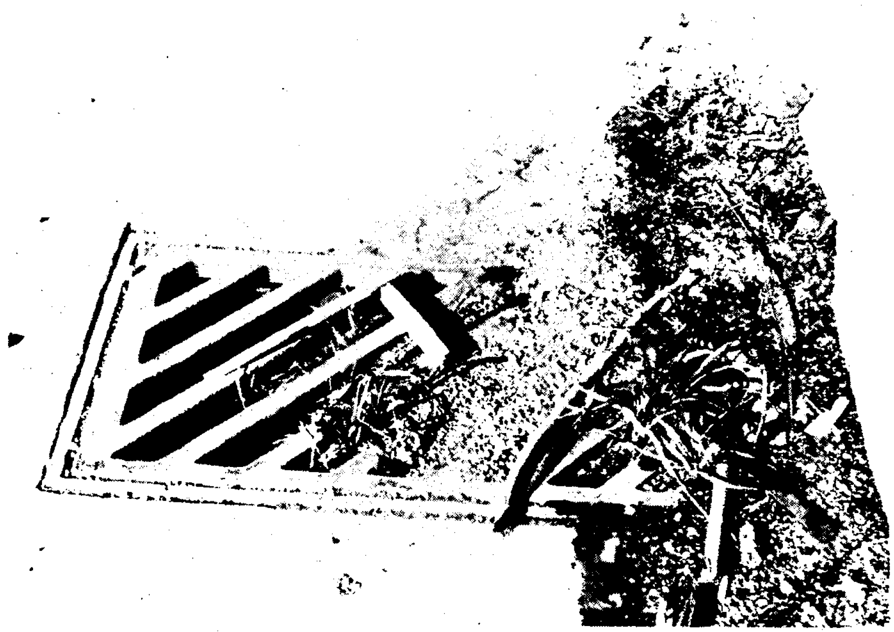


Figure 7-14 Partially Clogged Drainage Inlet

Outlet Pipes

Outlet pipes carry runoff away from the structure. The outlet pipe may be a straight extension of the deck drain, in which case it should be long enough so that runoff is not discharged onto the structure. The outlet pipe may also be a series of pipes, called downspouting. This type of outlet pipe should be examined for split or disconnected pipes that may allow runoff to accelerate deterioration of the structure.

7.7 Safety Features

As a vehicle travels on a highway, there are safety features, such as guardrails, to protect it in case it should divert from the normal travel lanes. Similarly, as the vehicle travels over a bridge, additional safety features, such as bridge railing and barriers, are present to prevent it from driving off of the bridge. A transition between the highway and the bridge should be provided so that the safety features can function as a continuous unit. Therefore, a thorough inspection of bridge safety features should include:

- Bridge barriers
- Approach guardrail
- Transitions
- End treatments
- Median barriers

7.7.1 Bridge Barriers

Bridge barriers can be broken down into two categories:

- Bridge railing
- Pedestrian railing

Bridge Railing

The primary function of the bridge railing is to keep errant vehicles from driving off the edge of the bridge. Bridge railings must also smoothly redirect the vehicle in such a manner that the vehicle does not overturn and the railing does not fail.

Examples of Bridge Railing

Bridge railings have changed substantially since they were first used on bridges. The evolution of bridge railing can be seen by examining older structures:

- The earliest existing stone bridges had bridge rail constructed of cut stone with mortared joints.

- The earliest existing steel and timber bridges had bridge rail consisting of timber planks nailed together in a picket fence-like arrangement.

- Railing made of steel angles and bars were popular on many turn-of-the-century structures.

- Solid concrete parapets were used on concrete slabs and encased I-beam bridges. Although they appeared to be strong, vertical reinforcement of 1/2 inch diameter bars at 18 inch spacing suggests otherwise. In some cases, the parapet was actually the top portion of a reinforced concrete girder.

- Reinforced concrete tee beam bridges of the 1930's introduced the pigeonhole or doghouse parapet (see Figure 7-15). Bars 1/2 inch in diameter at 1-foot spacing were the only vertical reinforcement.

- Bridge rail consisting of welded steel tubing was often used on smaller, locally owned structures.

- Today, galvanized W-shaped rail supported by wide flange posts is frequently used to replace damaged rail on older timber and concrete decks.

- Steel and aluminum railings using multiple pipes were usually used only if the bridge had a sidewalk and curb.

- Concrete parapets with steel or aluminum railing attached to the top are commonly used today.

- If a bridge passed over another roadway, a parapet with fencing attached to the top was often used. Sometimes the fencing was curved near the top to make it more difficult for objects to be thrown onto traffic below.

Figure 7-15 Pigeonhole Parapet

While all of these bridge railings were popular in their day, most have one thing in common: they do not conform to the current minimum criteria set by the American Association of State Highway and Transportation Officials (AASHTO) and the Federal Highway Administration (FHWA) for crashworthiness of bridge railing.

AASHTO Requirements for Bridge Railing

AASHTO sets minimum criteria for acceptable railing. These criteria include the height, material, strength, and geometric features of the railing. In addition, many state agencies have developed guidelines for bridge railings in their state. The inspector should be familiar with these criteria and guidelines and should verify that the bridge railing is acceptable.

To meet the minimum criteria, a barrier must pass the following tests:

- It must withstand two vehicular hits at 60 mph: one from a 4,500 pound vehicle hitting the barrier at a 25 degree angle, and the other from a 2,250 pound vehicle at a 15 degree angle.
- It must redirect the vehicle away from the barrier.
- It must not cause the vehicle to abruptly decelerate.
- It must not cause the vehicle to roll over.
- It must be designed such that the vehicle shall remain upright during and after impact.

The most common barrier to pass all of these tests is the New Jersey type barrier (see Figure 7-16).

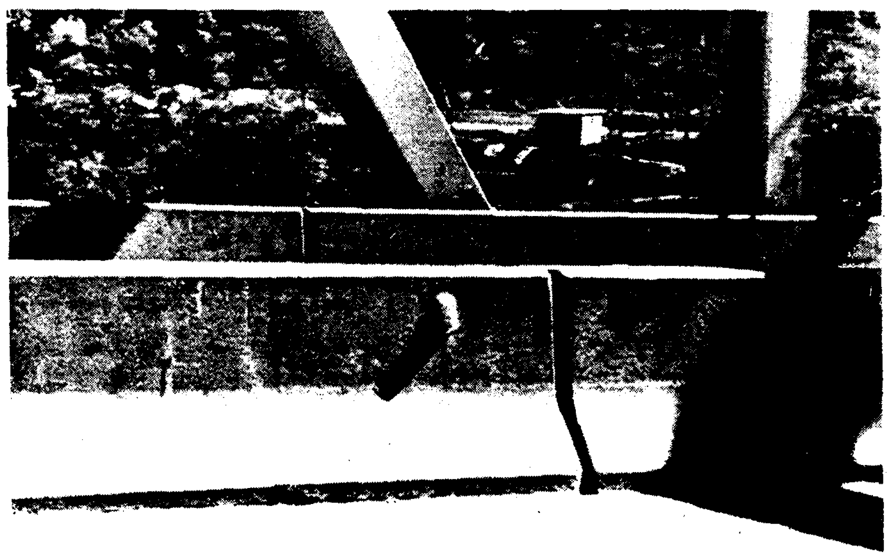


Figure 7-16 New Jersey Type Barrier

Pedestrian Railing

Pedestrian railing is a fence-like barrier constructed of wood, brick, stone, metal, or concrete. It is built on structures at the outermost edge of sidewalks and is used to guard or guide the movement of pedestrian traffic.

Inspection of Bridge Barriers

Steel bridge barriers should be firmly attached to the deck, and they should be functional. Investigate for corrosion and collision damage (see Figure 7-17).

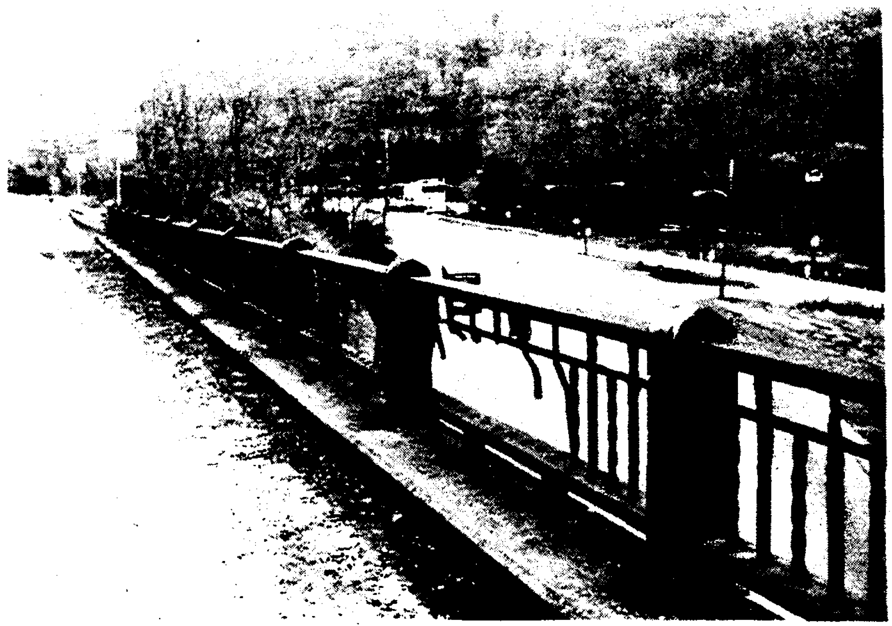


Figure 7-17 Damaged Steel Post Bridge Railing

Concrete bridge railing is generally cast-in-place and engages reinforcing bars to develop anchorage. Inspect for deterioration and spalling, and check the attachment of any additional railing.

7.7.2 Approach Guardrail

The approach guardrail is the first rail that a motorist encounters near a bridge. Its purpose is to protect the motorist from the hazards of the bridge site. It must be of adequate length and strength to safely redirect an impacting vehicle with a minimum of damage to the vehicle. Similar to bridge railing, agency standards are available for approach guardrail, specifying acceptable heights, materials, strengths, and geometric features.

Inspection of Approach Guardrail

The inspector should verify that agency standards are met. Note the dimensions of the rail and the post spacing, if applicable. Document any collision damage and any deterioration of the guardrail which could weaken the system (see Figure 7-18). Note any areas where the railing may "pocket" during impact, snagging the vehicle and causing an abrupt deceleration or erratic rebound. Loose or missing bolts should also be noted. Unless specifically designed for impact, timber approach guardrail does not meet minimum criteria for strength.

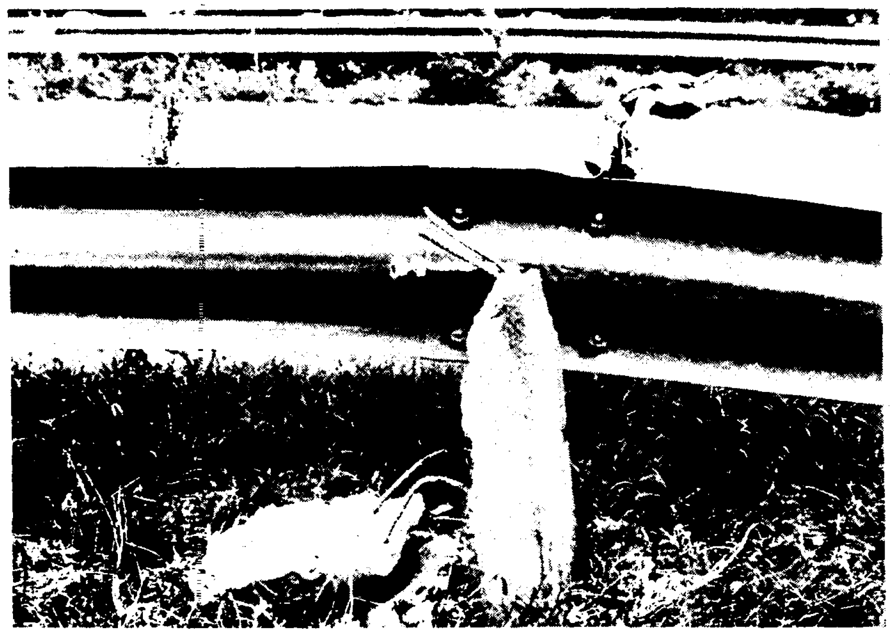


Figure 7-18 Approach Guardrail Collision Damage

7.7.3 Transitions

The transition is the portion of the approach guardrail that is connected to the bridge railing. A proper transition is characterized by a stiffening of the approach guardrail, which is usually accomplished by a narrow post spacing near the bridge. This stiffening allows impacting vehicles to be deflected away from the rail instead of possibly being snagged or hitting the end of the bridge railing. The transition design should be geometrically compatible with the bridge railing to provide a smooth transition.

Inspection of Transitions

Check the approach guardrail transition to the bridge railing for a smooth transition, rigid attachment, and reduced post spacing. Timber should not be used for the rails in transitions.

7.7.4 End Treatments

The ends of approach rails are modified to prevent a vehicle from becoming impaled on them. Four basic types of approved treatment are:

- Flaring
- Burying
- Breakaway ends
- Shielding

Flaring

Flaring of an approach guardrail turns the ends of the rail slightly away from the approaching traffic. Many end treatments exist with insufficient flaring. The ends should be flared enough to keep an impacting vehicle from becoming impaled on the rail.

Burying

Burying of an approach guardrail consists of gradually sloping the ends of the rail and twisting them 90 degrees. The end is either attached to or buried in the ground.

While the possibility of vehicle impalement is virtually eliminated with burying, there are other problems that are introduced. A vehicle can be flipped over into the traffic lanes or into an obstacle behind the rail. The likelihood of this occurring can be reduced by providing an end treatment that combines the features of flaring and burying.

Breakaway Ends

Breakaway ends are designed to fail at impact. A typical arrangement consists of two end posts attached to concrete footings in such a manner that they are allowed to shear off when hit by a vehicle. A cable attached to the rail and footing slows the vehicle.

Shielding

Shielding involves the addition of an impact attenuator to the end of the approach rail. The attenuator is a multicelled absorption system that can be filled with water, foam, or sand. The crushing of the attenuator slows the vehicle to a stop with little damage.

The water-filled system features plastic tubes filled with water to absorb impact. At impact, the plastic tubes collapse and the water is forced out. This slows the vehicle to a stop.

The foam-filled system features foam cartridges as a means to absorb impact. The foam-filled cartridges act similarly to the water-filled tubes.

The sand-filled system features free-standing barrels filled with sand to absorb impact.

The momentum transfer system dissipates impact energy through the crush of lightweight concrete components and through the transfer of momentum associated with the movement of the cushion mass.

Inspection of End Treatments

Note the type of end treatment used, as well as the condition of the end treatment. End treatments may not be required on the trailing end of a one-way bridge.

7.7.5 Median Barriers

Median barriers are used to separate opposing traffic lanes when the average daily traffic (ADT) on the road exceeds a specified amount. They are usually found on high speed, limited access highways.

The most commonly used median barrier on bridges is the concrete median barrier. This is a double sided parapet, and it should meet the current criteria for the crash testing of bridge railing. The only acceptable end treatment for a concrete median barrier is an impact attenuator.

Another common median barrier is a steel railing on steel posts. Median barriers can be mountable, and these are generally found on multilane bridges with low speed limits.

Inspection of Median Barriers

Median barriers should be firmly attached to the deck, and they should be functional. Inspect for collision damage and attachment to any additional safety features. Check for deterioration and spalling on concrete median barriers, and examine for corrosion on steel railings and posts.

7.7.6 Appraisal Rating

Although the condition of the safety features is not considered in the appraisal, it should be well documented in the inspection report. After determining whether the safety features at the site are acceptable, the inspector should assign an appraisal code. The FHWA *Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges* (*Coding Guide*) contains four entries for safety features: one each for the bridge railing, approach guardrail, transition, and end treatment.

While there is only one safety features coding for each element, there are at least two bridge railings and four approach guardrail treatments. Therefore, the bridge inspector should code the worst condition for each element even though they may occur at different locations on the bridge.

7.8 Signing and Lighting

7.8.1 Signing

Signing serves to inform the motorist about bridge or roadway conditions that may be hazardous. Signs should be located sufficiently in advance of the structure to permit the driver adequate time to react. Among the various types of signs to be encountered are signs indicating:

- Weight limit
- Vertical clearance
- Lateral clearance
- Narrow underpass
- Speed traffic marker

Weight Limit

Weight limit signs are very important since they indicate the maximum vehicle load that can safely use the bridge.

Vertical Clearance

Vertical clearance signs indicate the minimum vertical clearance for the structure. This clearance is measured at the most restrictive location within the traveling lanes.

Lateral Clearance

Lateral clearance signs indicate that the bridge width is less than the approach roadway width. Lateral clearance restrictions may be called out with a "Narrow Bridge" sign or with reflective stripe boards at the bridge.

Narrow Underpass

Narrow underpass signs indicate where the roadway narrows at an underpass or where there is a pier in the middle of the roadway. Striped hazard markings and reflective hazard markers should be placed on these abutment walls and pier edges. The approaching pavement should be appropriately marked to warn motorists of the hazard.

Speed Traffic Marker

Speed traffic marker signs indicate speed restrictions which are consistent with the bridge and roadway design. Additional traffic markers may be present to facilitate the safe and continuous flow of traffic.

Inspection of Signing

All signs should be clearly legible. Verify that signs have not been defaced and are not obstructed from view. Inspect for corrosion and collision damage to sign supports. Verify that appropriate signing is provided.

7.8.2 Lighting

The five types of lighting which may be encountered on a bridge are as follows:

- Highway lighting
- Traffic control lighting
- Aerial obstruction lighting
- Navigation lighting
- Sign lighting

Highway Lighting

The typical highway lighting standard consists of a lamp or luminaire attached to a bracket arm. Both the luminaire and bracket arm are usually made of aluminum. The bracket arm is attached to a shaft or pole made of concrete, steel, cast iron, aluminum, or, in some cases, timber. It is generally tapered toward the top of the pole.

The shaft is attached at the bottom to an anchor base. Steel and aluminum shafts are fitted inside and welded to the base. In the case of concrete, the shaft is normally cast as an integral part of the base. Where the standard is exposed to vehicular traffic, a breakaway type base or guardrail may be used. Anchor bolts hold the light standard in place. These L-shaped or U-shaped bolts are normally embedded in a concrete foundation.

Traffic Control Lighting

Traffic control lights are used to control traffic flow on a structure. Lights can serve a similar purpose to those found at intersections, but they can also indicate which lanes vehicular traffic is to use. These are referred to as lane control signals. Red and green overhead lights indicate the appropriate travel lanes.

Aerial Obstruction Lighting

Aerial obstruction lights are used to alert aircraft pilots that a hazard exists below and around the lights. They are red and should be visible all around and above the structure. Aerial obstruction lights are located on the topmost portion of any bridge considered by the Federal Aviation Administration (FAA) to present a hazard to aircraft. Depending on the bridge size, more than one light may be required.

Navigation Lighting

Navigation lights are used for the safe control of waterway traffic. The United States Coast Guard determines the requirements for the type, number, and placement of navigation lights on bridges. The lights are either green, red, or white.

Green lights indicate the center of a channel. These lights are placed at the bottom mid-span of the superstructure.

Red lights indicate the existence of an obstacle. When placed on the bottom of the superstructure, a red light indicates the limit of the channel. Lights placed to indicate a pier are placed on the pier near the waterline.

Three white lights in a vertical fashion placed on the superstructure indicate the main channel.

Sign Lighting

Sign lighting provides proper illumination for traffic signs.

Inspection of Lighting

All lights should be clearly visible. Verify that all lights are functioning and that they are not obstructed from view. Check for corrosion and collision damage to light supports. Verify that appropriate lighting is provided.

7.9 Approach Roadways

The primary function of the approach roadway is to provide a smooth transition between the roadway pavement and the bridge deck. This smooth transition decreases the impact forces and therefore increases bridge safety, as well as driver comfort.

Elements

There are four basic elements of a typical approach roadway:

- Pavement structure
- Subgrade
- Embankment
- Embankment foundation

The pavement structure varies with the type of approach roadway. For bituminous approaches, the pavement structure consists of a bituminous wearing surface and a bituminous subbase material. For concrete approaches, it consists of an approach slab, a relief joint, and an aggregate subbase material.

An approach slab is a concrete slab that rests on the abutment and spans over the region of abutment footing excavation. The joint between the approach slab and backwall is typically sealed.

On concrete roadways, the pavement tends to migrate toward the bridge, pressing the approach slab against the backwall. Therefore, a pavement relief joint is sometimes used to relieve this additional, undesired loading. A pavement relief joint uses a replacement asphalt strip, which fails as the roadway pavement migrates. However, its replacement is considerably cheaper and easier than that of the entire abutment or slab.

The subgrade is the prepared and compacted soil immediately below the pavement system. The approach embankment is the fill material required to bring the existing ground line up to the proposed grade for the roadway subgrade. Finally, the embankment foundation is the material below the original ground surface which supports the embankment.

Inspection of Approach Roadways

Vertical settlement of the approach roadway is caused by a consolidation of the embankment material. Settlement is especially a problem near the abutment where compaction efforts are hampered during construction. Heave of the approach slab can occur due to rotation of the abutment or an expansive reaction of backfill material (see Figure 7-19). Any vertical displacement should be documented, and its cause should be evaluated.

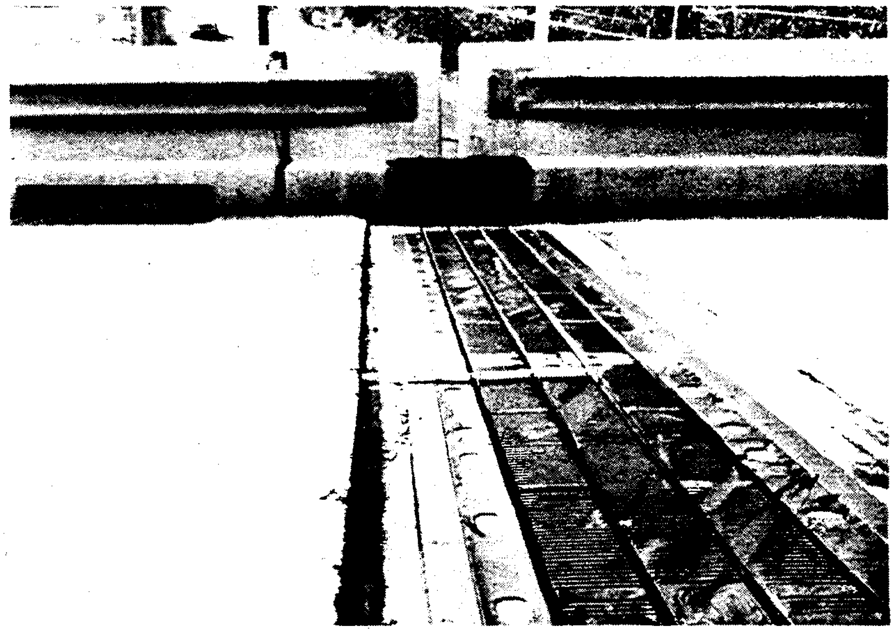


Figure 7-19 Heaving of the Approach Pavement

The riding surface should be smooth, free of potholes, and properly sloped for drainage. It should not compromise the quality of ride for a vehicle traveling at the posted speed limit.

The approach roadway width is the normal width of usable roadway approaching a structure. It includes the shoulders which are structurally adequate for all weather and traffic conditions consistent with the facility being carried. In most cases, shoulders that meet this standard are paved.

Shoulders are normally constructed and maintained flush with the adjacent traffic lanes. Grass and dirt to the side of the traffic lanes do not qualify as shoulders. Embankment slopes should have adequate vegetation to prevent erosion. Roadway inlets located in the approach area should be in good condition and fully operational.

Approach roadway alignment is the only deck-related item which receives an appraisal coding. The evaluation of the approach roadway alignment is based on the need to decrease operating speed from the posted speed limit. Any decrease in speed must be due to the alignment of the approach and not due to the road itself or the bridge deck geometry.

8

Inspection and Evaluation of Common Timber Superstructures

Grades of Timber and Their Allowable Design Properties

Grade of Timber	Allowable Stresses (psi)					E (psi)	Use
	F_b	F_c	F_t	F_{br}	F_v		
Southern pine:							
No. 1 SR	1350	775	875	375	110	1,500,000	Girders, beams, columns, caps
No. 2 SR	1100	625	725	375	95	1,400,000	
No. 1 J&P	1200	825	775	375	85	1,500,000	Decks
No. 2 J&P	1100	675	500	375	85	1,400,000	
Select Decking	1300	----	----	375	85	1,400,000	
Standard Decking	1800	----	----	440	85	1,600,000	
Douglas fir:							
No. 1 B&S	1300	925	675	625	85	1,600,000	Girders, beams, caps
No. 2 B&S	875	600	425	625	85	1,300,000	
No. 1 P&T	1200	1000	825	625	85	1,600,000	Columns
No. 2 P&T	750	700	475	625	85	1,300,000	
No. 1 J&P	1750	1250	1000	625	95	1,800,000	Decks
No. 2 J&P	1450	1050	650	625	95	1,700,000	
Select Decking	2000	----	----	625	95	1,800,000	
Commercial Deck	1650	----	----	625	95	1,700,000	

where:
F_b = bending
F_c = compression parallel to grain
F_t = tension parallel to grain
F_{br} = compression perpendicular to grain
F_v = shear
E = modulus of elasticity
SR = Stress Rated
J&P = joists and plank
B&S = beams and stringers
P&T = posts and timber

Notes:
1. The above properties are based on Allowable Stress Design.
2. For wet conditions, some of the properties must be reduced.
3. Refer to *Design Values for Wood Construction*, National Forest Products Association.

8

Inspection and Evaluation of Common Timber Superstructures

8.1 Introduction

Timber bridges are gaining a resurgence in popularity in the United States, especially in the northeast. This chapter presents the most common types of timber bridges, their design characteristics, and their inspection locations and procedures.

Construction Classifications

There are two basic classifications in timber construction: solid sawn and glued-laminated (glulam). A solid sawn beam is simply a tree, with its bark and branches removed, that is sawn down to the desired size. A glulam member is made by gluing strips of wood together to form a structural member of the desired size (see Figure 8-1).

Figure 8-1 Elevation View of a Glulam Multi-Beam Bridge

An advantage of glulam members is that they allow for a higher utilization of the wood, since a lower grade of material can be used in areas where stresses are not extremely high. Many strength reducing characteristics of wood, such as knots and checks, can be controlled through laminating. Also, the size and length of a glulam member is not limited by the size or length of a tree. Strips of wood used in glulam members are generally 3/4 to 1 1/2 inches thick. Timber bridges, unless of a highly temporary nature, should always be pressure treated with an oil-bourne wood preservation. This not only prevents decay and insect damage but also reduces the effects of ambient moisture and weathering.

Common Timber Defects

The most common defects in timber bridges include damage by fungi, parasites, fire, impact and collisions, abrasion and wear, weathering and warping, and overstress. Refer to Section 4.2 for a more detailed presentation of the properties of timber, types and causes of timber deterioration, and the examination of timber.

Common Timber Bridge Types

Currently the most common timber bridge types are:

- Solid sawn multi-beam bridges
- Glued-laminated (glulam) multi-beam bridges
- Trusses and covered bridges

Timber arch bridges are also used, and stressed timber bridges are a recently developed timber bridge type. As timber bridge technology continues to develop, other prototype timber bridges may also become realities.

For a description of advanced inspection techniques for timber bridges, refer to Section 15.2. For a description of protective systems for timber bridges, refer to Section 16.2.

8.2 Solid Sawn Multi-Beam Bridges

8.2.1 Design Characteristics

Solid sawn multi-beam bridges are the simplest type of timber bridge. They consist of multiple solid sawn beams spanning between substructure units (see Figure 8-2). The deck is typically comprised of transversely laid timber planks which are supported by the beams. Sometimes a bituminous wearing surface is placed on the deck planks to provide a less slippery riding surface for vehicles, as well as a protective surface for the planks. Beam sizes typically range from about 6 inches by 12 inches to 8 inches by 16 inches, and the beams are usually spaced about 24 inches on center.

This bridge type is generally used in older, shorter span bridges, spanning up to about 25 feet. Shorter spans are sometimes combined to form longer multiple span bridges and trestles. They are usually found on local or out of the way roads. Many older timber trestles were built for railroads and trolley lines. Solid sawn timbers have become obsolete for most major bridge members due to the development of high quality glulam members.

The primary members of solid sawn multi-beam bridges are the beams, and the secondary members are the diaphragms or cross bracing. These bridges usually have timber diaphragms or cross bracing between beams at several locations along the span.

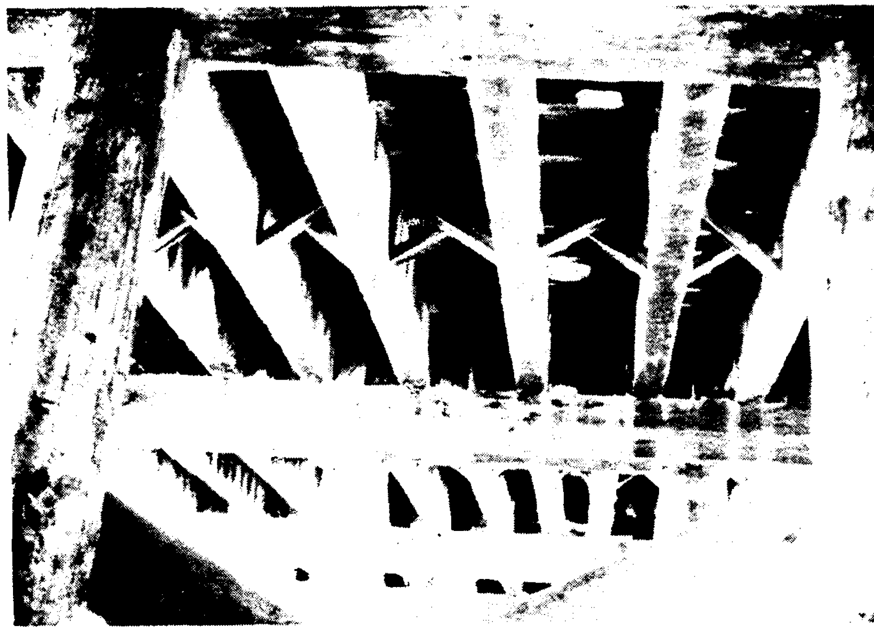


Figure 8-2 Underside View of a Solid Sawn Multi-Beam Bridge

8.2.2 Inspection Locations and Procedures

Bearing Areas

Check the bearing areas for crushing of the beams near the bearing seat. Investigate for decay and insect damage at the ends of the beams where dirt, debris, and moisture tend to accumulate. Also verify the condition and operation of the bearing devices if they are present (refer to Chapter 11).

Beams

Examine the maximum shear and tension zones for signs of structural distress. The maximum shear zones are at the ends of the beam, and the maximum tension zone is at the bottom half of the middle of the beam. Examine for decay at the top of the beam where the deck planks are attached. Investigate for section loss due to decay or fire, especially near mid-span and at the ends.

Inspect for horizontal shear cracks near the ends of the beam (see Figure 8-3). These cracks run horizontally along the length of the beam at about mid-depth and are sometimes due to overloading of the beam.

Investigate for signs of decay or insect damage along the full length of the beam but especially where the beam is subjected to continual wetness (see Figure 8-4). Decay and chemical attack may be evidenced by discolored wood and a soft, rotted texture of the wood. Additional signs of decay are the formation of fruiting bodies and "sunken" faces in the wood.

Insect infestation can be detected in various ways. Carpenter ants generally leave piles of sawdust; powder-post beetles leave small holes in the surface of the wood; and termites can often be readily seen. Another indication of insect infestation is hollow sounding wood. Further probing or drilling should be performed in suspect areas.

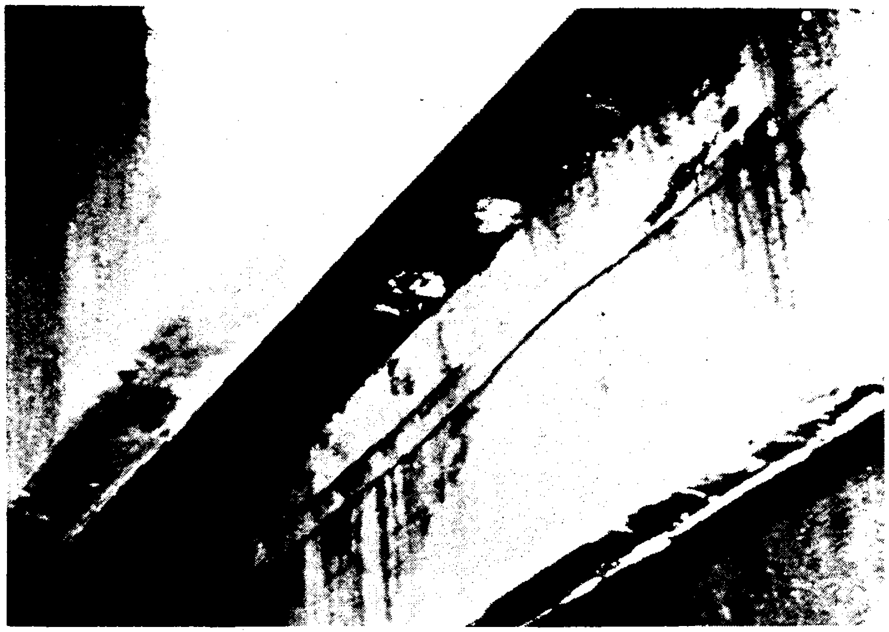


Figure 8-3 Horizontal Shear Crack in a Timber Beam

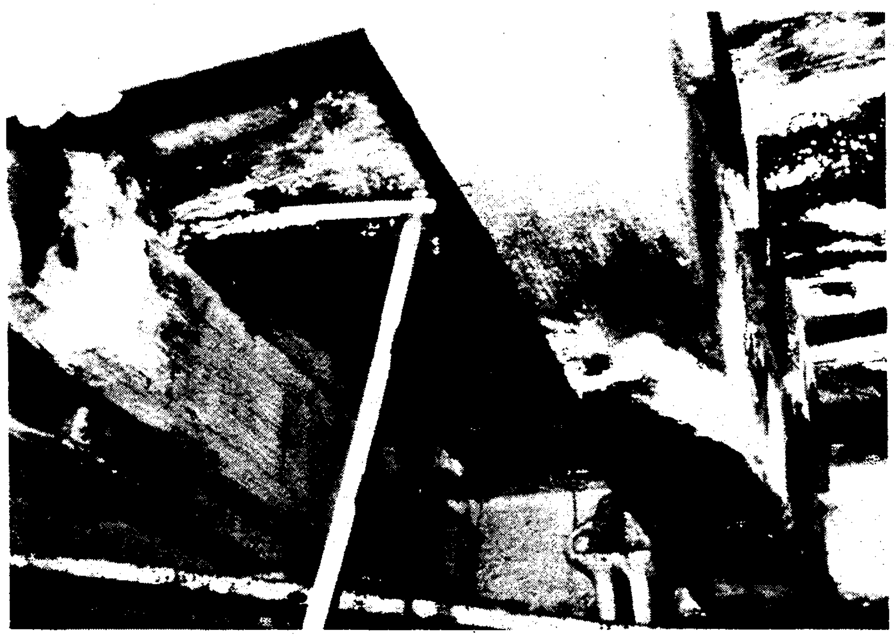


Figure 8-4 Decay in a Timber Beam

Examine beams for excessive deflection or sagging. For overhead structures, check for collision damage from vehicles passing below.

Diaphragms and Cross Bracing

Inspect bracing members for decay and fire damage. Examine connections of bracing to beams for tightness, cracked or split members, and corroded or missing fasteners.

Fasteners and Connectors

Check all fasteners (e.g., nails, screws, bolts, and deck clips) for corrosion. Also inspect for loose or missing fasteners.

8.3 Glued-Laminated Multi-Beam Bridges

8.3.1 Design Characteristics

Glued-laminated (glulam) multi-beam bridges are very similar to solid sawn multi-beam bridges, but they generally use larger members to span greater distances. Glulam multi-beam bridges consist of multiple glulam beams spanning between substructure units (see Figure 8-1). They usually support a deck consisting of glulam panels with a bituminous wearing surface. Beam sizes typically range from about 6 3/4 inches by 24 inches to 12 1/4 inches by 60 inches, and the beams are usually spaced 5 1/2 feet to 6 1/2 feet on center.

These more modern multi-beam bridges can typically be used in spans of up to 80 feet, although some span as long as 150 feet. These too can be used to form longer multiple span structures. They are generally found on local and secondary roads, as well as in park settings.

The primary members of glulam multi-beam bridges are the beams, and the secondary members are the diaphragms or cross bracing. Due to the larger depth of the glulam beams, diaphragms or cross bracing should always be present. Diaphragms can be constructed of short glulam members, and cross bracing can be constructed of steel angles.

8.3.2 Inspection Locations and Procedures

Since these superstructures are very similar to solid sawn multi-beam superstructures, the inspection locations and procedures for glulam multi-beams are virtually the same as those for solid sawn multi-beams.

Bearing Areas

Inspect the bearing areas for crushing of the beams (see Figure 8-5). Investigate for decay and insect damage at the ends of the beams. Also check the condition and operation of the bearing devices if they are present (refer to Chapter 11).

Beams

Examine the maximum shear zones (i.e., ends of beam) and the maximum tension zone (i.e., bottom half of middle of beam) for signs of structural distress. Check for section loss due to decay or fire, especially near mid-span and at the ends.

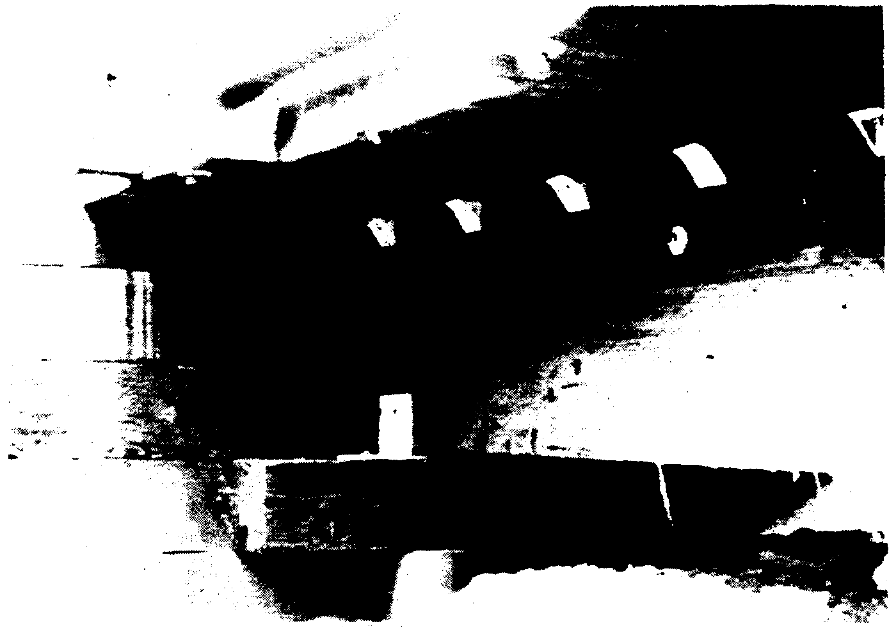


Figure 8-5 Bearing Area on a Typical Glulam Beam

Examine for horizontal shear cracks and delaminations near the ends of the beam. Delaminations (i.e., separations in the laminations) can occur due to either failure of the glue or failure at the bond between the glue and the lamination. Delaminations that extend completely through the cross section of the member are the most serious since this makes the member act as two smaller members. Delaminations that are located near the center of the cross section are more serious than those that are not. Delaminations directly through a connector are also undesirable.

Investigate for signs of decay or insect damage along the full length of the member, but especially where the beam is subjected to continual wetness or prolonged exposure to moisture.

Inspect for excessive deflection or sagging in the beams. Check beams in overhead structures for collision damage from vehicles passing below.

Diaphragms and Cross Bracing

Examine solid sawn or glulam diaphragms for decay, fire damage, and insect damage. Check steel cross bracing for corrosion, and bowing or buckling. Examine connections for tightness, cracks and splits, and corroded or missing fasteners.

Fasteners and Connectors

Inspect all fasteners for corrosion, tightness, and missing parts.

8.4 Trusses and Covered Bridges

8.4.1 Design Characteristics

A wide variety of truss types are used in timber bridges, but the bowstring truss and the parallel chord truss are two of the most popular truss configurations. Timber trusses are generally used for spans that are not economically feasible for multi-beam bridges. Timber trusses are practical for spans that range from 150 to 250 feet.

Modern Timber Trusses

Trusses may be of the through-type or of the deck-type. They may be constructed of solid sawn members, glulam members, or both. Usually the floor system consists of a timber deck supported by timber stringers and floorbeams, all of which are supported by the trusses.

The primary members are the trusses, stringers, and floorbeams. The secondary members are the diaphragms and cross bracing between stringers, and the lateral bracing between trusses.

Covered Bridges

Covered bridges are essentially truss bridges with covers (see Figure 8-6). Solid sawn timber trusses serve as the main supporting element of these historic structures. The covers on the bridges prevent decay of the truss and undoubtedly are responsible for their longevity. The floor system consists of timber deck, stringers, and floorbeams.

Figure 8-6 Typical Covered Bridge

Typical truss types for covered bridges include the king post, queen post, Burr arch-truss, Town, Warren, and Howe (see Figure 2-7). The span lengths of covered bridges are generally in the range of 50 to 100 feet, although some span over 200 feet.

Covered bridges are generally found along rural, local roads. They are usually owned by local municipalities, although some are owned by states or private individuals. Some still carry highway traffic, but many are only open to pedestrians. While most covered bridges were built during the 1800's and early 1900's, there are a number of covered bridges being built today.

The primary members are the trusses, stringers, and floorbeams. The secondary members are the diaphragms and cross bracing between stringers, the lateral bracing between trusses, and the covers on the roof and sides.

8.4.2 Inspection Locations and Procedures

Bearing Areas

Inspect the bearing areas for crushing of the bottom chord. Also examine for crushing in the stringers where they bear on the floorbeams, and at the ends if they rest directly on the abutment. Check for decay and insect damage at the ends of the stringers, floorbeams, and trusses. Investigate the condition and operation of any bearing devices present under the ends of the trusses (refer to Chapter 11).

Stringers

Stringers should be inspected in a manner similar to that used for multi-beam bridges. Examine the maximum shear zones (i.e., ends of beam) and the maximum tension zone (i.e., bottom half of middle of beam) for signs of structural distress. Inspect the entire stringer for signs of decay or fire damage, paying particular attention to the areas that are subjected to continual wetness or prolonged exposure to moisture. Look for excessive deflection or sagging.

Floorbeams

Examine floorbeams for decay, fire damage, deflection, and structural distress similar to the stringers. Carefully inspect the ends of the floorbeams where they are connected to the truss for checks and splits, since these defects can seriously weaken the connection.

Trusses

Examine the various truss members for decay, fire damage, and insect damage, paying close attention to the ends of the members at the connections where moisture can become trapped.

Investigate the vertical and horizontal alignment of the trusses to see if any permanent misalignment has occurred. Also check for excessive live load deflection as traffic crosses the structure.

Examine all of the members for checks and splits. Checks are normally of little importance unless they become water traps. However, depending upon the type of stress in the member, their presence may be significant. For example, at the ends of members stressed in tension parallel to the grain, such as bottom chords and web members, splits may be significant if they occur within the connector area. At the ends of members stressed in compression parallel to the grain, such as top chords and web members, checks and splits are relatively unimportant, provided they have caused no slippage in the connections. For end splits in either tension or compression members with connector loads acting in a direction other than parallel to the grain, the splits may or may not be significant. In any case, all splits and checks at the ends of members should be noted.

Examine through trusses for collision damage from vehicular impact (see Figure 8-7).

Figure 8-7 Collision Damage on a Timber Truss

Diaphragms and Cross Bracing

If timber diaphragms are present between the stringers, examine them for decay and fire damage. Inspect connections to the stringers for tightness, checks and splits, and corroded or missing fasteners.

Lateral Bracing

Lateral bracing may be wood, steel, or wrought iron. Bracing should be examined for bowing and buckling. Examine timber bracing for decay and fire damage. Check steel or wrought iron bracing for corrosion and section loss. Investigate bracing connections to trusses for tightness, deterioration, and missing fasteners.

Connections

Inspect all connections for any signs of weakness or slippage. Check metal fasteners for corrosion, section loss, and missing fasteners. Examine wooden peg type fasteners for decay and splits.

Covers

Check the covered roof for leaks. (This may be difficult to do unless it is raining during the inspection.) Investigate the overall physical condition of the roof and side coverings, noting the condition of the siding and roof, paint, and fasteners.

8.5 Other Timber Bridges

8.5.1 Arch Bridges

Glulam Arch Bridges

Glulam arch bridges usually consist of two glulam three-hinged deck arches which support a glulam deck and floor system. Glulam arches are practical for spans of up to about 300 feet. Although they are not widely used for highway bridges, they are frequently used for pedestrian overpasses and in locations such as parks where aesthetics is important.

Covered Bridge Arches

Timber arches were first used in covered bridges by Theodore Burr to strengthen the series of king post trusses normally used in covered bridges. These became known as Burr arch-trusses (see Figures 2-7 and 8-8). The arch served as the main supporting element, and the king posts simply strengthened the arch. Many of these structures still exist today.

Figure 8-8 Inside View of a Covered Bridge with a Burr Arch-Truss

Inspection Locations and Procedures

The inspection locations and procedures for timber arch bridges are similar to those for glulam multi-beam bridges and for timber truss bridges.

8.5.2 Stressed Timber Bridges

Stressed Deck Bridges

Stressed deck bridges were first developed in Canada, in 1976, by the Ontario Ministry of Transportation and Communications. (50, 55) These bridges consist of multiple laminations of solid sawn timber planks squeezed together by high strength steel rods passing through predrilled holes in the laminations (see Figure 8-9). The compression and frictional resistance within the timber laminations are the mechanism that makes this structural system effective. Solid sawn stressed decks can be used in simple spans of up to about 50 feet and are capable of carrying heavy loads (see Figure 8-10).

Figure 8-9 Stressed Deck Section Being Fabricated (Source: Barry Dickson, West Virginia University)

Figure 8-10 Stressed Deck Bridge Carrying a 90,000 Pound Logging Truck (Source: Barry Dickson, West Virginia University)

Stressed deck bridges have also been constructed using glulam members. Glulam stressed decks have been used in spans of up to about 63 feet.

Stressed K-Frame Bridges

Stressed K-frame bridges represent further development of the stressed deck bridge by the Ontario Ministry of Transportation and Communications. (50) These bridges consist of three spans in which the stressed deck is supported at two intermediate points by stressed laminated timber struts. This bridge type has been used for a bridge with a total length of 43 feet, and it has a potential for span lengths over 50 feet.

Stressed Tee Beam Bridges

The idea for stressed tee beam bridges was developed at West Virginia University. (26) These bridges consist of a stressed deck and glulam beams, made with laminated veneer lumber (see Figure 8-11). High strength steel rods are used to join the stressed deck and glulam beams together to form laminated timber tee beams.

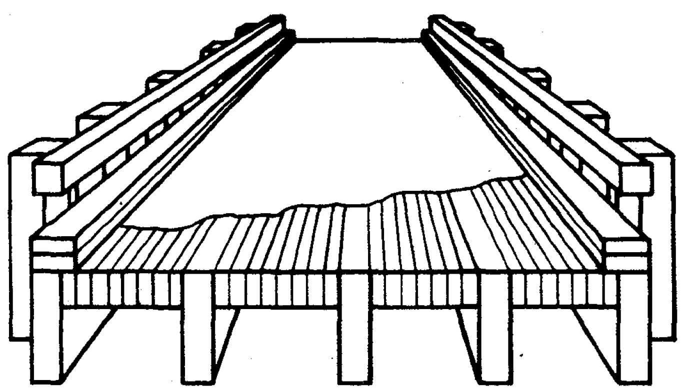


Figure 8-11 Stressed Tee Beam Bridge (Source: Barry Dickson, West Virginia University)

The first structure of this type was built in 1988, near Charleston, West Virginia. It is about 75 feet long and has stressing rods spaced at two feet. It has performed well so far, and stressed tee beams will likely be used in the future to achieve even longer span lengths.

Stressed Box Beam Bridges

Stressed box beam bridges represent further development of timber bridges by West Virginia University. (51) These bridges consist of adjacent box beam panels formed by a stressed deck top flange and stressed deck bottom flange with glulam webs separating them (see Figure 8-12). This bridge type is also known as a cellular stressed deck. Span lengths of up to 60 feet have been designed, and there is a potential for longer spans.

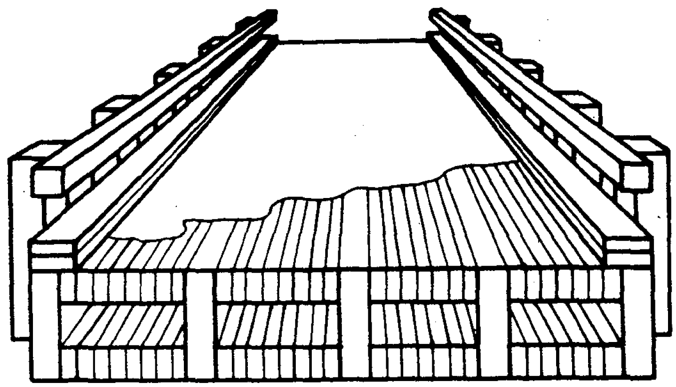


Figure 8-12 Stressed Box Beam Bridge (Source: Barry Dickson, West Virginia University)

Further development of the stressed timber bridge concept if being performed at the University of Wisconsin, West Virginia University, and Pennsylvania State University, as well as in Canada.

Inspection Locations and Procedures

The inspection locations and procedures for stressed timber bridges are similar to those for glulam multi-beam bridges. Examine the condition of the steel stressing rods, and inspect for cracks and delaminations in the stressed timber members. Check for loss of prestress in the rods and for separation cracks in prestressed timber members. This is best observed when the bridge is subject to a moving live load.

9

Inspection and Evaluation of Common Concrete Superstructures

Standard Reinforcing Bars (1930)				
Size, In.		Cross-Sectional Area, In.	Perimeter, In.	Unit Weight per Foot, Lb.
Plain	Deformed			
1/4Φ	-----	0.05	0.785	0.167
-----	3/8Φ	0.11	1.178	0.376
-----	1/2Φ	0.20	1.571	0.668
-----	1/2□	0.25	2.000	0.850
-----	5/8Φ	0.31	1.963	1.043
-----	3/4Φ	0.44	2.356	1.502
-----	7/8Φ	0.60	2.749	2.044
-----	1Φ	0.79	3.142	2.670
-----	1□	1.00	4.000	3.400
-----	1 1/8□	1.27	4.500	4.303
-----	1 1/4□	1.56	5.000	5.313

Standard Spiral Rods (1932)			
Size, In. Plain	Cross-Sectional Area, In.	Perimeter, In.	Unit Weight per Foot, Lb.
1/4Φ	0.05	0.785	0.167
3/8Φ	0.11	1.178	0.376
1/2Φ	0.20	1.571	0.668
5/8Φ	0.31	1.963	1.043

Reinforcing Bars (Current)				
Bar No.	Diameter, In.	Cross-Sectional Area, In.	Perimeter, In.	Unit Weight per Foot, Lb.
2	1/4 = 0.250	0.05	0.79	0.167
3	3/8 = 0.375	0.11	1.18	0.376
4	1/2 = 0.500	0.20	1.57	0.668
5	5/8 = 0.625	0.31	1.96	1.043
6	3/4 = 0.750	0.44	2.36	1.502
7	7/8 = 0.875	0.60	2.75	2.044
8	1 = 1.000	0.79	3.14	2.670
9	1.128	1.00	3.54	3.400
10	1.270	1.27	3.99	4.303
11	1.410	1.56	4.43	5.313
14	1.693	2.25	5.32	7.650
18	2.257	4.00	7.09	13.600

Notes:

1. Φ represents the diameter of a circular cross section.
2. □ represents the length of each side of a square cross section.

9

Inspection and Evaluation of Common Concrete Superstructures

9.1 Introduction

Concrete superstructures are classified according to the method of construction - cast-in-place or precast - and the method of reinforcement - conventional (mild steel) reinforcement or prestressed. Older concrete bridges built before World War II were typically cast-in-place, conventionally reinforced structures. Modern concrete bridges are typically precast or cast-in-place prestressed structures.

This chapter is organized according to the method of reinforcement. The next two sections explain the inspection of conventionally reinforced concrete superstructures and prestressed concrete superstructures. The last section focuses on the evaluation of concrete superstructures.

For a description of advanced inspection techniques for concrete bridges, refer to Section 15.3. For a description of protective systems for concrete bridges, refer to Section 16.3.

9.1.1 Common Defects

Prior to the description of inspection, we should first recall the common defects that occur on concrete bridges. They include:

- Cracking
- Scaling
- Delamination
- Spalling
- Efflorescence
- Honeycombs
- Pop-outs
- Wear
- Collision damage
- Abrasion
- Overload damage
- Reinforcing steel corrosion
- Prestressed concrete deterioration

Refer to Section 4.3 for a more detailed presentation of the properties of concrete, types and causes of concrete deterioration, and the examination of concrete.

9.2 Inspection of Reinforced Concrete Superstructures

Most older concrete superstructures can be described as cast-in-place, conventionally reinforced structures. This section presents inspection procedures for the following types of reinforced concrete superstructures:

- Cast-in-place slab
- Tee beams
- Through girders
- Channel beams
- Open spandrel arch
- Closed spandrel arch
- Rigid frame

9.2.1 Cast-in-Place Slab

Design Characteristics

The cast-in-place slab bridge is the simplest type of reinforced concrete bridge. The slab functions as a wide shallow beam in which the beam itself acts as the deck. This type of bridge generally has a single span less than 30 feet. Simple and continuous multi-span slab bridges are also common (see Figure 9-1).

Figure 9-1 Typical Multi-Span Slab Bridge

Steel Reinforcement

The primary, or main tension, reinforcement is located in the bottom of the slab. The reinforcement is placed from abutment to abutment, parallel to the direction of traffic.

For continuous spans, additional primary reinforcement is located in the top of the slab over the piers.

The secondary reinforcement, known as temperature and shrinkage steel, is located in the bottom portion of the slab. Temperature and shrinkage steel is placed perpendicular to the direction of traffic (see Figure 9-2).

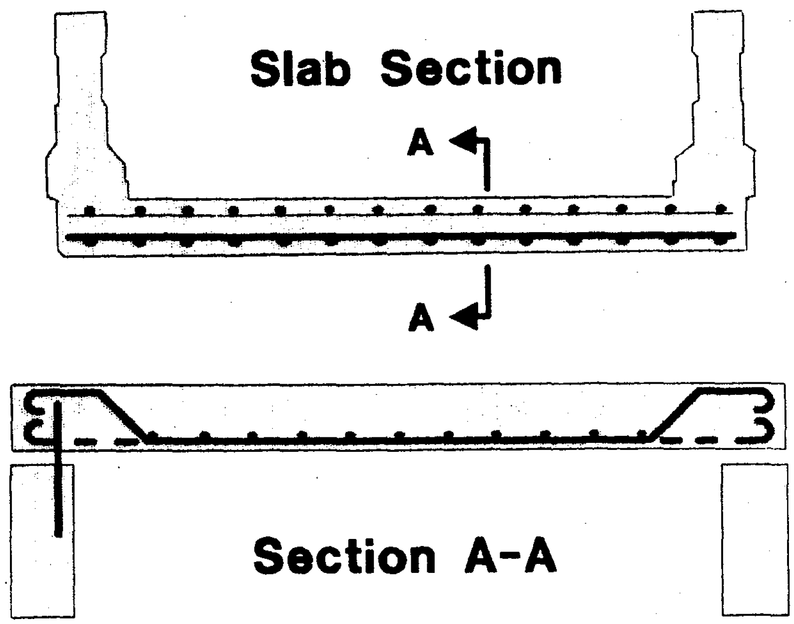


Figure 9-2 Steel Reinforcement in a Concrete Slab

Primary Members

The only primary member in a cast-in-place slab bridge is the slab itself.

Inspection Procedures

Inspect a cast-in-place slab bridge using the following procedures:

- Examine bearing areas for spalling where friction from thermal movement and high edge or bearing pressure could cause the concrete to spall.
- Investigate areas near the supports for diagonal (shear) cracking. The presence of diagonal cracks on the sides of the slab may indicate the beginning of shear failure. These cracks should be measured and documented.
- The tension areas should be examined for flexure cracks (vertical on the sides and transverse across the slab) or the disintegration of the concrete. This may indicate extreme bending stresses. Check for efflorescence from cracks. Discoloration of the concrete is caused by rust stains from the reinforcing steel (see Figure 9-3). In severe cases, the reinforcing steel may become exposed. Document any section loss of reinforcing steel since it will decrease live load capacity.
- Inspect areas exposed to roadway drainage for deteriorated concrete, particularly around scuppers or drains. Spalling may also be found along the curbline and fascias.
- Check areas of damage caused by collision or fire.
- Examine acute corners of skewed bridges for cracking.
- Inspect for lateral displacement.

9.2.2

Tee Beams

Design Characteristics

The concrete tee beam is generally a cast-in-place monolithic deck and beam system formed in the shape of the letter "T." The deck or slab portion of the beam acts integrally with the stem, providing greater stiffness and allowing increased span lengths. The tee beam bridge is used for spans between 30 and 50 feet. Multi-span and continuous tee beam bridges are common (see Figure 9-4).

Figure 9-3 Delamination and Efflorescence With Rust Stains on Slab Underside

Figure 9-4 Multi-Span Tee Beam Bridge

Spacing of the tee beams is generally 3 to 8 feet, center-to-center of beam stems. The depth of the stems is generally 18 to 24 inches.

The cast-in-place tee beam is the most common type of tee beam. However, precast tee beam shapes are used by some highway agencies. Types of precast tee beams include bulb tee, double tee, quad tee, and rib tee.

The inspector should be careful not to confuse a tee beam bridge with a concrete encased steel I-beam bridge. A review of the structure file should eliminate this problem.

Steel Reinforcement

The primary (tension) reinforcing steel is located in the bottom of the beam stem and placed longitudinally. The sides of the beam contain primary vertical shear reinforcing, called stirrups. The need for stirrups is greatest near the beam supports where shear stresses are the highest.

The primary reinforcing steel for the slab portion of the beam is located in the bottom of the slab and is placed transversely, or perpendicular to the beam stems.

The secondary (temperature and shrinkage) reinforcing steel can be found longitudinally in the sides of the beam stems and longitudinally and transversely in the top of the slab (see Figure 9-5).

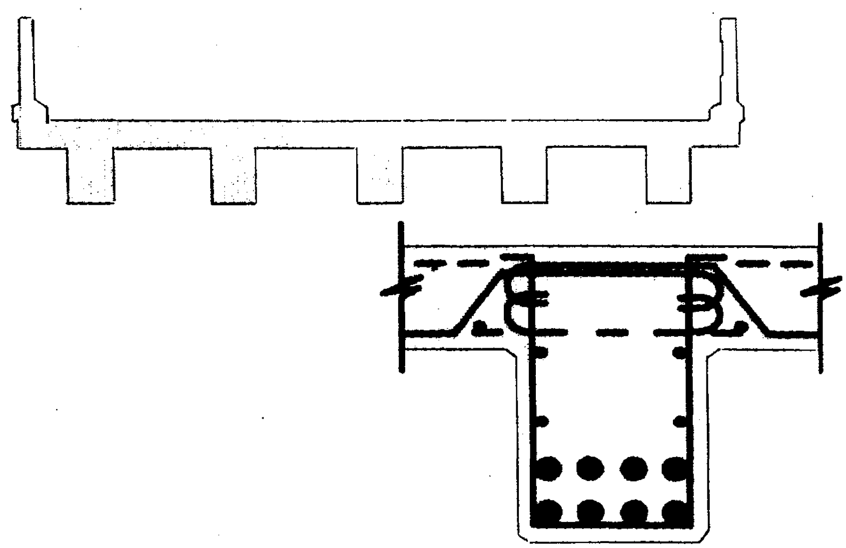


Figure 9-5 Steel Reinforcement in a Concrete Tee Beam

Primary Members

The primary members of a tee beam bridge are the tee beam stem (web) and slab (flange).

Secondary Members

The only secondary members on a tee beam bridge are the diaphragms. Diaphragms are located at the end of the beams and support the end portion of the slab. Intermediate diaphragms may also be present.

The diaphragms are designed as simple beams and should be inspected for typical concrete defects.

Inspection Procedures

Inspect a tee beam bridge using the following procedures:

- Examine bearing areas for spalling due to friction from thermal movement and high bearing pressure. Check the condition and operation of any bearing devices.

- Investigate the area near the supports for the presence of diagonal (shear) cracks. These will occur on the stem and project up from the supports toward mid-span.

- The tension areas should be examined for flexure cracks. Look for flexure cracks in the bottom of the beam stem near mid-span (see Figure 9-6) and in the top of the beam (slab portion) at the piers on continuous spans (see Figure 9-7).

- Inspect the tension zones for deteriorated concrete. This could cause debonding of the tension reinforcement and would include delamination, spalls, and contaminated concrete (efflorescence).

- Examine cracks for rust stains. This indicates corrosion of the steel reinforcement. Document all section loss on reinforcement. Measurable section loss will decrease live load capacity.

- Check areas exposed to drainage for concrete spalling or cracking. This may occur at the ends of the beams where drainage has seeped through the joints.

- Investigate areas that may be damaged due to collision. Any loss of section should be carefully observed and measured.

- Examine areas that have been previously repaired. Determine if the repairs are in place and if they are functioning properly.

9.2.3
Through Girders

Design Characteristics

Concrete through girders are cast monolithically with the deck slab. The girders are very large in appearance and actually serve as the bridge's parapets, as well as the main supporting members (see Figure 9-8).

Concrete through girders are used for simple spans ranging from 30 to 60 feet. They are not, however, economical for wide roadways and are usually limited to about 24 foot width. Girders are usually 18 to 30 inches wide and 4 to 6 feet deep.

In a through girder structure, the loads from the roadway surface are carried to the girders through the deck slab. The girders in turn carry the loads to the abutments.

Figure 9-6 Flexure Cracks on a Tee Beam

Figure 9-7 Flexure Cracks in Tee Beam Top Flanges

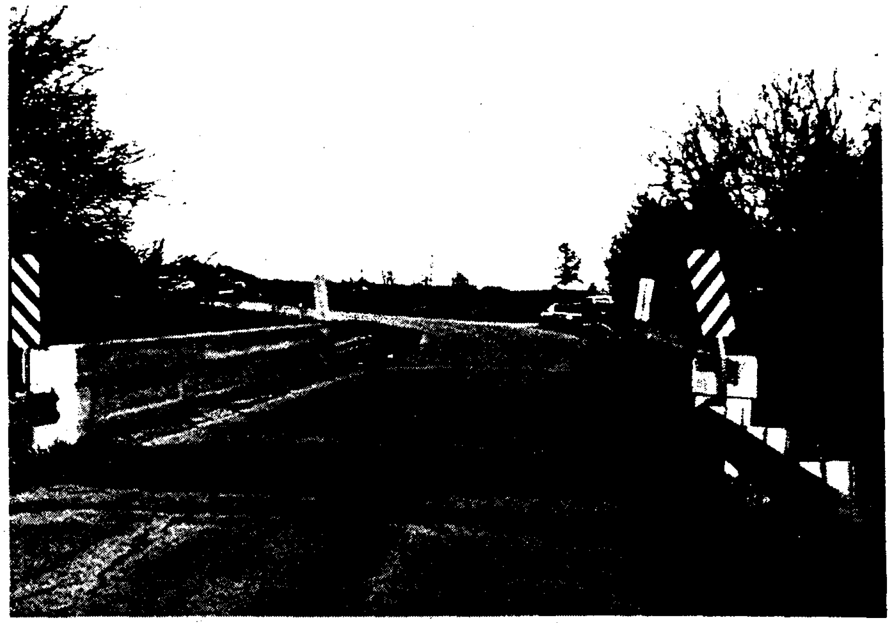


Figure 9-8 Typical Concrete Through Girder Bridge

Steel Reinforcement

The primary (tension) reinforcing steel for a through girder is located in the bottom of the girder and is placed longitudinally. Vertical stirrups serve as shear reinforcement. The primary reinforcing steel in the slab is located in the bottom of the slab and is placed transversely or perpendicular to the direction of traffic (see Figure 9-9).

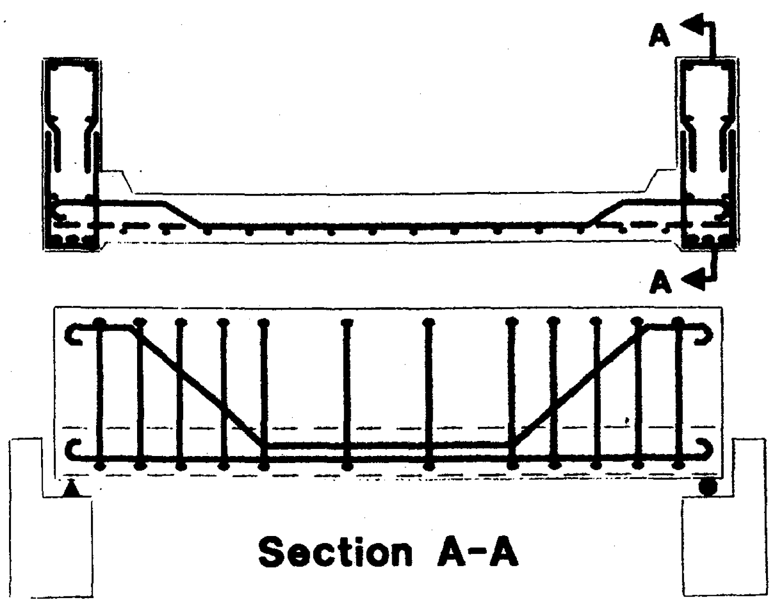


Figure 9-9 Steel Reinforcement in a Concrete Through Girder

Temperature and shrinkage reinforcement is also located in the slab and girders.

Primary Members

The primary members of a through girder bridge are the concrete girders.

Secondary Members

The secondary member of a through girder bridge is the deck slab.

Inspection Procedures

Inspect a through girder bridge using the following procedures:

- Examine bearing areas at the end of the girders for spalled and cracked concrete.

- Investigate areas near the supports for diagonal (shear) cracks. These cracks will appear on the sides of the girders and project diagonally toward the top of the girder. Check for exposed and corroded stirrups.

- Inspect the tension areas for flexure cracks with rust stains and efflorescence. These will usually be found at the mid-span of the girders and may extend across the underside of the slab. Flexure cracks in the deck will be longitudinal because the primary slab steel is transverse. Investigate for contaminated concrete around the primary reinforcement. Also, look for exposed and corroded tension reinforcement (see Figure 9-10).

- Inspect areas exposed to drainage. These areas will usually be at any joints or around the scuppers. Look for contamination due to deicing agents.

- Examine areas that have been previously damaged. Observe and document any change to a previously recorded defect, especially section loss of reinforcing steel.

Figure 9-10 Exposed Reinforcement in a Through Girder

9.2.4
Channel Beams

Design Characteristics

Channel beams are generally precast and consist of a thin slab cast monolithically with two legs about three to four feet apart. In appearance, the channel beam bridge resembles the tee beam bridge because the legs of two adjacent channel beams are bolted together to form a single stem. In addition to the appearance of the finished concrete, the channel beam is different from the tee beam by the presence of a full length seam or joint along the bottom of the stem (see Figure 9-11). Channel beams are usually found on spans up to 50 feet.

Reinforcement cover for older channel beam bridges is often less than today's cover requirements. Air entrained concrete was not specified in channel beams fabricated in the 1940's and early 1950's, and concrete was often poorly consolidated.

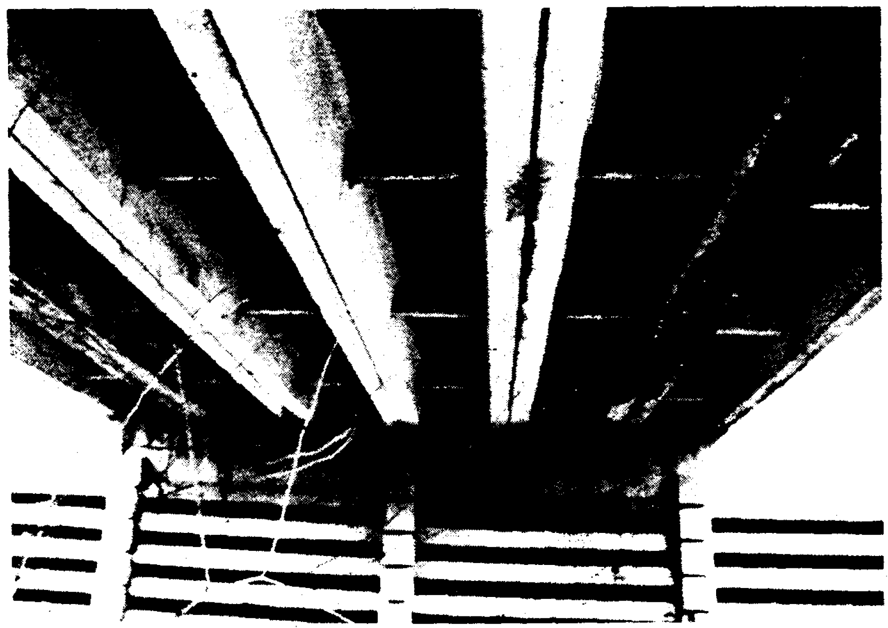


Figure 9-11 Typical Channel Beam Bridge

Steel Reinforcement

The primary (tension) reinforcing steel is located in the bottom of the channel leg and is placed longitudinally. The sides of the legs are reinforced with stirrups. The need for stirrups is greatest near the beam supports.

The primary reinforcing steel for the slab portion of the beam is located in the bottom of the slab and is placed transversely, or perpendicular to the channel legs.

The secondary (temperature and shrinkage) reinforcing steel can be found longitudinally in the sides of deep channel legs and longitudinally and transversely in the top of the slab.

Primary Members

The primary members of channel beam bridges are the channel beams.

Inspection Procedures

Inspect a channel beam bridge using the following procedures:

- Examine the bearing areas for spalling or crushed concrete.

- Investigate areas near the supports for diagonal or shear cracks. Cracks with efflorescence or rust stains may indicate insufficient reinforcement cover and significant deterioration of the reinforcement.

- Tension areas should be examined for flexure cracks. These could occur on both the concrete legs and the slab. Cracks with efflorescence or rust stains indicate contaminated concrete and corrosion of reinforcing steel. Flexure cracks in the slab will be found on the underside in a longitudinal direction.

- Inspect the seam or joint between two adjacent beams for leakage. Leakage indicates a broken shear key between the channel beams (see Figure 9-12). If signs of leakage are present between beams, the superstructure should be observed closely for differential beam deflection under live load.

- Examine areas exposed to drainage. Look for spalls and contamination at the ends of the channel beams and around the scuppers.

- Check the tie bolts for tightness and corrosion.

- Investigate areas that have been previously damaged or repaired.

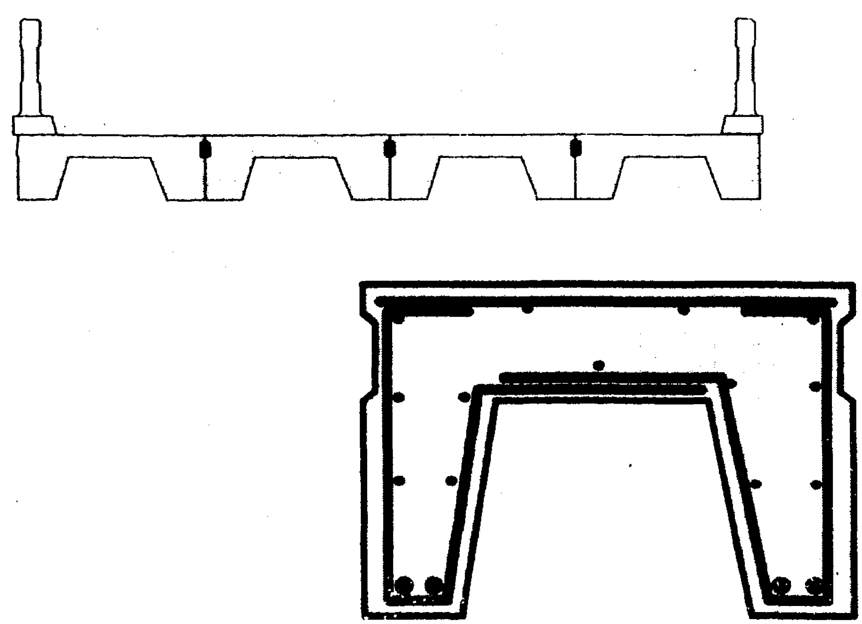


Figure 9-12 Channel Beam Cross Section

9.2.5
Open Spandrel Arch

Design Characteristics

A true arch has an elliptical shape and functions in a state of pure axial compression. It can be thought of as a long curved column. This makes the true arch an ideal form for the use of concrete. Unfortunately, the true arch form is often compromised to adjust for a specific bridge site. Because of this compromise, modern concrete arches resist a load combination of axial compression and bending moment.

The open spandrel concrete arch is considered a deck arch since the roadway is above the arches. The area between the arches and the roadway is called the spandrel.

Open spandrel concrete arches receive traffic loads through spandrel bents which support a slab or tee beam floor system (see Figure 9-13).

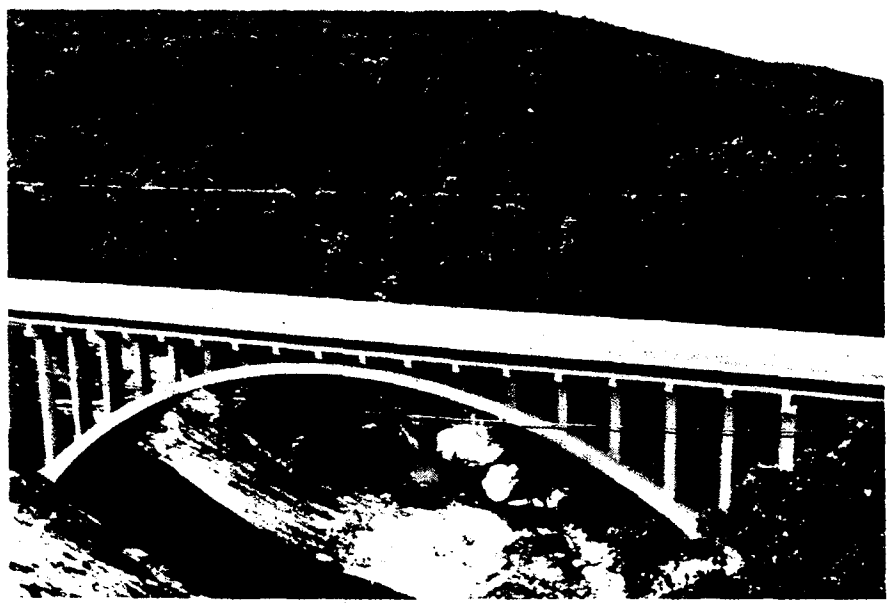


Figure 9-13 Typical Open Spandrel Arch Bridge

Steel Reinforcement

The primary reinforcing steel in an arch follows the shape of the arch from support to support. Since the arch is a compression member, reinforcement is similar to column reinforcement. The surfaces of the arch rib are reinforced with equal amounts of longitudinal steel held in place with lateral ties. This longitudinal or column reinforcement can act as compression reinforcement when the arch must resist moment due to axial load eccentricity or lateral loads. Spandrel columns are also compression members and are reinforced similar to the arch rib (see Figure 9-14).

In spandrel bent caps, the primary reinforcement is tension and shear steel. This is provided using "Z" shaped bars since the cap behaves like a fixed end beam (see Figure 9-15).

The floor system is designed and reinforced similar to other concrete beams (e.g. tee beams). The floor system contains both primary reinforcing steel and temperature and shrinkage reinforcement.

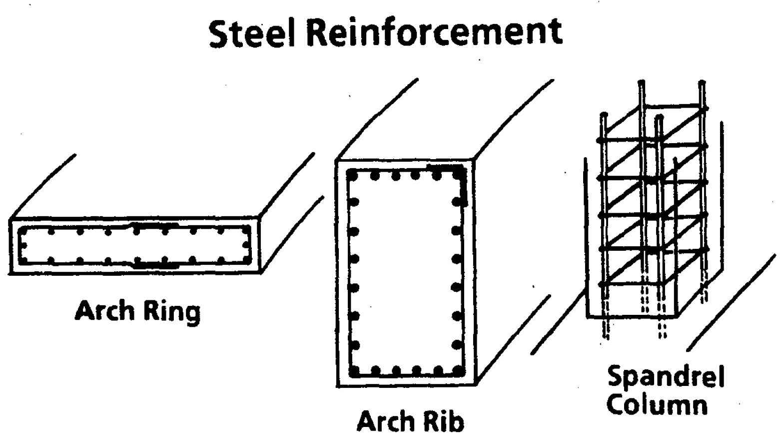


Figure 9-14 Open Spandrel Arch Reinforcement

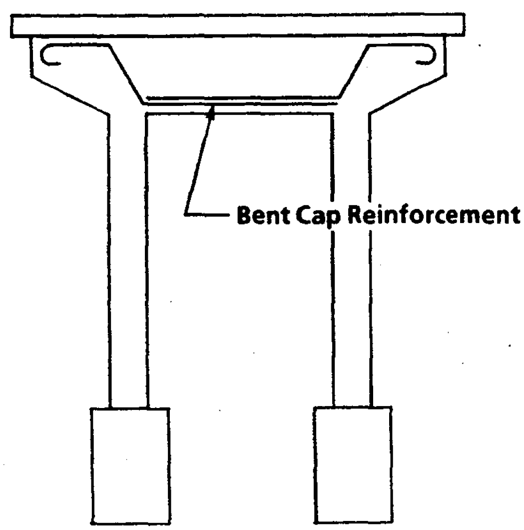


Figure 9-15 Spandrel Bent Cap Reinforcement

Primary Members

The reinforced concrete open spandrel arch consists of two or more arch ribs. The arch members are the primary load-carrying elements of the superstructure. The arch and the following members supported by the arch are considered superstructures elements:

- Spandrel bents - support floor system
- Spandrel bent cap - transverse beam member of the spandrel bent
- Spandrel columns - vertical members of the spandrel bent which support the spandrel bent cap
- Spandrel beams - fascia beams of the floor system
- Floor system - a slab or tee beam arrangement supported by the spandrel bent caps and the substructure elements

Secondary Members

The secondary members of an open spandrel arch bridge are the arch struts, which are transverse beam elements which connect the arch ribs. Arch struts provide stability against lateral forces.

Inspection Procedures

Inspect an open spandrel arch bridge using the following procedures:

- Examine the bearing areas. Arch construction uses a "building block" erection approach. Arch elements, although connected, are basically stacked or "bearing" on one another. The elements at the bottom of the stack receive the largest compressive loads due to the weight of the elements above.
- The arch/skewback interface has the greatest bearing load magnitude. Inspect for loss of cross-section due to spalls. Examine the arch for longitudinal cracks. These indicate an overstress condition.
- The arch/spandrel column interface has the second greatest bearing load magnitude. Examine for loss of cross-section due to spalls. Check for horizontal cracks in the columns within several feet from the arch. These indicate excessive bending in the column, which is caused by overloads and differential arch rib deflection.
- The spandrel column/cap interface has the third greatest bearing load magnitude. Inspect for loss of section due to spalling. Examine the column for diagonal cracks which begin at the inside corner and propagate upward. These indicate differential arch rib deflection (see Figure 9-16).
- The floor system/bent cap interface has the smallest bearing load magnitude. Examine bearing areas as described in the slab and tee beam sections.
- Check for shear cracks at the ends of the spandrel bent caps. When arch ribs are connected with struts, examine the arches near the connection for diagonal cracks due to torsional shear. These cracks indicate excessive differential deflection in the arch ribs. Also investigate the floor system for shear cracks.

- Inspect the tension areas of the spandrel bent caps (i.e., mid-span at the bottom and ends at the top). Also check the tension areas in the floor system.

- Investigate the compression areas throughout the arches and spandrel columns (not only at the bearing areas). Transverse or lateral cracks indicate excessive surface tension stresses caused by buckling forces and moment.

- Examine the concrete for efflorescence, rust stains, spalling, and exposed or corroded reinforcing steel.

- Check the areas exposed to drainage and roadway runoff. Elements beneath the floor system are prone to scaling, spalling, and concrete contamination.

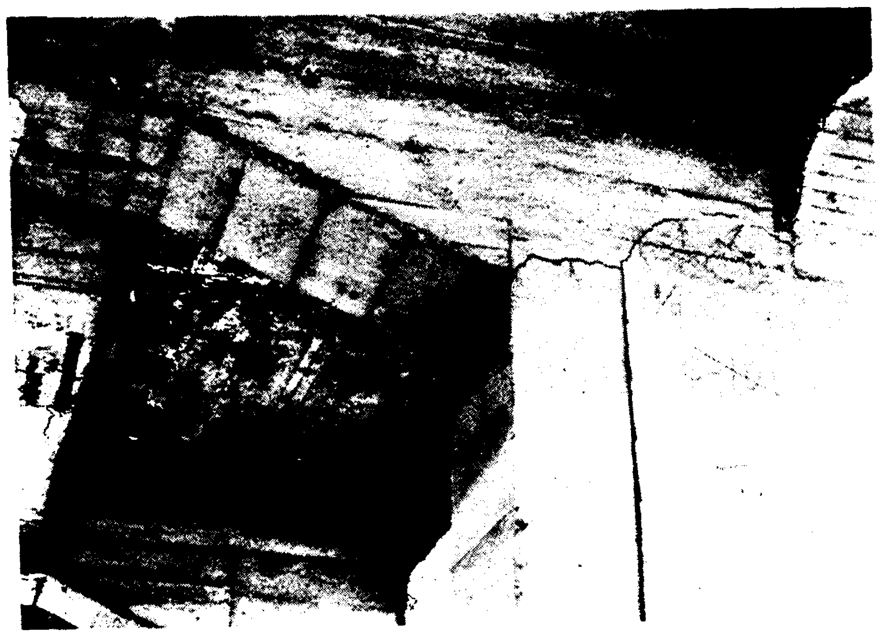


Figure 9-16 Diagonal Crack in Spandrel Column Cap

9.2.6 Closed Spandrel Arch

Design Characteristics

Closed spandrel arches are deck arches. The spandrel area (i.e., the area between the arch and the roadway) is occupied by fill retained by vertical walls. The arch member is called a ring or barrel and is continuous between spandrel walls.

The arch and members supported by the arch are superstructure elements. The arch itself is the primary load-carrying element of the superstructure.

Closed spandrel arches are considered simple spans because of the basic arch function. Closed spandrel arches receive traffic loads through the fill material which is contained by spandrel walls (see Figure 9-17).

Figure 9-17 Typical Closed Spandrel Arch Bridge

A closed spandrel arch with no fill material has a hollow vault between the spandrel walls. This type of arch has a floor system similar to the open spandrel arch and should be inspected accordingly. This section deals only with filled closed spandrel arches.

Steel Reinforcement

The primary reinforcing steel in the arch ring follows the shape of the arch from support to support and consists of a mat of reinforcing steel on both the top and bottom surfaces of the arch. The inspector will be unable to inspect the top surface of the arch due to the backfill.

The spandrel walls are designed to retain the backfill material. The primary tension steel for the wall is usually at the back, or unexposed, face of the wall, hidden from view. The front, or outside, face of the wall is reinforced in both directions with temperature and shrinkage steel (see Figure 9-18).

Primary Members

For a closed spandrel arch, the primary members are the arch rings which support fill material, roadway, and traffic, and the spandrel walls which retain fill material and support the bridge parapets.

Inspection Procedures

Inspect a closed spandrel arch bridge using the following procedures:

- Examine the arch ring for sound concrete. Look for rust stains, cracks, discoloration, crushing, and deterioration of the concrete. The interface between the spandrel wall and the arch should be carefully inspected for spalls that could reduce the bearing area. Investigate the arch for transverse cracks, which indicate an overstress condition.

- Inspect the spandrel walls for sound concrete. Look for cracks, movement, and general deterioration of the concrete (see Figure 9-19).

- Investigate areas exposed to drainage and seepage for deteriorated and contaminated concrete.

- Make sure that weep holes are working properly.

- Check that surface water drains properly and does not penetrate the fill material.

- Inspect for areas of previous repairs.

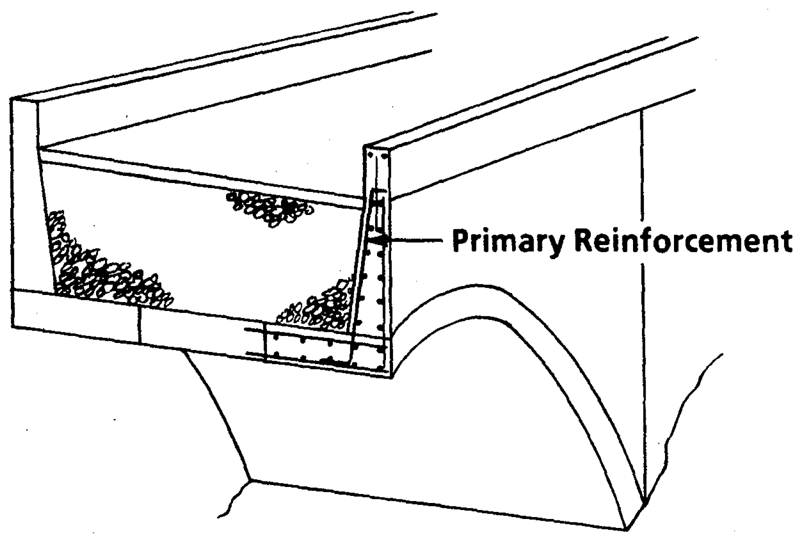


Figure 9-18 Reinforcement in a Closed Spandrel Arch

9.2.7 Rigid Frame

Design Characteristics

A concrete rigid frame structure is a bridge type in which the superstructure and substructure components are constructed as a single unit. Reinforced concrete rigid frame bridges are cast-in-place monolithic units (see Figure 9-20).

The rigid frame bridge can either be single span or multi-span. Single span frame bridges span up to 50 feet and are generally a slab beam design. Multi-span frame bridges are used for spans over 50 feet with slab or rectangular beam designs.

Steel Reinforcement

Rigid frame structures develop positive and negative moment throughout due to the interaction of the frame legs and frame beams. In slab beam frames, the primary reinforcement is tension steel.

For gravity and traffic loads on single span slab frames, the tension steel is placed longitudinally in the bottom of the frame slab, vertically in the front face of the frame legs, and longitudinally and vertically in the outside corners of the frame (see Figure 9-21).

Figure 9-19 Deteriorated Arch/Spandrel Wall Interface

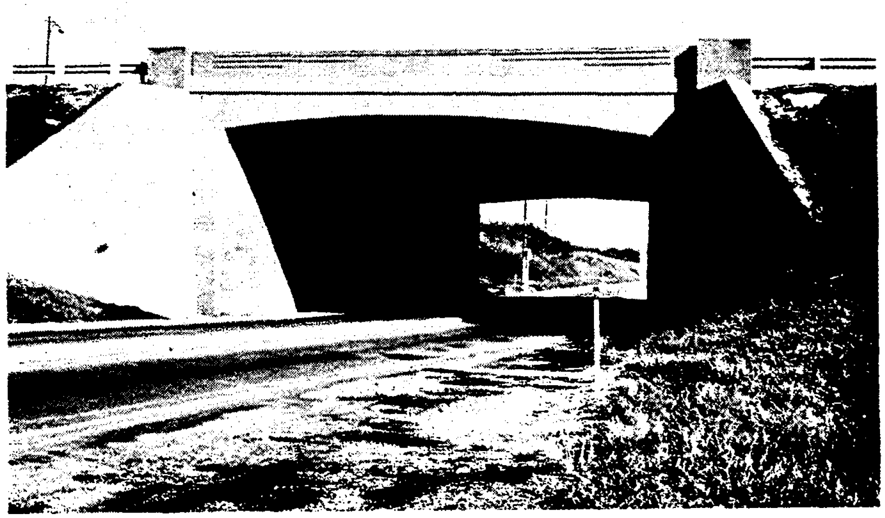


Figure 9-20 Typical Single Span Rigid Frame Bridge

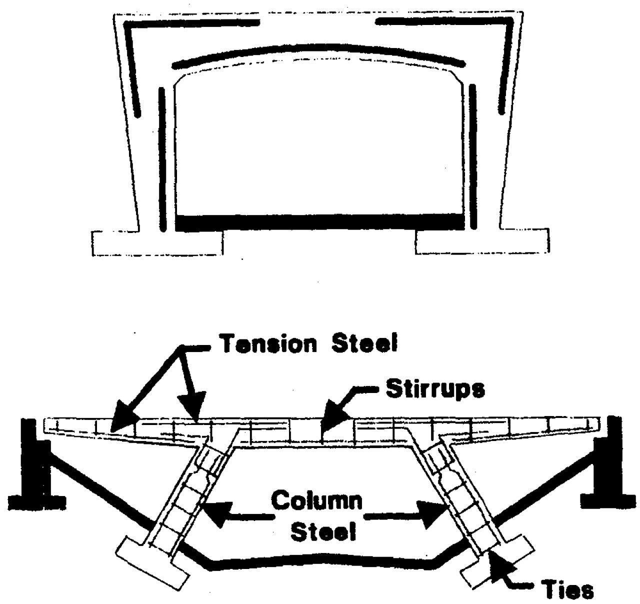


Figure 9-21 Reinforcement in Rigid Frames

For multi-span slab frames, the tension steel is placed longitudinally in the top and bottom of the frame slab and vertically in both faces of the frame legs.

In the beam portion of rectangular beam frames, the primary reinforcement is tension and shear steel, similar to continuous beam reinforcing. In the frame legs, the primary reinforcement is tension and shear steel near the top and compression steel with column ties for the remaining length.

Temperature and shrinkage reinforcement is also included in slab frames and in the beam portion of rectangular beam frames.

Primary Members

For single span frames, the superstructure is the primary member and is considered to be the slab portion above the "legs" of the frame. For multi-span frames, the primary members include the frame legs (the slanted beam portions which replace the piers) and the frame beams (the horizontal portion which is supported by the frame legs and abutments).

Inspection Procedures

Inspect a rigid frame bridge using the following procedures:

- Examine the bearing areas for spalling. Check the condition of the bearings, if present.

- Inspect the joint zones where the frame legs meet the frame beams. Look for shear cracks in the frame beams (beginning at the frame legs and propagating toward the adjacent span), in the frame legs (beginning at the top and propagating downward), and in the ends of the frame beams at the end spans.

- Investigate the tension areas for flexure cracks, rust stains, efflorescence, exposed and corroded reinforcement, and deteriorated concrete which would cause debonding of the tension reinforcement. The tension areas are located at the bottom of the frame beam at mid-span, the base of each frame leg (usually buried), the inside faces of the frame legs at mid-height, and the outside corners or the "knee" (the beam/leg interface) of single span slab frames (see Figure 9-22).

- Investigate the compression areas for spalling, scaling, and exposed reinforcement. The legs of a frame act primarily as columns with a moment applied at the top. Check the entire length of the frame legs for horizontal cracks which indicate buckling.

- Examine the areas exposed to drainage for deteriorated and contaminated concrete. Check the roadway surface of the slab beam frames for delamination and spalls. Look for leaks at construction and deck joints.

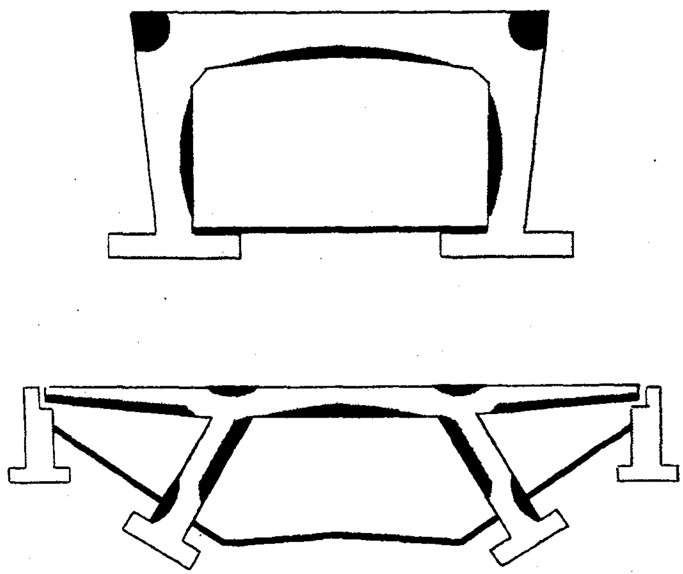


Figure 9-22 Tension Areas (Shown in Black) in Rigid Frames Due to Gravity Loads

9.3 Inspection of Prestressed Concrete Superstructures

Since the 1950's, the most common concrete bridges have been prestressed, in which the reinforcing steel consists of high strength tendons stressed before or after the concrete is placed.

Prestressed members are not designed for tensile stresses. If structural cracks are found on a prestressed member, it is a serious problem. Cracks in prestressed concrete structures can point to significant structural distress and need to be pointed out to the bridge engineer immediately.

Precast prestressed concrete I-girder bridges are usually designed with composite decks. Prestressed concrete bridges are made continuous for live load and superimposed dead load by the use of non-prestressed reinforcement in the deck slab and in the diaphragms over piers.

This section presents inspection guidelines for the most common types of prestressed concrete superstructures:

- Precast voided slab
- Prestressed box beams
- Prestressed I-beams and bulb-tees
- Box girders

9.3.1 Precast Voided Slab

Design Characteristics

The precast voided slab bridge is the modern replacement of the cast-in-place slab. This type of bridge is comprised of individual precast slab beams fabricated with circular voids. The voids afford economy of material and reduce dead load.

Precast slab units are used for spans of up to about 70 feet. The units are typically 36 or 48 inches wide and have a depth of 15, 18, 21, or 26 inches. They can be either pretensioned or posttensioned (see Figure 9-23). Adjacent slab units are posttensioned together with tie rods and grouted at the shear keys. This enables the slab units to act monolithically. Drain holes are placed strategically in the bottom of the slab to allow accumulated moisture to escape.

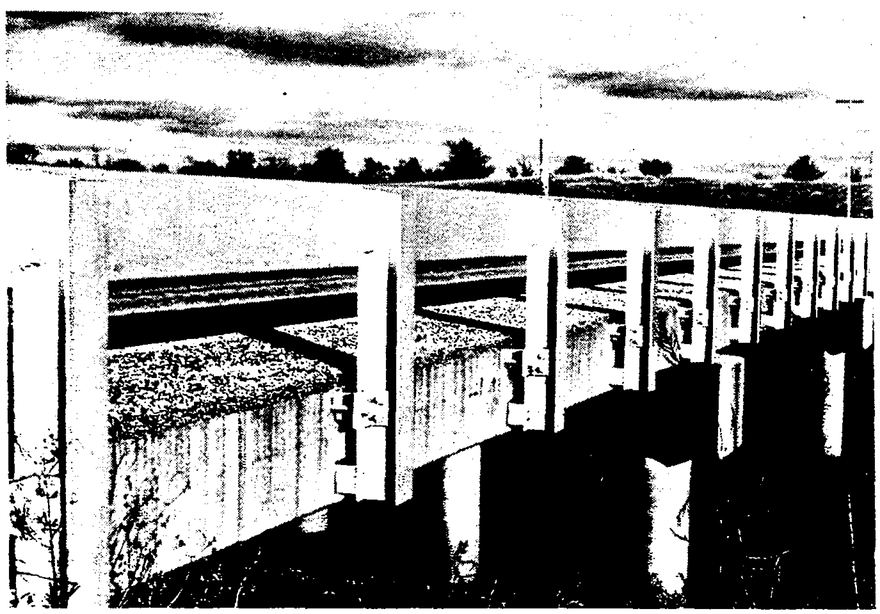


Figure 9-23 Typical Prestressed Slab Beam Bridge

Physical dimensions alone are not enough to distinguish a slab unit from a box beam. Design or construction plans need to be reviewed. A box beam has one rectangular void, bounded by a top slab, bottom slab, and two webs. A voided slab section has two or three circular voids through it. It is also possible to find precast solid slab units.

Steel Reinforcement

The prestressing strands are generally located in the bottom of the slab. Draped strands are often located in the webs. Depending on the age of the structure, the strand size will be 1/4, 3/8, 7/16, or 1/2 inch diameter. Strands are normally spaced 2 inches apart (see Figure 9-24).

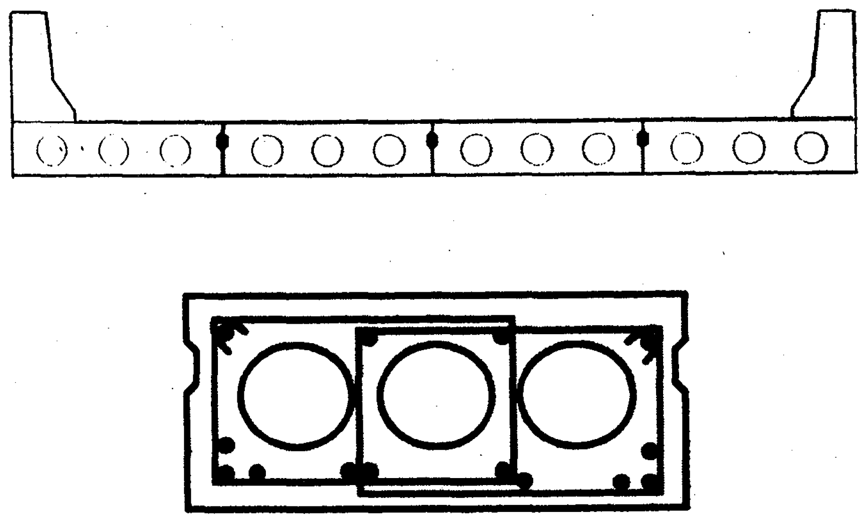


Figure 9-24 Prestressed Slab Beam Bridge Reinforcement

Primary Members

Each of the voided slab units is a primary member.

Inspection Procedures

Inspect a precast voided slab bridge using the following procedures:

- Examine the bearing areas for spalling concrete. End spalling can eventually lead to the loss of bond in the prestressing tendons.
- Inspect near the supports for diagonal or shear cracks.
- Check the bottom of the slab sections for flexure cracks. Since prestressed concrete is under high compressive forces, no cracks should be visible. Cracks can be a serious problem since they indicate overloading or loss of prestress. All cracks should be measured with an optical crack gauge.
- Examine the top of the slab sections (if exposed) near the ends for tensile cracks due to prestress eccentricity. This indicates excessive prestress force.

- Investigate for evidence of sagging, which indicates a loss of prestress.

- Inspect the slabs for exposed strands. Prestressed strands will corrode rapidly and fail abruptly. Therefore, any exposure is significant (see Figure 9-25).

- Inspect between the slab sections for leakage and for reflective cracking in the traffic surface. These problems indicate that the slab units are no longer tied together. Observe if there is individual slab beam deflection under live load.

- Investigate areas exposed to drainage for deteriorated and contaminated concrete.

- Check for collision damage.

- Examine areas of previous repairs.

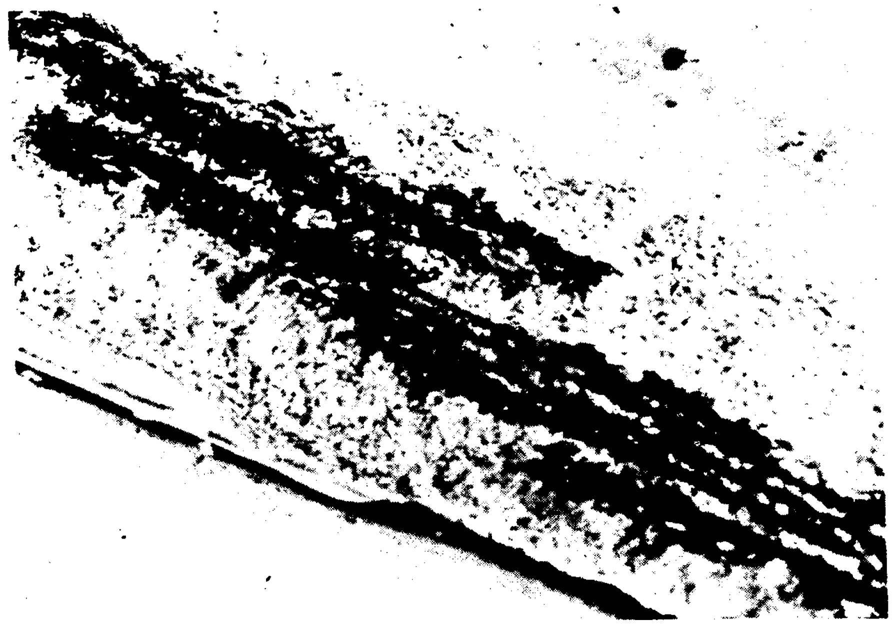


Figure 9-25 Exposed Strands in a Precast Slab Beam

9.3.2 Prestressed Box Beams

Design Characteristics

Prestressed box beams have become quite popular since the 1960's. They are constructed with a rectangular cross section with a single void inside. Many prestressed box beams constructed in the 1950's have single circular voids. The top and bottom slabs act as the flanges, while the side walls act as webs.

Prestressed box beams are typically either 36 or 48 inches wide. The depth of a box beam can be 12, 17, 21, 27, 33, 36, 42, 48, or 60 inches. Wall thicknesses range from 3 to 6 inches.

There are two applications of prestressed box beams (see Figure 9-26):

- Adjacent box beams
- Spread box beams

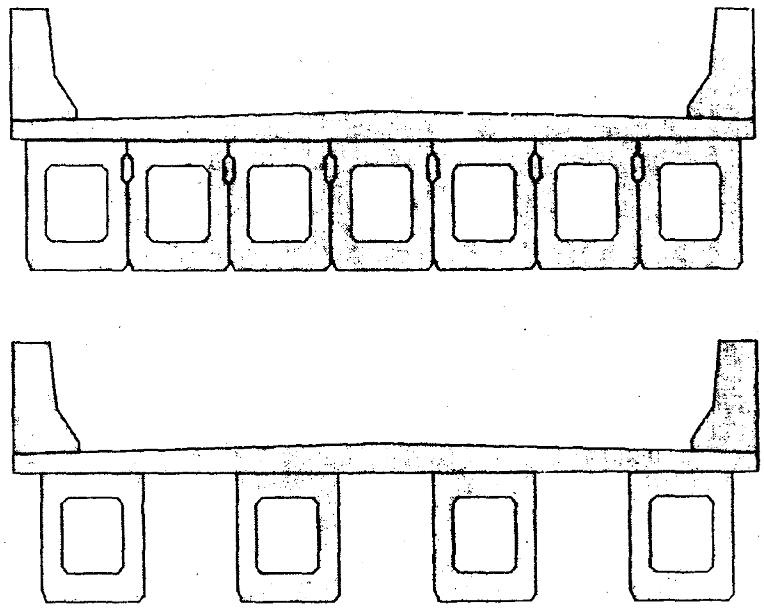


Figure 9-26 Applications of Prestressed Box Beams

Adjacent Box Beams

On an adjacent box beam bridge, the adjacent box beams are placed laterally side by side with no space between them. In some early applications, the top flange of each box is exposed and functions as the deck.

In modern applications, the deck is typically a cast-in-place composite concrete deck for longer spans and a nonstructural asphalt overlay on shorter spans.

This configuration of adjacent boxes is also called multiple boxes.

Like precast slab units, adjacent boxes are posttensioned together using tie rods and use grouted shear keys for monolithic action.

The practical span lengths range from 20 to 130 feet, with the most economical spans ranging from 40 to 90 feet.

All modern box beams have drain holes in the bottom to allow any moisture in the void to escape.

Spread Box Beams

On a spread box beam bridge, the box beams are spaced from 2 to 6 feet apart and typically use a composite cast-in-place concrete deck. This application is practical for span lengths from 25 to 85 feet.

Steel Reinforcement

The prestressing strands are located in the bottom flange and sometimes in the lower part of the web walls. Depending on the age of the structure, the strand size will be 1/4, 3/8, 7/16, or 1/2 inches in diameter. The strands are normally spaced 2 inches apart (see Figure 9-27). Mild steel stirrups are provided as shear reinforcement.

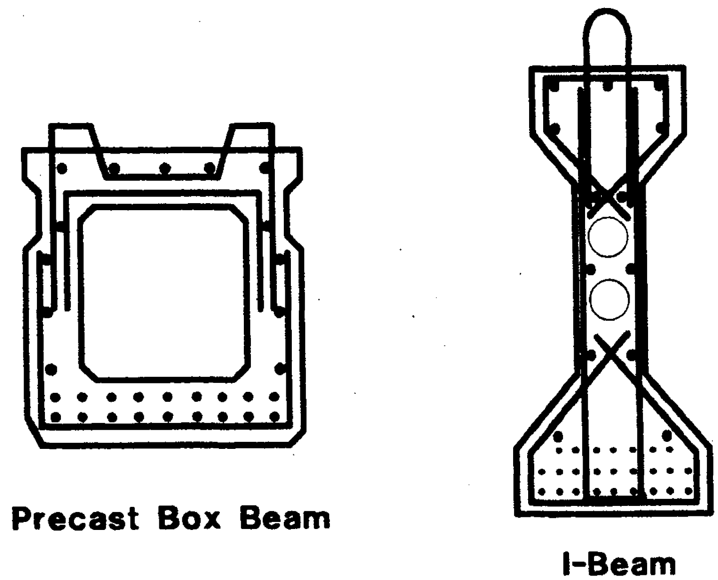


Figure 9-27 Reinforcement in Precast Box Beams and I-Beams

Primary Members

Each of the box beams is a primary member.

Secondary Members

External diaphragms are the only secondary members on box beam bridges, and they are only found on spread box beam bridges. The diaphragms may be cast-in-place, precast, or steel. They should be inspected as a beam.

Most box beams have internal diaphragms which provide rigidity, as well as tie rod bearing locations in adjacent box beam applications.

Inspection Procedures

Since prestressed box beams are designed to maintain all concrete in compression, cracks are indications of serious problems. For this reason, any crack should be carefully measured with an optical crack gauge and documented.

Inspect a prestressed box beam bridge using the following procedures:

- The top of the beam ends should be examined for horizontal or vertical cracks. These cracks indicate a deficiency of reinforcing steel. These cracks are caused by the stresses created at the transfer of the prestressing forces.

- Investigate the lower portion of the beam, particularly at mid-span, for flexure cracks. This indicates a very serious problem resulting from overloading or loss of prestress.

- Examine the sides of the beams for cracks. Adjacent box beam side surfaces are visible only on the fascias. For interior beams, inspect the bottom chamfers for cracks which may extend along the sides of the beams.

- Inspect beams near the supports for vertical cracks which may be caused by restricted movement by the bearing assemblies.

- Check the bottom of beams for parallel cracks that originate from the bearing location.

- Investigate the beam for any evidence of sagging. This indicates a loss of prestress.

- Inspect at the end of beams for shear cracks.

- Examine between boxes in adjacent box beam bridges for leakage. Look for reflective cracking in the traffic surface and individual beam deflection under live load. These problems indicate that the shear key between boxes has been broken and that the boxes are acting independently of each other (see Figure 9-28).

- Check areas damaged by collision. A significant amount of prestressed concrete bridge deterioration and loss of section is due to traffic damage. The loss of concrete due to such an accident is not always serious, but it can be, depending on the amount and location of the section loss (see Figure 9-29).

- Investigate underneath boxes for excessive deflection and misalignment. Movement of a bridge can be either catastrophic or of minor concern, depending on the amount and direction of the movement.

- On older bridges, verify that void drain holes are open.

Figure 9-28 Leaking Joints Between Adjacent Boxes

Figure 9-29 Collision Damage on a Prestressed Box Beam

9.3.3 Prestressed I-Beams and Bulb-Tees

Design Characteristics

Prestressed I-beams and bulb-tees make economical use of material since most of the concrete mass is located away from the neutral axis of the beam.

The most common prestressed concrete I-beam shapes are the AASHTO shapes used by most state highway agencies (see Figure 9-30). However, some highway agencies have developed variations of the AASHTO shapes to accommodate their particular needs.

Prestressed I-beams are used in spans ranging from 20 to 150 feet and are most economical in spans from 60 to 115 feet.

For increased economy in multi-span applications, prestressed I-beams are made continuous for live load (see Figure 9-31). This is achieved through a continuous composite action deck and the mechanical anchorage of mild steel reinforcement in a common end diaphragm. Posttensioning of prestressed beams may also be used for continuity. Cast-in-place concrete diaphragms are framed around the beams at the abutments and piers.

Figure 9-30 Type IV AASHTO Precast I-Beam

Figure 9-31 Continuous Prestressed I-Beam Bridge

Steel Reinforcement

Steel prestressing strands are placed symmetrically in the lower portion of the beam. Strands are 3/8, 7/16, or 1/2 inch in diameter and are generally spaced in a 2 inch grid (see Figure 9-27). Strands in the web may be draped or partially unbonded.

Primary Members

The primary members are the prestressed I-beams.

Secondary Members

The secondary members are the end diaphragms and the intermediate diaphragms.

End diaphragms are usually full depth and located at the abutments. Intermediate diaphragms are partial depth and are used within the span for longer spans.

Inspection Procedures

Inspect a prestressed I-beam bridge and a bulb-tee bridge using the following procedures:

- Examine the areas near the bearings and the cast-in-place end diaphragms for spalling concrete.
- Inspect the fixed diaphragms for diagonal cracking. This is a possible sign of shear failure caused by structure movement.
- Investigate the intermediate diaphragms for cracking and spalling concrete.
- Check beam flange surfaces for longitudinal cracks. This may indicate a deficiency of prestressing steel.
- Inspect the tension and shear zones of the beams for structural cracks (see Figure 9-32). Any crack should be carefully measured with an optical crack gauge and documented.
- Examine underneath the beams for alignment and camber of the prestressed beams. Signs of deflection usually indicates loss of prestress.
- Investigate the beams for any collision damage. This is a major cause of damage to prestressed I-beams.
- Examine thoroughly any repairs that have been made previously. Determine if the repaired areas are functioning properly. Effective repairs and patching are usually limited to protection of exposed tendons and reinforcement.

9.3.4
Box Girders

Design Characteristics

The box girder bridge is the current state-of-the-art bridge type for concrete. Using a trapezoidal box shape with cantilevered top flange extensions, a single box girder can accommodate an entire roadway width. Designs are common, although not yet standardized, for both segmental and monolithic box girder construction. In addition, reinforced concrete (mild steel reinforcement) box girder bridges were once commonly constructed for short spans, and many of those bridges still exist today.

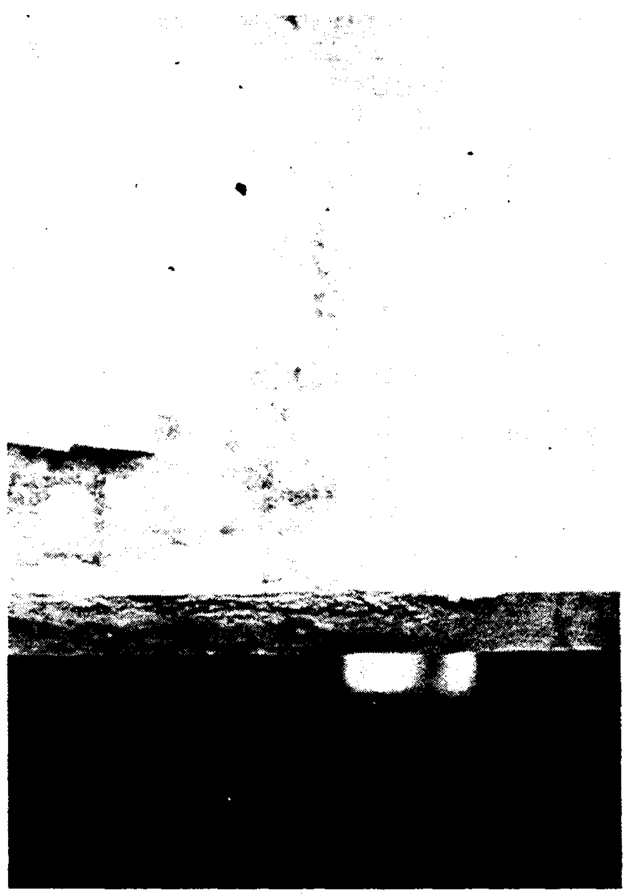


Figure 9-32 Crack in Prestressed I-Beam

For wide roadways, the box portion generally has internal webs and is referred to as a multi-cell box girder. Concrete box girder bridges are typically either single span or continuous multi-span structures. Spans can have a straight or curved alignment and are generally in excess of 150 feet (see Figure 9-33).

The following description applies to monolithic box girder construction only. For a detailed description of segmental concrete bridges, refer to Section 21.4.

Steel Reinforcement

Box girder structures use a combination of mild steel reinforcement and high strength post tensioning steel tendons (see Figure 9-34). Shear reinforcement is provided to resist standard beam action shear. For curved girder applications, torsional shear reinforcement is sometimes required. This reinforcement is provided in the form of additional stirrups.

Flexure reinforcement is provided in the top and bottom flanges of the box girder as necessary. However, because of the design span lengths, mild steel reinforcement does not have sufficient strength to resist all of the tension forces.

To reduce these tensile stresses to acceptable levels, prestressing of the concrete is introduced through posttensioning. Galvanized metal ducts are placed in the forms at the desired location of the tendons. When the concrete has cured to an acceptable strength level, the tendons are installed in the ducts, tensioned, and then grouted (see Figure 9-35).

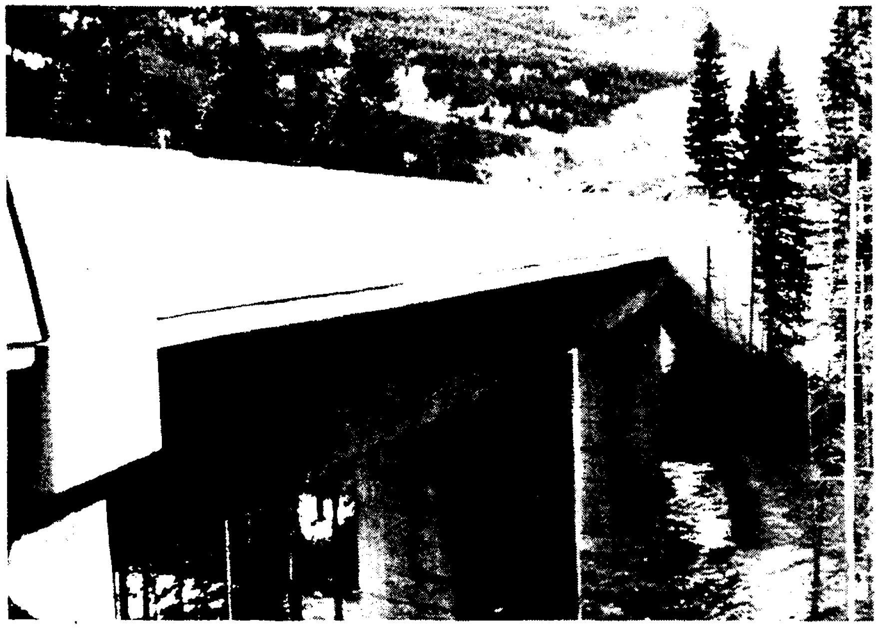


Figure 9-33 Typical Cast-in-Place Concrete Box Girder Bridge

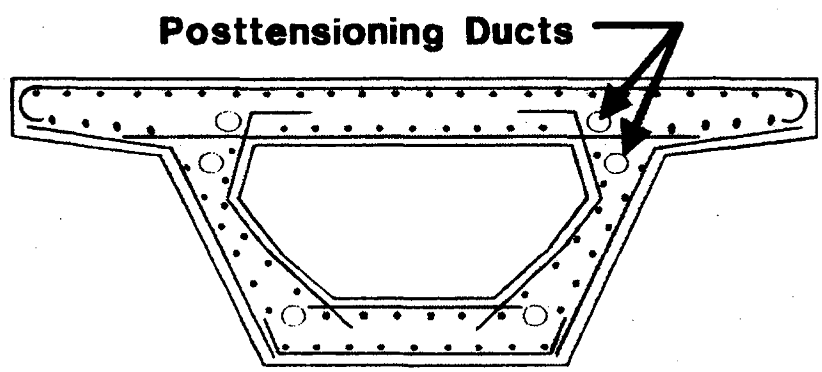


Figure 9-34 Longitudinal Reinforcement in a Concrete Box Girder

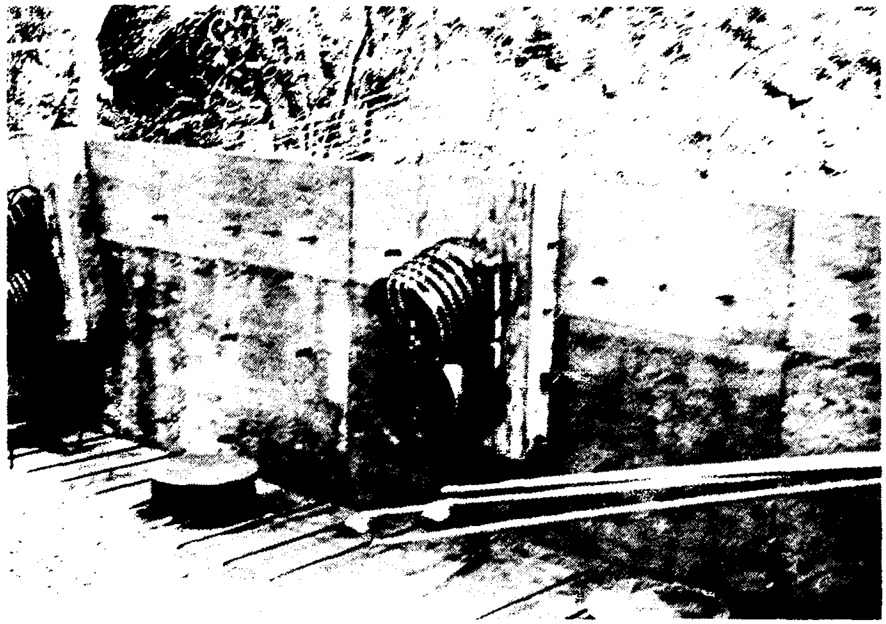


Figure 9-35 Formwork with Posttensioning Ducts Located

Construction Techniques

There are four basic construction techniques used for cast-in-place monolithic box girders:

- High level casting
- At-grade casting
- Cantilever construction
- Traveling self-supporting formwork

The high level casting method employs formwork supported by falsework. This technique is used when the structure must cross an existing feature, such as a roadway, railway, or waterway (see Figures 9-36 and 9-37).

The at-grade casting method employs formwork supported by fill material or the existing ground. When the construction is complete, the fill beneath the bridge is removed. This technique is used when the structure is crossing or part of a new highway system or interchange (see Figures 9-38 and 9-39).

The cantilever construction method consists of building the superstructure by a succession of segments with each segment carrying the weight of the next segment. In balanced construction, the segments are cantilevered from both sides of a supporting pier. This technique is used when the height of the superstructure precludes the use of falsework.

The traveling self-supporting formwork method uses an incremental launching approach. This technique is also used when falsework is not viable.

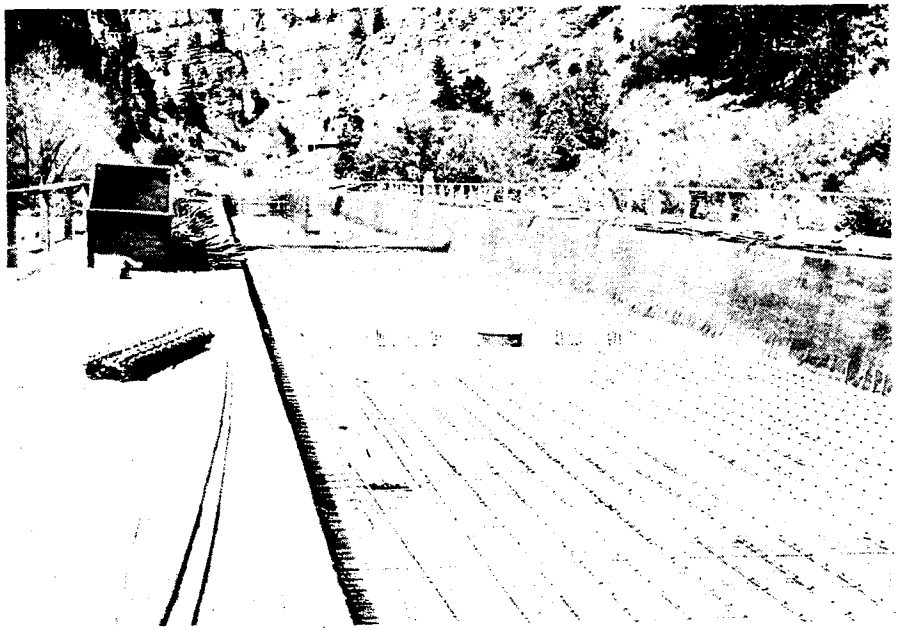


Figure 9-36 High Level Formwork

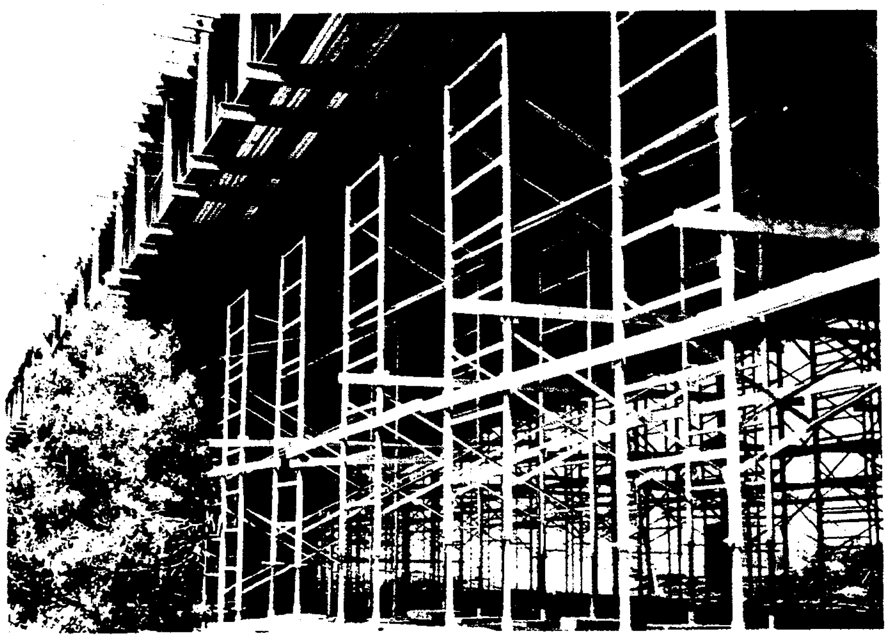


Figure 9-37 High Level Formwork Support Scaffolding

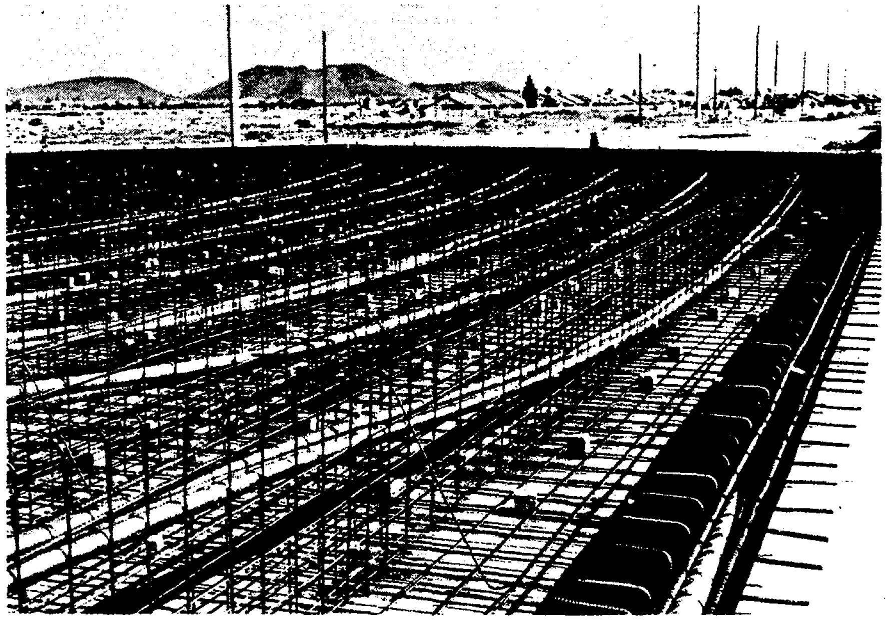


Figure 9-38 At-Grade Formwork With Posttensioning Ducts

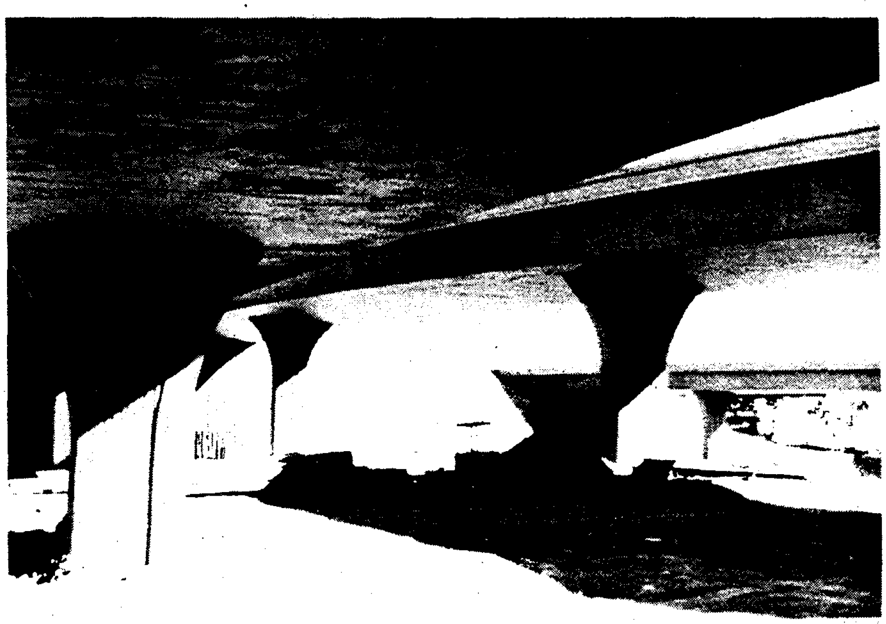


Figure 9-39 Box Girder Bridge Constructed Using At-Grade Forming

Primary Members

For box girder structures, the primary member is the box girder. When a single cell box girder design is used, the top flange or deck slab, the bottom flange, and both side walls are all primary elements of the box girder. The top flange is considered an integral deck component.

In some multi-cell box girder applications, the top flange or deck slab must be removable for future replacement. The top flange in these cases functions similarly to a composite deck slab and is in fact considered a separate deck component. Most exterior webs have higher stress levels than interior webs, but the interior webs of the box also play a significant role in the girder (see Figure 9-40).

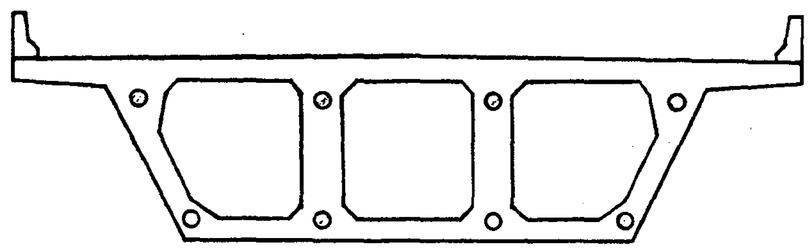


Figure 9-40 Multi-Cell Box Girder

Inspection Procedures

The inspection of a box girder bridge requires a clear understanding of the girder function. This requires a thorough review of design or as-built drawings prior to the inspection and a realization of the high stress regions peculiar to a particular structure.

In general, inspect a box girder bridge using the following procedures:

- Examine the girder for any delaminations, spalling, or scaling which may lead to exposure of reinforcing steel. Areas exposed to drainage should receive special attention.
- Check the bearing areas and the bearings for proper movement and movement capability.
- Inspect the girder for the proper camber by sighting along the fascia of the top flange.

- On curved box girders, check for irregularities in the superelevation of the top flange which could indicate torsional distress.

- Inspect the top side of the top flange for longitudinal flexure cracking directly over interior and exterior girder walls.

- Inside the box, examine the bottom of the top flange for longitudinal flexure cracking between the girder walls. Any efflorescence or leakage through the top flange should be documented.

- The girder should be inspected throughout for flexure and shear cracks as well as prestress-induced cracks. Some shrinkage cracks are to be expected. Likewise, although posttensioned, some small working cracks will be present. As with all prestressed concrete members, any cracks should be carefully measured with an optical crack gauge and its location, length, and width documented.

For a more complete discussion of box girder cracking and causes, refer to the inspection procedures for segmental concrete bridges in Section 21.4.

9.4 Evaluation of Concrete Superstructures

9.4.1 Overall Condition

Superstructure Elements

The inspector should evaluate each element of the superstructure and assign to it a condition rating. Many states use various numerical rating systems for documenting the condition of individual bridge elements. A descriptive rating system of "good," "fair," or "poor" can also be used to document the deficiencies found on the individual elements. For example, each beam or member would receive either a "good," "fair," or "poor" rating. These ratings are defined as follows:

- Good - Element is limited to only minor problems.

- Fair - Structural capacity of the element is not affected by minor deterioration, section loss, spallings, cracking, collision damage, or other deficiency.

- Poor - Structural capacity of element is affected or jeopardized by advanced deterioration, section loss, spalling, cracking, collision damage, or other deficiency.

Since the condition rating is a function of structural capacity, considerable training and experience are needed to make this assessment.

In addition to identifying and recording the condition of each element, the inspector's notes should also explain the type, quantity, and severity for each particular deficiency. The result will be a complete evaluation of all superstructure elements and will provide a comprehensive inspection.

Superstructure Component

While each element of the superstructure must be evaluated, the superstructure component as a whole receives a numerical condition rating. Therefore, the conditions identified for each element must be considered to establish the superstructure condition rating. The overall condition rating of the superstructure can be determined based on either a quantitative evaluation or a qualitative evaluation.

Quantitative Evaluation

A quantitative evaluation is based on the quantity, or number, of elements exhibiting a particular deficiency.

Qualitative Evaluation

A qualitative evaluation is based on the "weak-link" principle, which assesses the severity of a deficiency occurring on an individual element. The "weak-link" principle is limited to situations in which element defects may result in a reduction in load-carrying capacity of the bridge.

The inspector should not attempt to assign numerical ratings to individual elements for the purpose of using the average as the overall superstructure condition rating.

9.4.2 Load Capacity

A bridge's design capacity will not be used in the determination of the condition rating. The fact that a bridge was designed for less than the current legal loads, and may even be posted, shall have no influence on the condition rating.

The inspector should recognize, however, that the severity of a deficiency on a primary member is evaluated by how much that deficiency affects the load capacity of the members.

9.4.3 Condition Rating

The actual condition rating number assigned to the superstructure component should be selected based on the actual field condition as compared to its original as-built condition.

The appropriate numerical rating will be a combination of the inspector's opinion about the component and the proper application of the coding guidelines contained in the Federal Highway Administration (FHWA) *Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges*.

10

Inspection and Evaluation of Common Steel Superstructures

Standard Designations for Structural Steel for Bridges			
	American Society for Testing and Materials (ASTM) Designation	American Association of State Highway and Transportation Officials (AASHTO) Designation	Years in Use[1]
Structural Carbon Steel	A7	M94	1900-1967
Structural Nickel Steel	A8	M96	1912-1962
Structural Steel	A36 (A709 Grade 36)	M183 (M270 Grade 36)	1960-Present (1974-Present)
Structural Silicon Steel	A94	M95	1925-1965
Structural Steel	A140		1932-1933
Structural Rivet Steel	A141	M97	1932-1966
High-Strength Structural Rivet Steel	A195	M98	1936-1966
High-Strength Low-Alloy Structural Steel	A242	M161	1941-Present
Low and Intermediate Tensile Strength Carbon Steel Plates	A283		1946-Present
Low and Intermediate Tensile Strength Carbon-Silicon Steel Plates	A284		1946-Present
Steel Sheet Piling	A328	M202	1950-Present
Structural Steel for Welding	A373	M165	1954-1965
High-Strength Structural Steel	A440	M187	1959-1979
High-Strength Low-Alloy Structural Manganese Vanadium Steel	A441	M188	1954-1989
High-Yield-Strength, Quenched and Tempered Alloy Steel Plate, Suitable for Welding	A514 (A709 Grade 100/100W)	M244 (M270 Grade 100/100W)	1964-Present (1974-Present)
High-Strength Low-Alloy Columbium-Vanadium Steel of Structural Quality	A572 (A709 Grade 50)	M223 (M270 Grade 50)	1966-Present (1974-Present)
High-Strength Low-Alloy Structural Steel with 50 ksi Minimum Yield Point to 4 inches Thick	A588 (A709 Grade 50W)	M222 (M270 Grade 50W)	1968-Present (1974-Present)
High-Strength Low-Alloy Steel H-Piles and Sheet Piling	A690		1974-Present
Quenched and Tempered Low-Alloy Structural Steel Plate with 70 ksi Minimum Yield Strength to 4 inches Thick	A852 (A709 Grade 70W)	(M270 Grade 70W)	1985-Present (1985-Present)

[1]Based on Publication of ASTM Designation

10

Inspection and Evaluation of Common Steel Superstructures

10.1 Introduction

Steel is one of the most common materials used in superstructures. There are many different types of steel superstructures, including:

- Rolled multi-beams
- Fabricated multi-girders
- Two-girders
- Through girders
- Box girders
- Trusses
- Deck arches
- Through arches
- Tied arches
- Rigid frames

The most common defects encountered in steel superstructures include corrosion, fatigue cracking due to out-of-plane distortion, collision damage, overload damage, and heat damage. Refer to Section 4.4 for a more detailed description of the properties of steel, the types and causes of steel deterioration, and the examination of steel members.

This chapter presents the design characteristics for each of the major types of steel superstructures, including the primary and secondary members of each type. It describes the inspection locations and procedures for each type, with special attention being given to shear zones, flexure zones, secondary members, areas exposed to traffic, and fatigue prone details including those that are subject to out-of-plane distortion. It also addresses the fracture critical nature of some steel superstructure types.

For a description of advanced inspection techniques for steel bridges, refer to Section 15.4. For a description of protective systems for steel bridges, refer to Section 16.4. For definitions concerning bridge redundancy and basic principles for the inspection of fracture critical members, refer to Chapter 18.

Cracks and fractures have occurred in a large number of steel bridges. A report, *Manual for Inspecting Bridges for Fatigue Damage Conditions*, was prepared in 1990 under the support of the Pennsylvania Department of Transportation and the Federal Highway Administration to aid in the inspection of bridges. It summarizes the basic information on fatigue strength of bridge details and contains examples and illustrations of fatigue damage in welded, bolted, and riveted structures. A number of case histories are contained in *Fatigue and Fracture in Steel Bridges - Case Studies*, by John W. Fisher. *Fatigue Cracking of Steel Bridge Structures*, published by the Federal Highway Administration (FHWA) in March 1990, also contains valuable case studies of actual bridges. These three publications are listed in the Bibliography.

10.2 Rolled Multi-Beams

10.2.1 Design Characteristics

The steel rolled multi-beam bridge is a configuration of three or more parallel rolled beams with a deck placed on top of the beams. The most common use of this superstructure type is for simple spans, with span lengths from 30 to 50 feet (see Figure 10-1). Continuous span designs have also been used, some of which incorporate pin and hanger connections. Rolled beams are manufactured in structural rolling mills from one piece of steel (i.e., the flanges and web are manufactured as an integral unit). Rolled beams are generally no larger than 36 inches in depth.

Figure 10-1 Simple Span Rolled Multi-Beam Bridge

In the past, a common method of economically increasing the capacity of a rolled multi-beam bridge was to weld cover plates to the flanges. This increased the beam's bending strength. However, this practice also created a fatigue prone detail in the tension flange which may lead to cracking. The cover plates were fabricated and attached by riveting or welding. Welded cover plates can cause serious fatigue cracking.

The primary members of a rolled multi-beam bridge are the rolled beams, and the secondary members are the diaphragms. Diaphragms are provided to stabilize the beams during construction of the deck and to help distribute the live load. Diaphragms may or may not be present on the bridge.

10.2.2 Inspection Locations and Procedures

Shear Zones

Examine the web areas near the supports for any section loss (see Figure 10-2). Shear stresses are greatest near the supports, while bending stresses are least near the supports (except for continuous structures). Therefore, the condition of the web is more critical near the ends than at mid-span. Also investigate the web for crippling due to overloads.

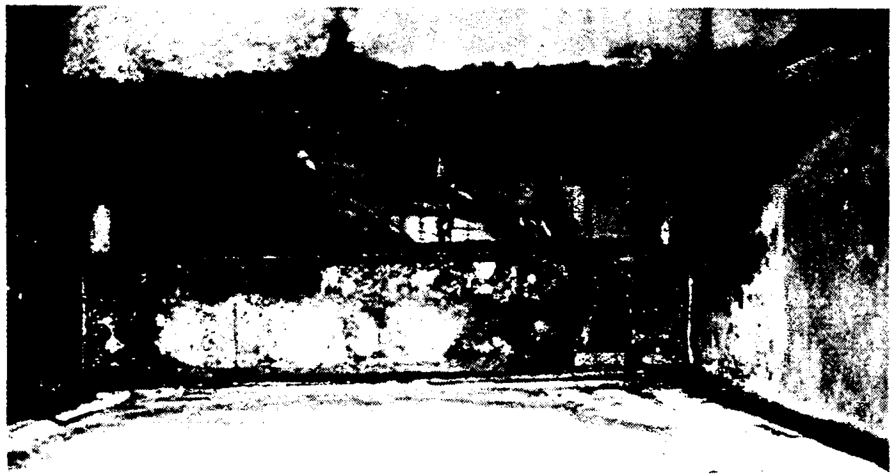


Figure 10-2 Corroded Shear Zone on a Rolled Multi-Beam Bridge

Flexure Zones

The flexure zone of each beam includes the entire length between the supports. Check the tension and compression flanges for corrosion and loss of section. Inspect the flanges in high stress areas for bending or flexure-related damage caused by live loads. Investigate the compression flange for local buckling and, although it is uncommon, for elongation or fracture of the tension flange. On continuous spans, the beams over the intermediate supports have high flexural stresses due to negative moment. Stresses are reversed in the region over the intermediate supports, and the top flange is in tension (refer to Section 3.4.2 and see Figure 3-8).

Secondary Members

Examine the diaphragm connections for loose fasteners or cracked welds. This problem is most common on skewed bridges. Check horizontal connection plates which can trap debris and moisture and are susceptible to a high degree of corrosion and deterioration.

Areas Exposed to Traffic

Inspect any beams that may have been damaged due to collision very closely. Loss of section, cracking, and any shape distortion should be carefully documented.

Fatigue Prone Details

Dirt and debris traps can result in active corrosion cells when water and salt are present. These corrosion cells can lead to excessive section loss. This can result in notches which are susceptible to fatigue or perforation.

If the structure has been painted, breaks in the paint accompanied by rust staining indicate the possible existence of a fatigue crack. Investigate the areas surrounding the ends of welded cover plates on the tension flange. The suspected crack area should be cleaned to determine the existence of a crack and its extent. If a crack with rust staining exists in the paint, the fatigue cracks in the steel can already be up to 1/4 inch deep in the beam flange. Check any attachment welds located in the tension zone of the beam.

Fracture Critical Members

A rolled multi-beam bridge has load path redundancy, and it therefore has no fracture critical members.

10.3 Fabricated Multi-Girders

10.3.1 Design Characteristics

The steel fabricated multi-girder bridge is similar to the rolled multi-beam bridge in appearance. However, fabricated girders are larger than those that could be provided by the rolling mills. Older fabricated multi-girders were riveted built-up members. Today's fabricated multi-beams are usually welded members.

The word "beam" is sometimes used in reference to this bridge type. However, in steel fabrication, the word "beam" refers to rolled shapes, while the word "girder" refers to fabricated members.

As fabricated girders become larger, the web plate depth increases, and it becomes susceptible to web buckling (i.e., failure of the web due to compressive stress). Bridge designers prevent this from occurring by increasing the web thickness or by reinforcing the web with steel stiffener plates. Stiffeners can be either transverse (vertical) or longitudinal (horizontal) (see Figure 10-3). They can be placed on one or both sides of the web.

This bridge type can be found in single span, multiple span, and continuous span designs, and it is widely used when curved bridges are required. Continuous welded multi-girders can have spans of over 500 feet. Like the rolled multi-beam bridge, this bridge type often incorporates composite action. Pin and hanger connections are also common.

For larger fabricated multi-girder bridges, the girders are frequently haunched at the intermediate supports, where additional flexural strength is required (see Figure 10-3).

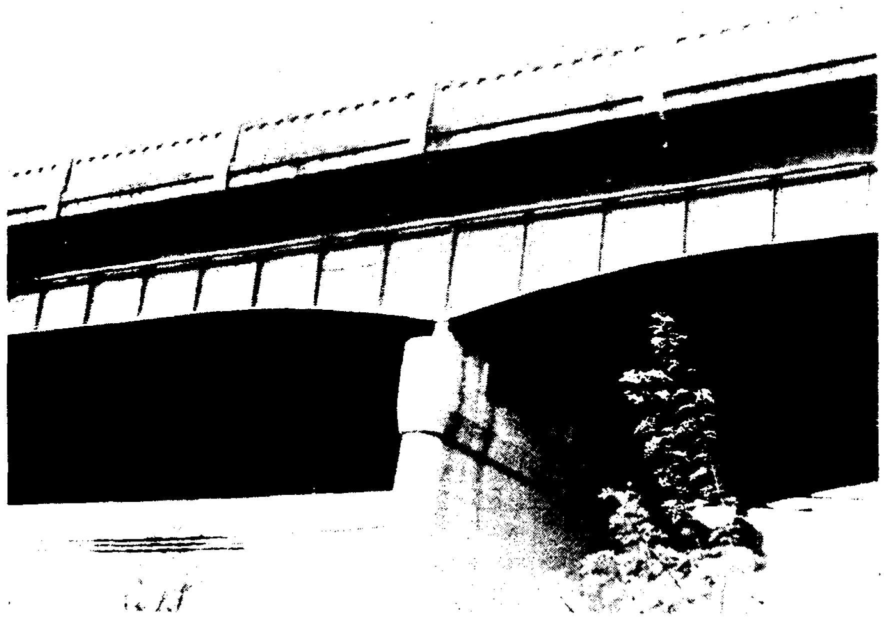


Figure 10-3 Web Stiffeners on a Fabricated Multi-Girder Bridge

The primary members of a fabricated multi-girder bridge are the fabricated girders, as well as the diaphragms on a curved bridge. In the case of a curved structure, the diaphragms are designed to withstand the torsional loading attributed to curved structures.

On straight bridges, the secondary members are the diaphragms, which are provided to stabilize the girders during construction of the deck and to help distribute live load. Diaphragms can be rolled shapes (e.g., I-beams and channels) or they can be cross frames constructed from angles, tee shapes, and plates. They are usually attached to transverse web stiffeners. On older bridges, secondary members also include lateral bracing, but design specifications no longer require this feature.

10.3.2 Inspection Locations and Procedures

Shear Zones

Examine the web areas near the supports for any section loss and buckling. Shear stresses are greatest near the supports, while bending stresses are least near the supports (except for continuous structures). Therefore, the condition of the web is more critical near the supports than at mid-span. Also inspect for web crippling due to overloads.

Flexure Zones

The flexure zone of each girder includes the entire length between the supports. Investigate the tension and compression flanges for corrosion and loss of section. Check the flanges in high stress areas for bending or flexure-related damage caused by live loads. Examine the compression flange for local buckling and, although it is uncommon, for elongation or fracture of the tension flange. On continuous spans, the beams over the intermediate supports have high flexural stresses due to negative moment. Stresses are reversed in the region over the intermediate supports, and the top flange is in tension (refer to Section 3.4.2 and see Figure 3-8).

Secondary Members

Examine the diaphragm and bracing connections for loose fasteners or cracked welds. This problem is most common on skewed bridges, and it has also been observed on bridges with a high frequency of combination truck loads. Check horizontal connection plates which can trap debris and moisture and are susceptible to a high degree of corrosion and deterioration.

Areas Exposed to Traffic

Inspect any members that may have been damaged due to collision very closely. Loss of section, cracking, and any shape distortion should be carefully documented.

Fatigue Prone Details

Dirt and debris traps can result in active corrosion cells when water and salt are present. These corrosion cells can lead to excessive section loss. This can result in notches which are susceptible to fatigue or perforation.

If the structure has been painted, breaks in the paint accompanied by rust staining in possible tension zones indicate the possible existence of a fatigue crack. The suspected crack area should be cleaned to determine the existence of a crack and its extent. If a crack with rust staining exists in the paint, the fatigue cracks in the steel can already be up to 1/4 inch deep in the beam flange. Examine any attachment welds located in the tension zone of the beam. Also check web stiffener welds, welded flange splices, and intersecting welds (see Figure 10-4).

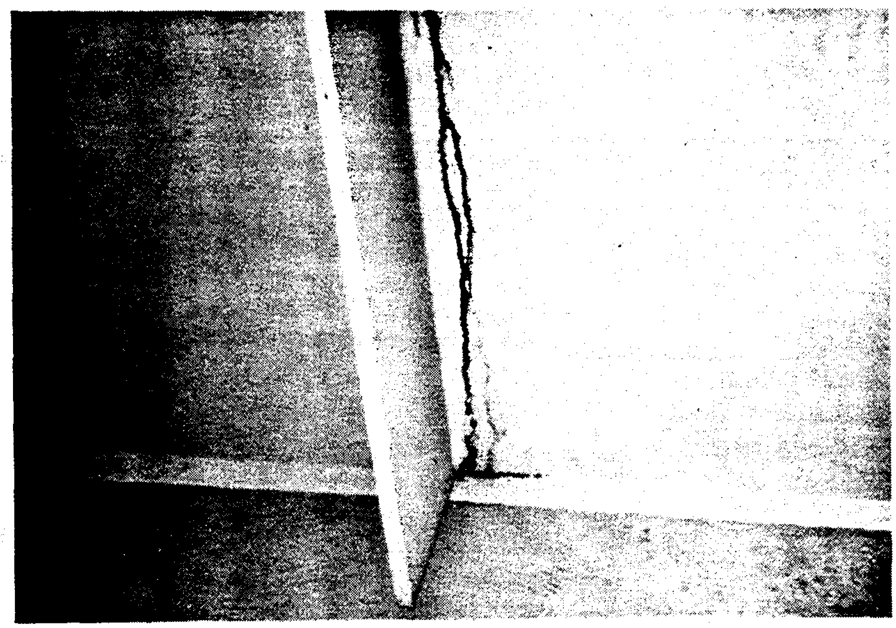


Figure 10-4 Fatigue Crack at Toe of Weld on a Fabricated Multi-Girder Bridge

Check for fatigue cracks due to web-gap distortion. This is the major source of cracking in steel bridges. However, it is not directly related to the categories of details cited in Reference 58.

Out-of-Plane Distortion

Out-of-plane distortion can occur in the girder web at diaphragm connections. This has caused web cracks near the flanges of steel bridges (see Figure 4-26).

Fracture Critical Members

A fabricated multi-girder bridge has load path redundancy, and it therefore has no fracture critical members.

10.4 Two-Girders

10.4.1 Design Characteristics

The steel two-girder bridge, like the fabricated multi-girder bridge, can use either riveted or welded construction. Two-girder bridges can also have features similar to those of fabricated multi-girder bridges, such as web insert plates, transverse web stiffeners, and longitudinal web stiffeners.

However, unlike the fabricated multi-girder bridge, the two-girder bridge has a floor system of smaller girders and beams that support the deck between the two main girders. The deck, therefore, rests on the top flanges of the girders and floor system.

Two-girders can be found in simple span and continuous span configurations. They can also be found on curved bridges, and pin and hanger connections are common details with this bridge type.

There are two types of floor systems found on two-girder bridges:

- Girder-floorbeam system
- Girder-floorbeam-stringer system

The girder-floorbeam (GF) system consists of floorbeams connected to the main girders. The floorbeams are considerably smaller than the girders and are perpendicular to traffic. The deck is supported by the floorbeams, which in turn transmit the loads to the main girders. The floorbeams can be either rolled beams, fabricated girders, or fabricated cross frames.

The girder-floorbeam-stringer (GFS) system consists of floorbeams connected to the main girders, and longitudinal stringers, parallel to the main girders, connected to the floorbeams (see Figure 10-5). The stringers may either connect to the web of the floorbeams or be stacked on top of the floorbeams, in which case they may be continuous stringers. Stringers are usually rolled beams and are considerably smaller than the floorbeams. It is also possible to find floorbeams which are stacked on top of the main girders, and the floorbeams may extend or overhang from the girders.

The primary members of a two-girder bridge are the girders, floorbeams, and stringers, if present. The secondary members are the lateral bracing members. These usually consist of angles or tee shapes placed diagonally in horizontal planes between the two main girders. The lateral bracing is generally in the plane of the bottom flange. Lateral bracing serves to minimize any differential movement between the two girders.

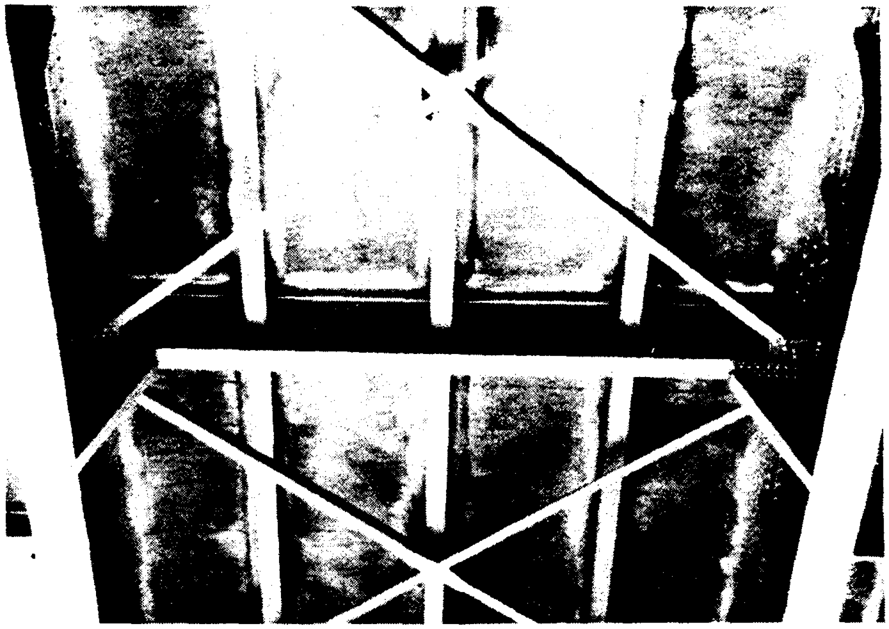


Figure 10-5 Two-Girder Bridge With a Girder-Floorbeam-Stringer System

10.4.2 Inspection Locations and Procedures

Shear Zones

Examine the web areas of the girders, floorbeams, and stringers near their supports for corrosion and buckling.

Flexure Zones

Check the tension and compression flanges for corrosion and section loss. Also, inspect the flange in high stress areas for bending or flexure-related damage caused by live loads. Check in both the positive and negative moment regions.

Secondary Members

Investigate the connection areas of the lateral bracing for cracked welds, fatigue cracks, and loose fasteners. Also inspect for distortion in the bracing members. Check horizontal connection plates which can trap debris and moisture and are susceptible to a high degree of corrosion and deterioration.

Areas Exposed to Traffic

Investigate the girders for collision damage if the bridge crosses over a highway, railway, or navigable channel. Document any cracks, section loss, or distortion found.

Fatigue Prone Details

Dirt and debris traps can result in active corrosion cells when water and salt are present. These corrosion cells can lead to excessive section loss. This can result in notches which are susceptible to fatigue or perforation.

Check web stiffener welds, welded flange splices, and intersecting welds. Also inspect any attachment welds located in the tension zone of the girder and floorbeam bracket tie plate.

Check for fatigue cracks due to web-gap distortion. This is the major source of cracking in steel bridges. However, it is not directly related to the categories of details cited in Reference 58.

Pin and Hanger Connections

Pin and hanger connections, when used in suspended span configurations in nonredundant two-girder bridges, are fracture critical (see Figure 10-6). They also occur in cantilevered span arrangements on continuous span structures. This type of connection warrants particular attention. Corrosion can cause fixity at pin and hanger connections. This changes the structural behavior of the connection and is a source of cracking.

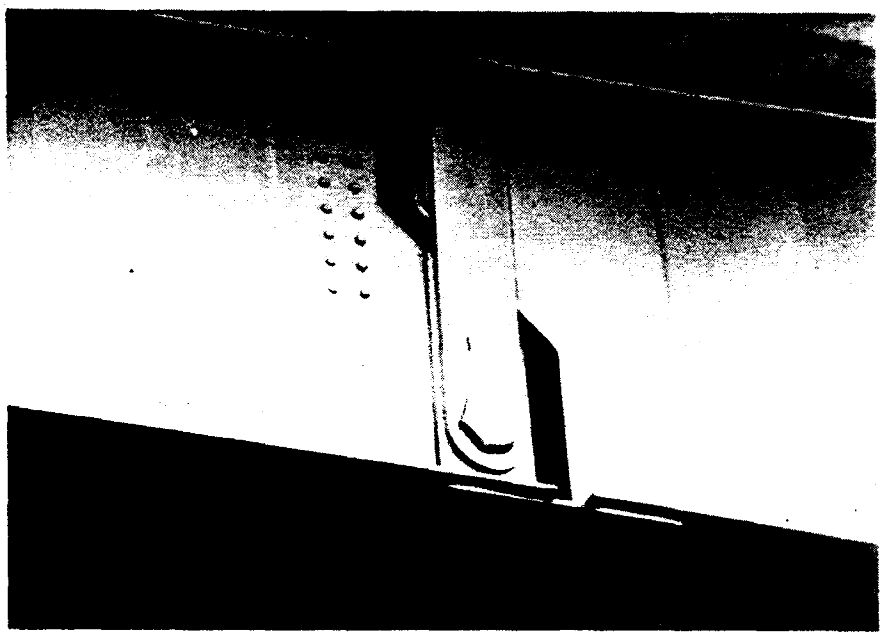


Figure 10-6 Two-Girder Bridge With a Pin and Hanger Connection

Due to the rotation of the pins and hangers under live load and thermal expansion, they tend to incur wear over a period of time. Since the pin is covered by the hanger plate, it is not normally painted by maintenance crews and will, with time, begin corroding. This type of connection may be exposed to the elements and the spray of passing traffic. It may also be directly underneath an expansion dam where water and brine solutions may collect. This moist, corrosion-causing solution will slowly dry out, only to be reactivated during the next wet cycle.

The hanger plate is as critical as the pin in a pin and hanger connection. It is, however, easier to inspect since it is exposed and readily accessible. Try to determine whether the hanger-pin connection is frozen, as this can induce large moments in the hanger plates.

Examine both sides of the plate for cracks due to bending of the plate from a frozen pin connection. Observe the amount of corrosion buildup between the webs of the girders and the back faces of the plates. Inspect the hanger plate for bowing or out-of-plane distortion from the webs of the girders. Any welds should be investigated for cracks. If the plate is bowed, check carefully at the point of maximum bow for cracks which might be indicated by a broken paint film and corrosion.

Rarely is the pin directly exposed in a pin and hanger connection. As a result, its inspection is difficult but not impossible. By carefully taking certain measurements, the apparent wear can be determined. If more than 1/8 inch net section loss has occurred, it should be brought to the attention of the bridge engineer in charge of that structure at once. In a girder pin and hanger, wear to the pins and hangers will generally occur in two locations: at the top of the pin and top of the hanger on the cantilevered span and at the bottom of the pin and the bottom of the hanger on the suspended span. Sometimes wear, loss of section, or lateral slippage may be indicated by misalignment of the deck expansion joints or surface over the hanger connection. When inspecting a girder pin and hanger, locate the center of the pin, measure the distance between the center of the pin and the end of the hanger, and compare to the plan dimensions, if available. Remember to allow for any tolerances since the pin was not machined to fit the hole exactly. Generally, this tolerance will be 1/32 inch. If plans are not available, compare to previous measurements. The reduction in this length will be the apparent wear on the pin.

In a fixed pin and girder, wear will generally be on the top surface of the pin due to rotation from live load deflection and attractive forces. Locate the center of the pin, and measure the distance between the center of the pin and some convenient fixed point, usually the bottom of the top flange. Compare this distance to the plan dimensions, and determine the amount of section loss.

Out-of-Plane Distortion

Out-of-plane distortion can occur in the girder web at the floorbeam connection. This has caused web cracks near the top flanges of numerous two-girder bridges (see Figure 4-26; this figure represents a multi-girder bridge, but the concept applies to two-girder structures as well).

Fracture Critical Members

A two-girder bridge does not have load path redundancy. It is therefore nonredundant and is a fracture critical bridge type. The main girders are fracture critical members. Pins in pin and hanger connections have fractured when "frozen" by corrosion. This is a critical situation when it occurs on a two-girder bridge.

10.5 Through Girders

10.5.1 Design Characteristics

A through girder bridge is similar to a two-girder bridge, in that it has only two main girders, it may be welded or riveted, it has web stiffeners, and it has girder-floorbeam or girder-floorbeam-stringer floor systems. However, the deck on a through girder bridge is placed between the girders which are visible from the roadway (see Figure 10-7).

While few through girders are constructed today, they were commonly used prior to the early 1950's. Their most common use was where vertical underclearance was a concern, such as over railroads.

Figure 10-7 Through Girder Bridge

Through girder bridges are most commonly single span structures, although multiple span and continuous configurations were constructed. A rare type of through girder has three or more girders, with the main girders actually separating the traffic lanes. These structures are probably converted railroad or trolley bridges. Through girder bridges are commonly riveted.

The primary members of a through girder bridge are the through girders, floorbeams, and stringers, if present. The secondary members are the lateral bracing.

10.5.2 Inspection Locations and Procedures

Shear Zones

Examine the web areas of the girders near the supports for corrosion and buckling.

Flexure Zones

Inspect the tension and compression flanges for corrosion and section loss. Also check the flanges in the high stress areas for flexure damage caused by live loads.

Secondary Members

Investigate the connection areas of the lateral bracing for cracked welds, fatigue cracks, and loose fasteners (see Figure 10-8). Inspect the bracing members for any distortion. Check horizontal connection plates which can trap debris and moisture and are susceptible to a high degree of corrosion and deterioration.

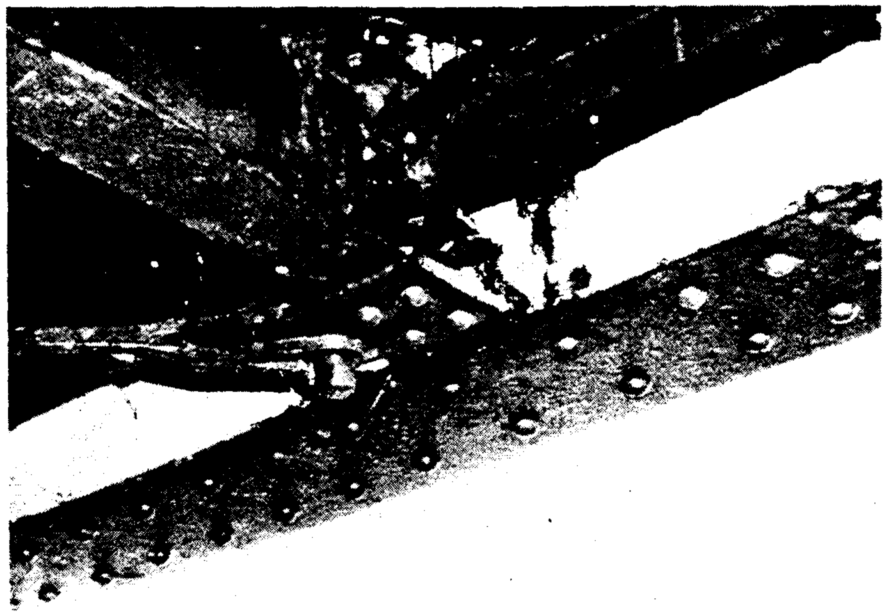


Figure 10-8 Lateral Bracing Connection on a Through Girder Bridge

Areas Exposed to Traffic

Investigate the main girders along the curb lines and at the ends for collision damage. Check underneath the bridge for collision damage to the main girders and bracing if the bridge crosses over a highway, railway, or navigable channel.

Fatigue Prone Details

Dirt and debris traps can result in active corrosion cells when water and salt are present. These corrosion cells can lead to excessive section loss. This can result in notches which are susceptible to fatigue or perforation.

Carefully inspect all tack welds, particularly in the tension zones.

Fracture Critical Members

A through girder bridge does not have load path redundancy. It is therefore nonredundant and is a fracture critical bridge type. The main girders are fracture critical members. Through girders are of riveted construction, and this bridge type has internal redundancy.

10.6 Box Girders

10.6.1 Design Characteristics

A box girder bridge is supported by one or more welded steel box girders. The rectangular or trapezoidal cross section of the box girder consists of two or more web plates connected to a single bottom flange plate.

The top flange may consist of individual plates welded to the top of each web plate, in which case the girder incorporates a composite deck. Alternatively, the top flange may consist of a single plate extending beyond the width of the box. This configuration is called an orthotropic steel plate deck.

Box girder bridges are used in simple spans of 75 feet or more and in continuous spans of 100 feet or more. They are frequently used for curved bridges due to their high degree of torsional rigidity (see Figure 10-9).

Figure 10-9 Curved Box Girder Bridge

The webs and bottom flange must be stiffened in areas of compressive stress. Orthotropic steel plate decks are also stiffened. All stiffeners are located inside the box member. Box girders may also incorporate both diaphragm and top flange lateral bracing systems. External diaphragms may be used between box girders. Box girders typically have an opening or access door to allow the bridge inspector to examine the inside of the box.

The primary members of a box girder bridge are the box girders (including all internal bracing) and, on a curved bridge, the diaphragms. On a straight bridge, the diaphragms are secondary members. Diaphragms can be solid plates, rolled shapes (e.g., I-beams and channels), or cross frames constructed with angles, tee shapes, and plates. Diaphragms may be on the interior or exterior of the box.

10.6.2 Inspection Locations and Procedures

Box girders must be inspected on both the interior and the exterior. When examining the interior, the inspector should proceed with caution. Major concerns involved with inspecting a confined space include lack of sufficient oxygen and the presence of toxic or explosive gases (refer to Section 5.7.4 for a more detailed description of these safety concerns).

Shear Zones

Examine the web areas near the supports for section loss and buckling.

Flexure Zones

The flexure zone of the box girder includes its entire length between the supports. Inspect the tension and compression flange areas for corrosion and loss of section. Examine the flange in high stress areas for flexure- and torsion-related damage caused by live loads. Similar to other steel superstructure types, investigate the negative moment regions for flexural damage. Inspect the diaphragms for distortion caused by torsional stresses.

Secondary Members

Examine the diaphragm connections for loose fasteners and cracked welds. Check horizontal connection plates which can trap debris and moisture and are susceptible to a high degree of corrosion and deterioration. Areas such as diaphragm to bottom flange connections can trap water, while lateral bracing connection plates collect bird droppings and roadway debris.

Areas Exposed to Traffic

Check the box girder for signs of collision damage. Loss of section, cracking, and any shape distortion should be carefully documented.

Fatigue Prone Details

Dirt and debris traps can result in active corrosion cells when water and salt are present. These corrosion cells can lead to excessive section loss. This can result in notches which are susceptible to fatigue or perforation.

Check all welds and welded attachments inside the box. This includes web stiffeners, flange stiffeners, diaphragms, lateral bracing, and stay-in-place deck panels. Butt welds joining adjacent longitudinal stiffeners on the bottom flange serve as potential sources for cracks to propagate into the bottom flange. Check all intersecting welds between the webs and flanges.

Check for fatigue cracks due to web-gap distortion. This is the major source of cracking in steel bridges. However, it is not directly related to the categories of details cited in Reference 58.

Fracture Critical Members

The redundant nature of a box girder bridge depends primarily on the number of box girders in the span. If two or less box girders are used, then the structure is considered nonredundant and the box girders are fracture critical members. If three or more box girders are used, then the structure is generally considered redundant. However, if the spacing of the box girders is large, the structure may not be redundant. The fracture critical nature of the member should be determined by a structural engineer.

10.7 Trusses

10.7.1 Design Characteristics

The superstructure of a truss bridge consists of two parallel trusses. The trusses are the main load-carrying members on the bridge. There are three types of trusses, grouped according to their position relative to the bridge roadway (see Figure 10-10):

- Through trusses - like the through girder, the roadway is placed between the main members (see Figure 10-11); through trusses are constructed when underclearance is limited
- Pony trusses - "half-through" trusses have no overhead bracing members connecting the two trusses; the vertical height of the pony truss is less than the height of a through truss; pony trusses are no longer built, having been replaced by the multi-beam bridge

- Deck trusses - like the deck girder, the roadway is placed on top of the main members; deck truss bridges have unlimited vertical and horizontal clearances and can readily be widened; for these reasons, they are preferred over through trusses

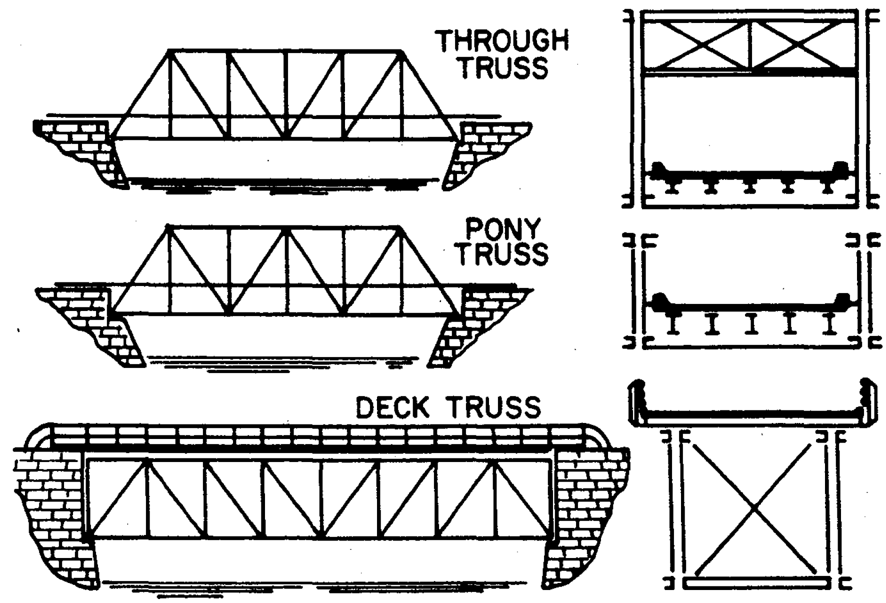


Figure 10-10 Comparison of Through, Pony, and Deck Trusses

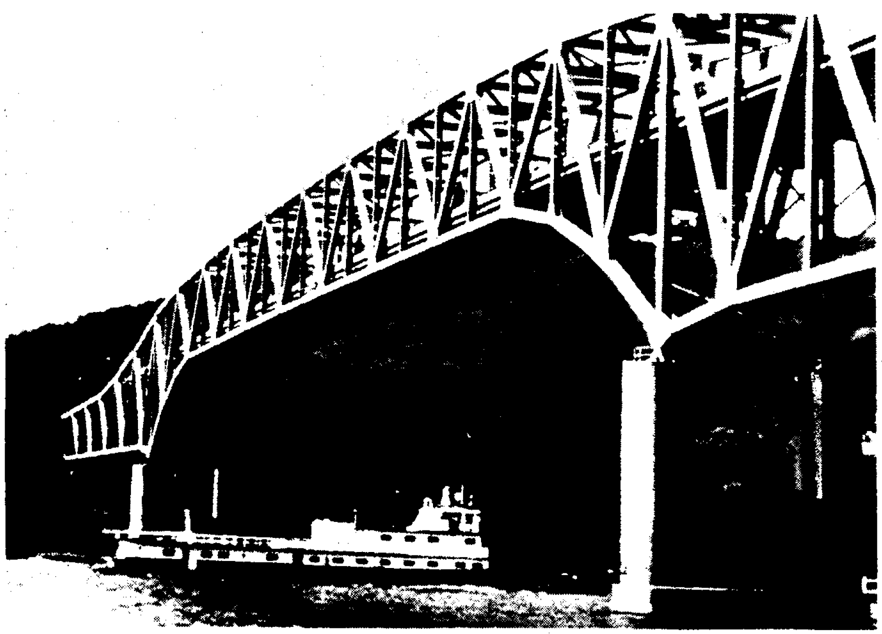


Figure 10-11 Through Truss Bridge

Truss Designs

Bridge engineers have used a variety of arrangements in the design of trusses. Many of the designs were patented by and named after their inventor. One characteristic that all bridge trusses have in common is that the arrangement of the truss members forms triangles.

Trusses have been constructed for short to very long spans, using simple, multiple, cantilever, and continuous designs. Cantilevered trusses often incorporate a "suspended" or "drop-in" span between two cantilever spans. The suspended span behaves as a simple span and is connected to cantilevered spans with pins or pin and hanger connections. The back span on a cantilever truss is called the anchor span.

A truss can be thought of as a very deep girder with portions of the web cut out. Individual, straight truss members are divided into three groups:

- Top chord members
- Web members
- Bottom chord members

Truss members are fabricated from eyebars, rolled shapes, and built-up members.

Chord Members

Trusses, like beams and girders, support their loads by resisting bending. As the truss bends, the bottom chord must stretch. On a simple span truss, the bottom chord is always in tension, while the top chord is always in compression. The top and bottom chords are connected together at the ends of the truss. The diagonally sloped end post is therefore a chord member. Top chords are also known as upper chords (U), and bottom chords are referred to as lower chords (L).

As truss bridge spans increase, cantilever and continuous designs are used, creating negative moment regions. Therefore, over an intermediate support, the top chord of a truss, like the top flange on a girder, is in tension. The negative moment regions produce very large moments. It is common to find varying depth trusses on large complex structures, with the greatest depth at the supports where the moments are the largest.

Web Members

The web members of trusses are typically connected to the top chord at one end and to the bottom chord at the other end. All trusses have diagonal web members, and most trusses also have vertical web members. Depending on the truss design, a web member may be in tension, compression, or both.

An easy method to determine when a truss diagonal is in tension or compression is to use the "imaginary cable - imaginary arch" rule (see Figure 10-12). Diagonals that point upward toward mid-span, like an arch, are in compression. Diagonals that point upward away from mid-span, like a cable, are in tension. This rule applies only to simple span trusses.

A tension diagonal can be referred to as a tie, while a compression diagonal is often called a strut or brace.

With more complex truss designs (continuous and cantilever), the diagonal web members must be capable of withstanding both tension and compression. This is known as force reversal, and it is the reason that, on many modern truss bridges, the appearance of the tension and compression diagonals is almost identical.

On older simple span trusses, it is easy to determine which members are in tension and which are in compression. The design of a 25-foot tension member, subjected to a load, will require a much smaller member (cross section) than a 25-foot compression member subjected to the same load. On older pin- connected trusses, compression members are always the larger built-up members as compared to the tension members, which were often eyebar members. The Pratt truss, with all its diagonals in tension, quickly replaced the Howe truss, whose diagonals are in compression. The Pratt truss was a lighter and therefore cheaper truss.

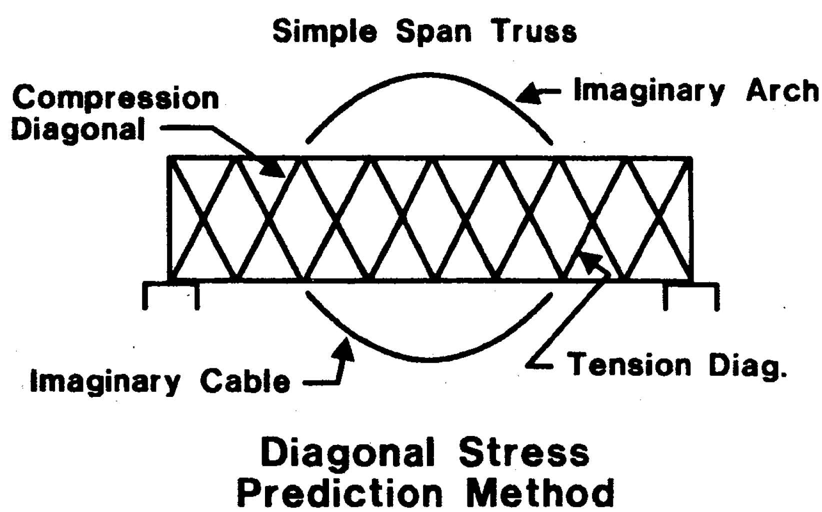


Figure 10-12 "Imaginary Cable - Imaginary Arch"

As trusses became longer and, more importantly, as live loads became larger, the forces in some diagonals on a bridge continually changed from tension to compression and back again. This situation was more likely to occur near the center of the trusses. This is because the positive dead load shear decreases toward the center where the live load can cause a large enough negative shear to overcome the positive shear, resulting in compressive forces for the diagonal.

The solution to this problem was provided by the introduction of counter diagonals. Counters are tension-resisting diagonals installed in the same panel in which the force reversal occurs. They are oriented opposite from the tension diagonal, creating an "X" pattern.

Counters are stressed only under live loads. On older bridges on which counters are bar shaped, they should be capable of being moved by hand during an inspection. Counters are found on most old trusses but rarely on new trusses.

Verticals

There is also an easy method to determine when a vertical member is in tension or compression for a simply-supported truss (see Figure 10-13). Verticals that have one diagonal at each end are opposite to the force of the diagonals. Verticals that have two diagonals at the same end are similar to the force in the diagonal closest to mid-span. Verticals that have counters on both sides are in compression.

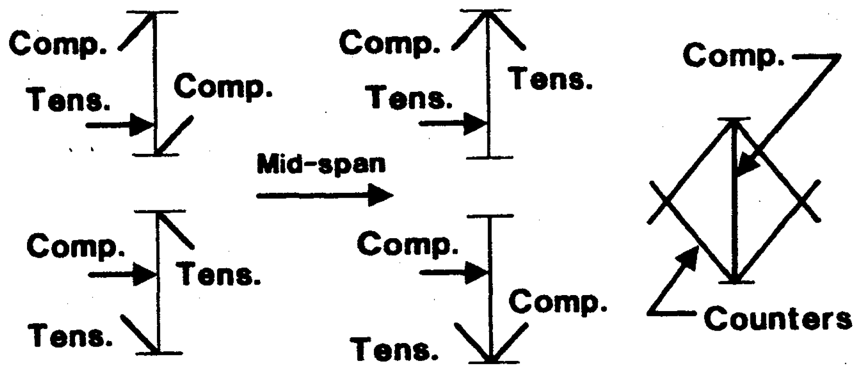


Figure 10-13 Prediction Method for Stresses in Truss Verticals

A vertical compression member is commonly called a post or column, while a vertical tension member is sometimes called a hanger.

Panel Points

A panel point is the location where the truss members are connected together. Modern truss bridges are generally designed so that all members have approximately the same depth, thereby minimizing the need for shims and filler plates at the connections. This is often accomplished by using several grades of steel to meet varying stress conditions.

The connections are typically made using gusset plates and are made by riveting, bolting, or welding. Old trusses used pins at their connections. Truss members may also be spliced, sometimes at locations other than the panel points.

A panel point is designated by either the letter U, for upper chord, or the letter L, for lower chord. Additionally, the panel points are numbered from bearing to bearing, beginning with 0 (zero). Most trusses begin with panel point L_0. Some deck trusses may begin with U_0. Upper and lower panel points of the same number are always in a vertical line with each other (e.g., U_7 is directly above L_7).

Panels

A panel is the space, or distance, between panel points. Truss panels are typically 20 to 25 feet long but range from about 16 to 32 feet. The panel length is a design compromise between cost and weight, with the longer panels requiring heavier floor systems.

As truss spans became longer, they also had to become deeper, increasing the distance between the upper and lower chords. They also required longer panels. As the panels became longer, the diagonals became even longer and the slope became flatter. The optimum angle between the diagonal and the horizontal is 45° to 55°.

To obtain a lighter floor system, designers subdivided the panel. The midpoint of each diagonal was braced with a downwardly inclined sub-diagonal in the opposite direction and with a sub-vertical down to the lower chord. Subpanel points are designated with the letter M and with the "half" number of the adjoining panels (e.g., $M_{7\ 1/2}$). The method of subdividing the truss created a secondary truss system within the main truss to support additional floorbeams. Baltimore and Pennsylvania trusses, patented in the 1870's, use this method. The K truss, a more recent design, accomplishes the same purpose.

Floor System

Trusses have floorbeams at each panel and subpanel point along the truss. Floorbeams should be designated by their panel point number. Most trusses also have stringers in the floor system. The floor system of a truss bridge is therefore similar to the GFS floor system found on girder bridges. The difference is that there are two main trusses rather than two main girders.

Lateral Bracing

Most trusses have upper and lower chord lateral bracing, although pony trusses do not have upper lateral bracing. Lateral bracing is in a horizontal plane and functions to keep the two trusses longitudinally in line with each other. The bracing is typically constructed from built-up and rolled shapes and is connected to the chords and floorbeams at each panel point using gusset plates.

Sway Bracing

Sway bracing is in a vertical plane and functions to keep the two trusses parallel. The bracing is typically constructed from built-up or rolled shapes. The sway bracing at the end diagonal is called portal bracing and is much heavier than the other sway bracing. Sway bracing on old through trusses often limits the vertical clearance, and it therefore often suffers collision damage. Large pony trusses also have sway bracing in the form of a transverse diagonal brace from chord to chord. This member functions to keep the compression vertical from buckling by bracing the top chord.

Truss Applications

Trusses are generally considered to be main members. However, they are also used as floor systems in arches and as stiffening trusses in suspension bridges. Trusses are also commonly used for movable bridge spans.

The primary members of a truss bridge are the trusses, floorbeams, and stringers (see Figure 10-14). The secondary members are the upper lateral bracing, lower lateral bracing, and sway bracing. The bracing resists wind loads and helps distribute live loads.

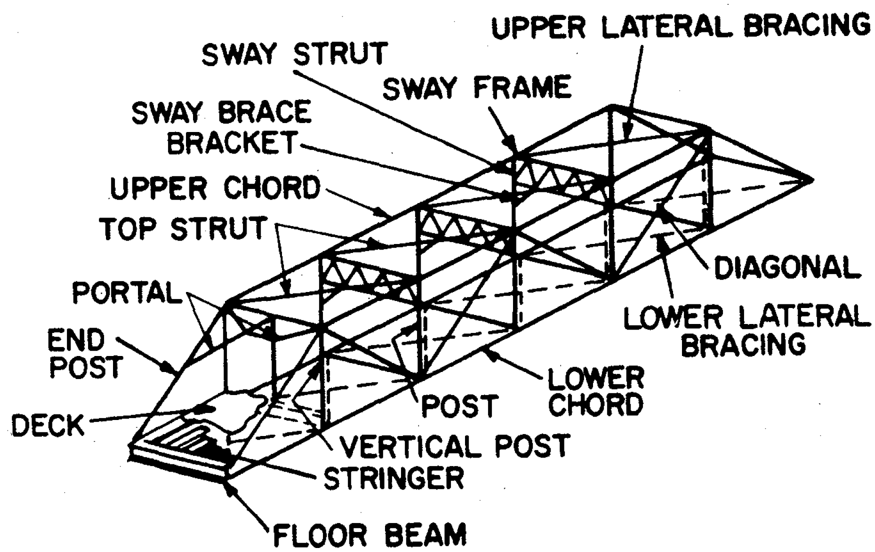


Figure 10-14 Truss Members and Elements

10.7.2 Inspection Locations and Procedures

Truss Members

A truss consists of members which are generally under axial loading only. Furthermore, many truss members are designed for force reversal. If a review of the bridge's design drawings indicates that a member is subjected to tension and compression, it should be inspected as a tension member.

In tension members, check for corrosion and cracks. Examine eyebar heads for corrosion and cracks in the eyes, and examine loop rods for cracking where the loop is formed. Where multiple eyebars form one member, check to see if the tension is evenly distributed. Determine whether the spacers on the pins are holding the eyebars and loop rods in their proper positions. Examine the alignment of the members, making sure that they are straight and not bowed (this could be a sign of permanent force reversal). Investigate the condition of threaded members, such as truss rods, at turnbuckles. Check for repair welds and repair splices. Inspect the members for welds transverse to the tension plane.

In compression members, check for local buckling, which is an indication of overstress. End posts and web members are vulnerable to collision damage from passing vehicles. Buckled, torn, or misaligned members may severely reduce the load-carrying capacity of the member. Wrinkles or waves in the flanges, webs, or cover plates are common forms of buckling.

Inspect chord members for corrosion, examining horizontal surfaces where moisture can collect. Check for corrosion and general deterioration of the lacing bars, stay plates, and batten plates. These elements do not contribute to the load-carrying capacity of the members. Rather, they function only to keep the member's primary elements (usually angles or channels) properly spaced. Only when that function is jeopardized will their condition influence the general condition of the member. It is common, however, for corrosion to occur on a member's primary element adjacent to the lacing bars. It should be noted that built-up corrosion products may be hidden by paint.

Fracture Critical Members

With two primary members in a truss, there is no load path redundancy. Therefore, trusses are nonredundant structures. Trusses are not, however, a single member. They are formed by the connection of many small members. Whether the failure of any given tension member would cause the truss to collapse is best determined by a detailed engineering analysis. The bridge inspector should assume that all tension members are fracture critical members until an analysis is performed.

Inspect pins for scoring and other signs of wear (see Figure 10-15). Be sure that spacers, nuts, retaining caps, and keys are in place.

Figure 10-15 Worn and Corroded Pin

Pin and Hanger Connections

Pin and hanger connections, when used in suspended span configurations in nonredundant truss systems, are fracture critical. This type of connection warrants particular attention. Corrosion can cause fixity in pin connections. This changes the structural behavior of the connection and is a source of cracking.

Usually the hanger plates are compact members similar to a vertical or diagonal. The hanger then slips between gusset plates at both the upper and lower chords. It is difficult to find a fixed reference point because the gusset plate dimensions are not usually given on design plans. However, two recommended options are the intersection of the upper or lower chord and nearest diagonal or the edge of the gusset plate along the axis of the hanger. Both these points will provide readily identifiable reference points which can be re-created easily by the next inspection team. For this reason, measurements should be carefully documented along with the temperature and weather conditions. When inspecting a truss pin and hanger, locate the center of the pin, measure to a reference point to determine section loss, and compare the measurements to plans or previous inspection notes. Refer to Section 10.4.2 for further details about the inspection of pin and hanger connections.

Floor System

The floor system on a truss contains floorbeams and, most likely, stringers. These members function as beam members and are therefore subjected to bending stresses. The shear and flexure inspection locations and procedures discussed in previous sections also apply here.

Examine the end connections of floorbeams for corrosion as they are exposed to moisture and deicing chemicals from the roadway. Corrosion from salt deposits is generally most serious at the end of the bridge and at deck joints. Inspect the flanges of the floorbeams and stringers for corrosion, particularly on open grid decks. Investigate the floorbeam and stringer connections for loose fasteners. Listen for noises caused by moving members with the passage of traffic.

Secondary Members

Inspect the portals for collision damage. Check for loose fasteners at the bracing connections. Examine the lateral bracing gusset plates for corrosion. These plates typically deteriorate more rapidly than other elements on a truss because they are exposed to, and retain, moisture and deicing salts. Examine the alignment of the lateral bracing members. Check horizontal connection plates which can trap debris and moisture and are susceptible to a high degree of corrosion and deterioration.

Fatigue Prone Details

Dirt and debris traps can result in active corrosion cells when water and salt are present. These corrosion cells can lead to excessive section loss. This can result in notches which are susceptible to fatigue or perforation.

Examine the ends of welded cover plates of floorbeam and stringer flanges. Check the welded attachment of signs, railings, and utilities to tension members. Inspect the welds on any repair or reinforcement plate attached to the truss member. Investigate for cracks at the copes and blocked flanges at the ends of floorbeams and stringers. Examine the floorbeam and stringer connection angles for cracks. Check the horizontal gusset plate connections of the lateral bracing to the floorbeam flanges or webs. Inspect the ends of the vertical truss members and the end gusset plates for cracks. Examine the ends of the vertical diagonal eyebar members for cracks. Examine all tack welds between gusset plates and main members and between floorbeam and stringer connections. If a plate or other attachment connects two eyebars by welding, examine the welds for cracks by welding, examine the welds for cracks which could penetrate the eyebars.

10.8 Deck Arches

10.8.1 Design Characteristics

Like its concrete counterpart, the steel open spandrel arch is designed to resist a load combination of axial compression and bending moment. The open spandrel steel arch is considered a deck arch since the roadway is above the arches. The area between the arches and the roadway is called the spandrel. Open spandrel steel arches receive traffic loads through spandrel bents which typically support a steel floor system and concrete deck. Arch bridges are considered simple spans because of the basic arch function. Steel deck arches can be used in very long spans.

The arch members are called ribs and can be fabricated into I-girders, boxes, or truss shapes. The arches are classified as either solid ribbed, braced ribbed, or spandrel braced (see Figure 10-16). The members are fabricated using riveted, bolted, or welded techniques. Most steel deck arches have two arch rib members, although some structures have three or more ribs.

Figure 10-16 Solid Ribbed Deck Arch

The reactions of an arch are diagonally oriented. An arch with a pin at each end of the arch is called a two-hinged arch. If there is also a pin at the crown, or top, of the arch, it is a three-hinged arch. It may also be possible to find one-hinged and fixed arches, although these are very rare. Foundation conditions, in part, dictate the requirements for hinges. Three-hinged arches, for example, are not significantly affected by small foundation movements.

The primary members of a deck arch bridge are the arches, spandrel columns, spandrel girders, floorbeams, and stringers, if present. The secondary members are the sway bracing, upper lateral bracing (floor system), and lower lateral bracing (arch rib).

10.8.2 Inspection Locations and Procedures

Arch Members

Investigate for signs of buckling and crippling in the arch ribs. Check for general corrosion and deterioration, and examine the pins for corrosion and wear. Inspect the alignment of the arch, and check the arch rib splice plates.

Spandrel Members

Examine the end connections of the spandrel columns and spandrel girders for cracks and loose fasteners. Check the spandrel girders for flexure damage.

Floor System

The floor system on an open spandrel steel arch should be inspected in the same manner as previously described under deck girders. Inspect the end connections or bearings areas in the floorbeam to girder connections, and check the stringer connections.

Secondary Members

The bracing systems should be inspected using methods similar to those previously described. Examine the end connections for cracks, corrosion, and loose fasteners, and investigate the alignment of the bracing elements. Check horizontal connection plates which can trap debris and moisture and are susceptible to a high degree of corrosion and deterioration.

Fatigue Prone Details

Inspect for tack welds on the floor system members, spandrel braces, and rib braces. Check the hinge pins. Examine the cover plate ends on the floor system members.

Fracture Critical Members

The arch bridge has two main members. However, the arch is not a tension member and is therefore not considered fracture critical.

10.9 Through Arches

10.9.1 Design Characteristics

The steel through arch is constructed with the crown of the arch above the roadway and the arch foundations below the roadway (see Figure 10-17). The deck is hung from the arch by wire rope cables or other tension members. Since the foundations are below the deck, this bridge type is sometimes referred to as a half-through arch. Traffic loads are transmitted through the deck to the steel floor system, to the hanger cables, and then to the arch.

Figure 10-17 Braced Ribbed Through Arch

Arch bridges are considered simple spans because of the arch function, even though many bridges of this type consist of multiple arches. Through arches are typically two or three hinged.

The arch members are called ribs and are usually fabricated box-type members. Steel through arches are known as either solid ribbed or braced ribbed. The solid ribbed arch has a single curve defining the arch shape, while the braced ribbed arch has two curves defining the arch shape, braced with truss webbing between the curves. The lower curve is the arch rib, and the upper curve is the top chord of the bracing truss. The braced ribbed arch is sometimes referred to as a trussed arch and is more common than the solid ribbed through arch.

The arch reactions, with their massive horizontal thrusts, are diagonally oriented and transmitted to the foundations at the base of the ribs.

The primary members of a through arch bridge are the arch ribs, rib bracing truss, hangers, and floor system. The secondary members are the sway bracing, lateral bracing, lateral bracing (top chord), and lateral bracing (floor system).

10.9.2 Inspection Locations and Procedures

Arch Members

Investigate the arch rib for signs of buckling and crippling and also for general corrosion and deterioration. Check the pins for corrosion and wear. Examine the arch alignment, and inspect the arch rib splice plates.

Bracing Truss

Inspect the web members in a manner similar to any other truss. Depending on the truss design (e.g., Pratt or Warren), the web members will either be designed for tension, compression, or both.

Examine the top chord of the truss. This chord will be in compression.

Hangers

Check the connections at both ends of the hangers, and look for corrosion and cracks. Examine the alignment of the hangers. The hangers may be near traffic, so look out for collision damage. Check the hangers for any welded attachment. Examine the welds between the attachment and the hanger for cracks.

Floor System

The floor system consists of girders, floorbeams, and possibly stringers. Inspect the floor system as described in previous sections. Check the floorbeam end connections, and the stringer end connections.

Secondary Members

The bracing systems are to be inspected as previously described. Inspect the end connections for corrosion, cracks, and loose fasteners. Investigate the alignment of the bracing elements. Check horizontal connection plates which can trap debris and moisture and are susceptible to a high degree of corrosion and deterioration.

Areas Exposed to Traffic

Check for collision damage.

Fatigue Prone Details

Inspect the floor system and the trussed brace for tack welds. Investigate the hinge pins for corrosion and wear. Examine any cover plate ends on the floor system members.

Fracture Critical Members

The arch is the main load-carrying member. Since there are typically only two arch ribs, the structure is nonredundant. However, the bridge is not classified as fracture critical because the arches are not tension members. The hangers may be fracture critical, depending on the results of a detailed structural analysis.

10.10 Tied Arches

10.10.1 Design Characteristics

The tied arch is a variation of the through arch with one significant difference. In a through arch, the horizontal thrust of the arch reactions are transferred to large rock, masonry, or concrete foundations. A tied arch transfers the horizontal reactions through a horizontal tie which connects the ends of the arch together, like the string on an archer's bow. As can be imagined, the tie is a tension member. If the string of a bow is cut, the bow will spring open. Similarly, if the arch tie fails, the arch will lose its compression and will collapse.

The arch members are called ribs and are usually fabricated box-type members. Most of the tied arches found today are solid ribbed (see Figure 10-18), although older tied arches incorporated the braced ribbed type.

Figure 10-18 Solid Ribbed Tied Arch

The tie member is also typically a fabricated box type member. On large spans, the tie is large enough for the inspector to get inside the box. Some ties consist of truss members. The tie is also supported by hangers, which usually consist of wire rope cable, but can also be built-up members.

Together, the hangers and the tie support the floor system. The floor system consists of floorbeams framed into the ties, and stringers may also be used.

The primary members of a tied arch bridge are the arch ribs, tie members, rib bracing truss, hangers, and floor system. The secondary members are the sway bracing, lateral bracing (arch rib), lateral bracing (top chord), and lateral bracing (floor system).

10.10.2 Inspection Locations and Procedures

Arch Members

Investigate the arch ribs for signs of buckling and crippling and for general corrosion and deterioration. Examine the pins for corrosion and wear. Investigate the arch alignment, and check the arch rib splice plates.

Tie Girder

Determine if back-up bars were used to make corner welds in the tie box. If so, the back-up bars should be carefully examined to determine if they are continuous. Weld cracks can occur at points where the bars are discontinuous. Check all welds, and examine the ends of any cover plate. Check especially welds connecting internal diaphragms to the tie box. Inspect the floorbeam connections and the corner welds of the tie box.

Bracing Truss

Inspect the web members similarly to any other truss. Depending on the truss design (e.g., Pratt or Warren), the web members will be designed either for tension, compression, or both. Examine the top chord of the truss. This chord will be in compression.

Hangers

Examine the connections at both ends of the hangers, looking for corrosion and cracks. Check the alignment of the hangers. The hangers may be near traffic, so inspect for collision damage. Examine the hangers for any welded attachment. Check the welds between the attachment and the hanger for cracks.

Floor System

The floor system consists of floorbeams and possibly stringers. Inspect the floor system as described in previous sections, checking the end connections and especially the floorbeam to tie connections.

Secondary Members

The bracing systems are to be inspected as described in previous sections, checking the alignment of the members and the end connections for corrosion, cracks, and loose fasteners. Check horizontal connection plates which can trap debris and moisture and are susceptible to a high degree of corrosion and deterioration.

Areas Exposed to Traffic

Inspect any areas exposed to traffic for collision damage.

Fatigue Prone Details

Examine the welds for cracks at the floorbeam to tie connection and the stringer to floorbeam connection. Check the floor system and trussed brace for tack welds. Investigate the hinge pins for corrosion and wear. Inspect any cover plate ends on the floor system members.

Investigate for fatigue cracks due to web-gap distortion. This is the major source of cracking in steel bridges. However, it is not directly related to the categories of details cited in Reference 58.

Out-of-Plane Distortion

Investigate the box tie girders at the floorbeam connection for cracks in the webs due to out-of-plane distortion.

Fracture Critical Members

With only two load paths, the tied arch is a nonredundant structure. The tie girders are fracture critical.

10.11 Rigid Frames

10.11.1 Design Characteristics

By definition, a frame is a multi-sided configuration in which the sides are rigidly connected in such a fashion that applied loads are distributed to each side.

Steel rigid frames are popular today in building construction because of their space-saving characteristics.

The same principles that permit the omission of intermediate column supports in buildings are applied to bridge frames.

In a steel rigid frame bridge structure, intermediate supports are replaced by the frame sides or "legs." Because the legs contribute to the structure's overall capacity, increased span lengths and material savings can be realized.

Frame bridges are typically of welded plate girder construction with bolted field splices in low stress areas. The frames are spaced from about 7 to 20 feet on centers, depending on loads, span lengths, and type of floor system (see Figure 10-19).

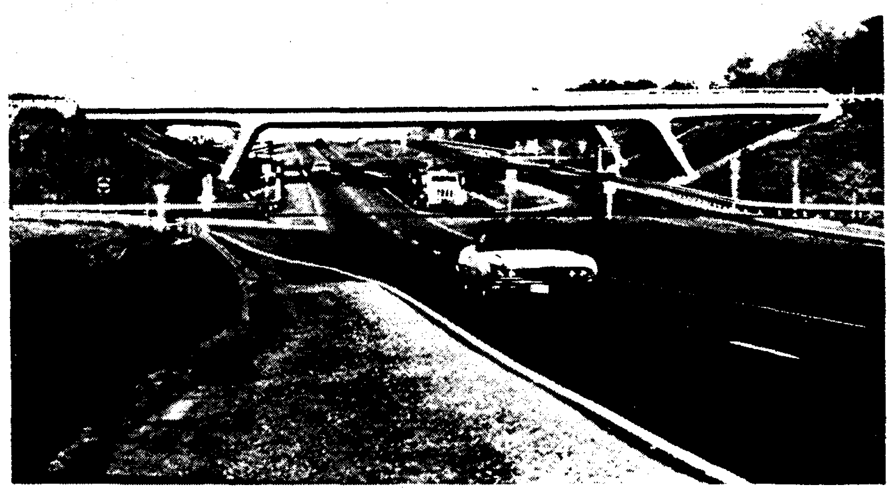


Figure 10-19 Typical Rigid Frame Bridge

Steel rigid frames can be economical for spans from 50 feet to over 200 feet.

Most steel rigid frame bridges are multi-span structures and are commonly referred to as "K-frame" or "grasshopper leg" bridges. In some designs, a triangular frame configuration is used and referred to as a delta frame.

Regardless of the frame configuration, the entire portion of the bridge which constitutes the frame is considered the superstructure. The legs of rigid frames are supported by relatively small concrete footings and bearings which are essentially hinges (see Figure 10-20).

The ends of the frame girders are supported by standard abutments and expansion bearings.

For steel rigid frame bridges, the primary members are the frames as a whole. However, for ease of discussion, the frame is commonly broken down into the following three elements:

- Frame girder - the horizontal sections
- Frame leg - the inclined sections
- Frame knee - the intersection between the frame girder and frame leg

Each element of the frame resists various levels of stress due to moment and shear. Tension zones are similar to those for concrete rigid frames (see Figure 9-22). If the structure has a floor system, all stringers and floorbeams are also primary members.

When a design uses multiple frames, intermediate and end diaphragms are used to maintain geometry and help distribute live loads.

In two frame only structures, lateral bracing is used on the frame girders as well as the frame legs (see Figure 10-21).

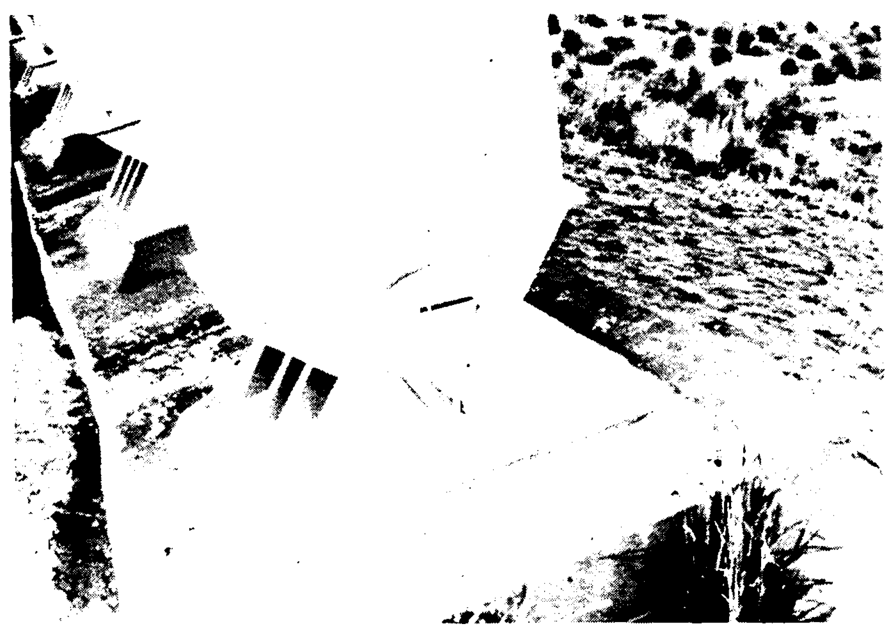


Figure 10-20 Typical Hinge Bearing

Figure 10-21 Rigid Frame Bridge with Only Two Frames

10.11.2 Inspection Locations and Procedures

Frame Elements

Inspect shear and flexure zones for section loss due to corrosion. Examine girder flanges in the compression zones for signs of buckling. Check end bearings for corrosion or malfunctions.

Secondary Members

Check horizontal connection plates which can trap debris and moisture and are susceptible to a high degree of corrosion and deterioration. Investigate the areas beneath drainpipe and deck joints for corrosion from exposure to roadway drainage.

Areas Exposed to Traffic

Inspect frame girder sections over roadways for collision damage.

Fatigue Prone Details

Examine regions of tensile stress for fatigue cracks in attachment welds. Inspect frame leg hinges for frozen or worn pins.

11

Inspection and Evaluation of Bearings

11

Inspection and Evaluation of Bearings

11.1 Introduction

A bridge bearing is a superstructure element which provides an interface between the superstructure and the substructure. The three primary functions (see Figure 11-1) of a bridge bearing are:

- To transmit all loads from the superstructure to the substructure
- To permit longitudinal movement of the superstructure due to thermal expansion and contraction
- To allow rotation caused by dead load and live load deflection

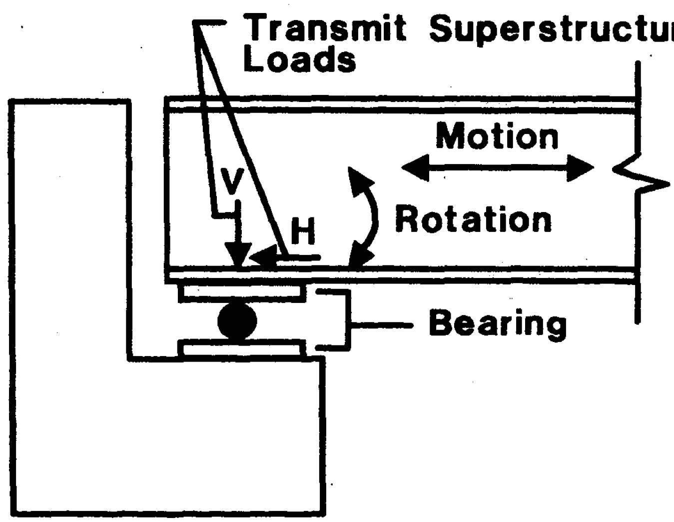


Figure 11-1 Functions of a Bearing

Fixed and Expansion Bearings

Bearings that do not allow for translation or movement of the superstructure are referred to as fixed bearings. Bearings that do allow for translation or movement of the superstructure are known as expansion bearings. Both fixed and expansion bearings permit rotation (see Figure 11-2).

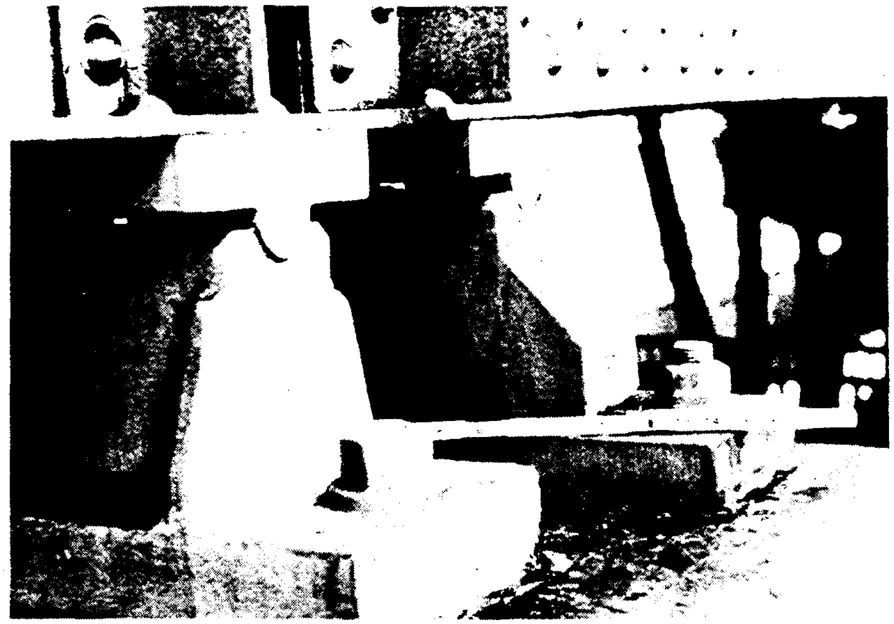


Figure 11-2 Fixed and Expansion Bearings

This chapter identifies the various types of bridge bearings, their elements, and how they function in relation to bridge structures. It also describes the inspection and evaluation of the various types of bearings.

11.1.1 Elements of Bridge Bearings

A bridge bearing consists of four basic elements (see Figure 11-3):

- Sole plate
- Bearing or bearing surface
- Masonry plate
- Anchorage

Sole Plate

The sole plate is a steel plate that is attached to the bottom flange of girders or beams or to the bottom chord of trusses. With concrete beams, girders, or slabs, the lower flange or bottom of the section may function as a sole plate.

Bearing or Bearing Surface

The bearing or bearing surface is secured to the sole plate and masonry plate and provides the function of transmitting the forces from the sole plate to the masonry plate.

Masonry Plate

The masonry plate is a steel plate that is attached to the supporting member, abutment, or pier. The masonry plate serves to distribute vertical forces from the bearing and superstructure above to the substructure below.

Anchorage

The anchor bolts generally serve to hold the bearing to a substructure unit. The anchor bolts can, however, pass through the bearing element to provide restraint against transverse movement. The American Association of State Highway and Transportation Officials (AASHTO) requirements call for anchor bolts to be at least one inch in diameter and to be embedded at least 10 inches into the masonry or supporting member.

Figure 11-3 Elements of a Typical Bridge Bearing

Not all bearings have these four distinct elements. All bearings do, however, have at least one of them: the bearing surface.

11.2 Types of Expansion Bearings

Various expansion bearing types have evolved out of the need to accommodate superstructure movement. These bearings include:

- Sliding plate bearings
- Roller bearings
- Rocker bearings
- Pin and link bearings
- Elastomeric bearings
- Pot bearings
- Restraining bearings

11.2.1 Sliding Plate Bearings

Several types of sliding plate bearings have been used in bridges over the years. They are primarily used on structures with a span length of less than 40 feet. Among the various types of plates are those presented below.

Lubricated Steel Plates

The first generation of lubricated steel plates consisted of two steel plates with the bearing surfaces planed smooth (see Figure 11-4). Lubrication between the plates consisted of grease, graphite, and tallow. Unfortunately, the lubricant tended to hold dirt which absorbed moisture, eventually corroding and freezing the bearing. ("Freezing," as used in describing bearings, indicates that the bearing has become inoperable due to corrosion, mechanical binding, dirt buildup, or other interference. The bearing can not move as intended.)

The next generation of sliding steel plates consisted of a small plate sliding on a considerably larger one. The theory behind this was that if the contact area was smaller, the forces transmitted would overcome the freezing forces. However, the smaller plate actually wore a groove in the larger one, eventually freezing the bearing anyway.

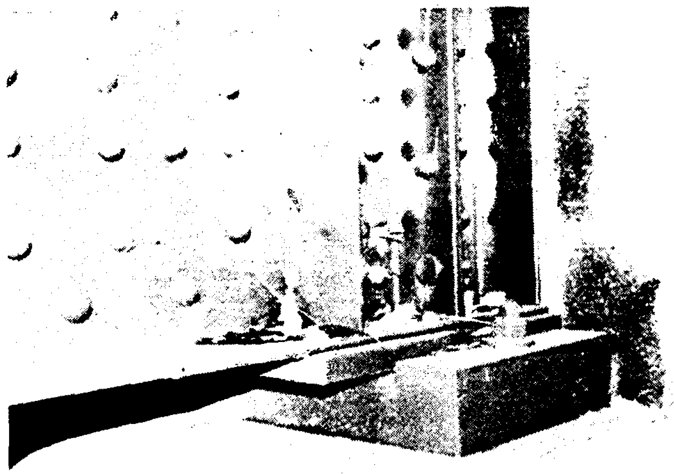


Figure 11-4 Lubricated Steel Plate Bearing

Lead Sheets Between Steel Plates

By placing a thin lead sheet between the steel plates, it is possible to keep the plates from freezing together when they corrode. However, in this type of bearing, the lead has a tendency to work its way out from between the plates.

Bronze Bearing Plates

A bronze bearing plate was introduced to avoid the corrosion problems of steel plates in contact. Although corrosion is reduced, the bronze becomes worn due to trapped dirt and the action of expansion and contraction. Eventually, a mechanical locking of the plates may take place.

Asbestos Sheet Packing Between Metal Plates

A graphite-impregnated asbestos sheet has been used between steel bearing plates to provide some movement in spans of less than 40 feet.

Self-Lubricating Bronze Bearings

The self-lubricating bronze bearing was developed to ensure a graphite lubricant between bearing plates, regardless of their wear. Portions of the face of the bearing were removed and replaced with a graphite compound, which continuously lubricated the bearing surfaces. Some manufacturers claim that these bearings are corrosion- resistant and never require any maintenance. If the bearings are kept free from dirt and abrasive dusts, this can be true.

These bearings are widely available in many different forms, including plates, plates with one side cut to a radius, and half cylinders. The bronze plate can either be attached to the masonry plate with the lubricated surface facing the sole plate, or it can be attached to the sole plate.

Roofing Felt or Tar Paper with Oil and Graphite

Another type of bearing consists of oil-soaked felt or tar paper that has been dusted with graphite. Several layers are placed on the abutment with the superstructure placed directly on it. This is a simple but effective bearing that is commonly used on short span concrete slabs and girders that sit on concrete abutments.

PTFE on Stainless Steel Plates

A compound known as "polytetrafluoroethylene" (PTFE or TFE) has the lowest coefficient of friction of any of the commonly available materials, making it quite desirable for use in bridge bearings.

Various types of bearings have been offered to take advantage of PTFE's characteristics. Today, bearings using PTFE have a sheet of stainless steel underneath the sole plate to slide across the PTFE. Pure PTFE has a low compressive strength and a high coefficient of thermal expansion. To make it suitable for use in bridge bearings, PTFE must be combined with suitable fillers. These fillers are typically glass fiber and bronze and, while giving strength to the PTFE, they do not change its low coefficient of friction.

11.2.2 Roller Bearings

A roller bearing consists of a cylinder which "rolls" between the sole plate and masonry plate as the superstructure expands and contracts. Roller bearings are used in a wide variety of forms, including roller nests and single rollers.

Roller Nests

First used in steel bridges in the early 1900's, roller nests consist of a group of rollers, each 1 1/2 to 2 inches in diameter (see Figure 11-5). When clean, roller nests work well. However, the small rollers offer many places for dirt and moisture to collect. This results in wear and corrosion of the rollers, and ultimately results in bearing failure. Attempts to seal this bearing require careful maintenance of protective covers and skirts and have usually met with little success.

Single Rollers

The single roller is one of the most widely used bearings (see Figure 11-6). Rollers can vary in size, with specified diameters ranging from about 6 to 15 inches. While the larger rollers are less susceptible to corrosion problems, dirt may get trapped in the contact areas along the top and bottom of the bearing. This enables moisture absorption, eventually deteriorating the bearing surface. However, because only a small portion of the roller actually becomes corroded, the corroded roller can be rotated and another portion of the roller surface can be used. Many single roller bearings are made of corrosion resistant steel, especially those supporting concrete superstructures.

An unrestrained roller will gradually work itself out from underneath a bridge. For this reason, pintle pins are used to keep the roller in place. These pins fit tightly into the roller but loosely into the upper and lower plates. The loose fit allows for the necessary structure movement.

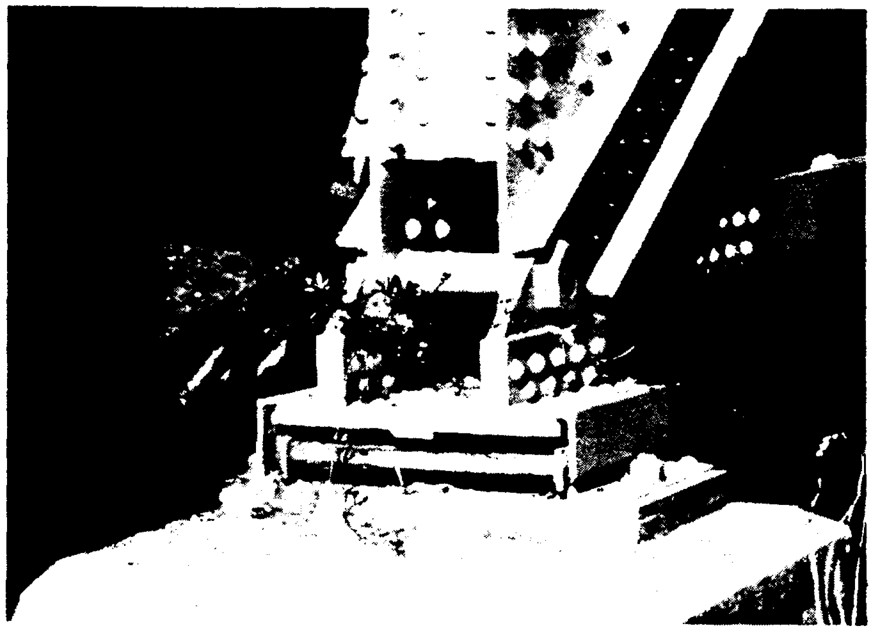


Figure 11-5 Roller Nest Bearing

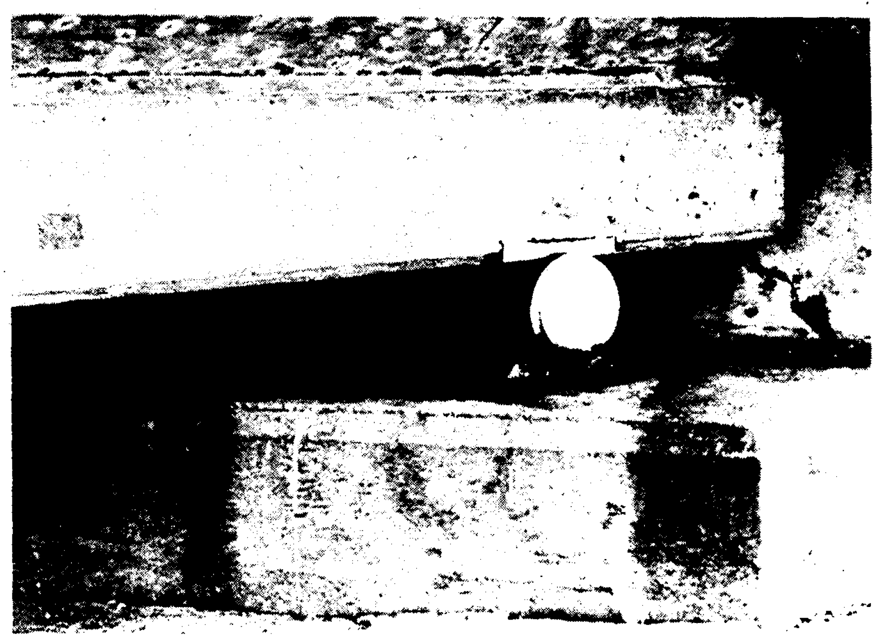


Figure 11-6 Single Roller Bearing

11.2.3 Rocker Bearings

The rocker bearing (see Figure 11-7) functions in a similar manner to the roller bearing and is generally used where a substantial amount of movement is required. As with roller bearings, rocker bearings come in different forms, such as segmental rockers, rocker nests, and pinned rockers.

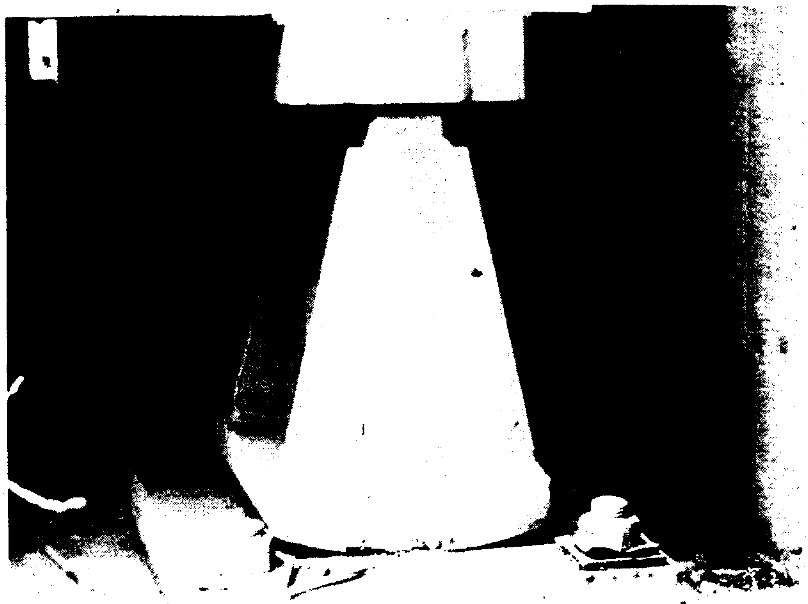


Figure 11-7 Rocker Bearing

Segmental Rockers

Segmental rocker bearings were the next major development in bearing devices. These rockers evolved out of the use of large rollers. When the rollers get up to 20 inches in diameter, they become very heavy and difficult to handle. Since only a small portion of the roller is actually used, the unused portion can be cut away and a substantial weight savings can be realized.

Larger segmental rockers have also been fabricated from rectangular blocks, rounded at both ends, on which the bearing plates roll.

Rocker Nests

A group of several rockers forms a rocker nest (see Figure 11-8). Rocker nests provide many small areas for dirt and moisture to collect.

Pinned Rockers

The pinned rocker is the most popular rocker bearing design today. The top is basically a large pin and tends to keep the bearing aligned correctly. When exposed to adverse environmental conditions, however, the pin can corrode and freeze. Pinned rocker bearings can be quite large and are commonly used for relatively long spans and heavy loads.

11.2.4 Pin and Link Bearings

The pin and link bearing is typically used on continuous cantilever structures to support the ends of a suspended span (see Figure 11-9). It can also be used as a type of restraining device, which is discussed in Section 11.2.7. A disadvantage of this type of bearing is that, as the superstructure expands and contracts, the deck rises and falls (but only slightly). Another disadvantage is that pins can fracture when frozen by corrosion.

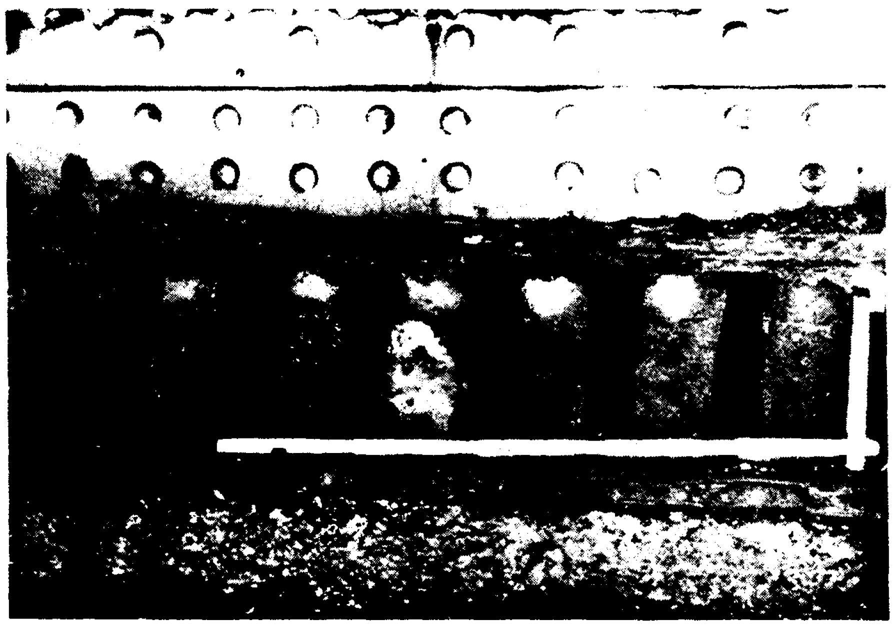


Figure 11-8 Rocker Nest Bearing

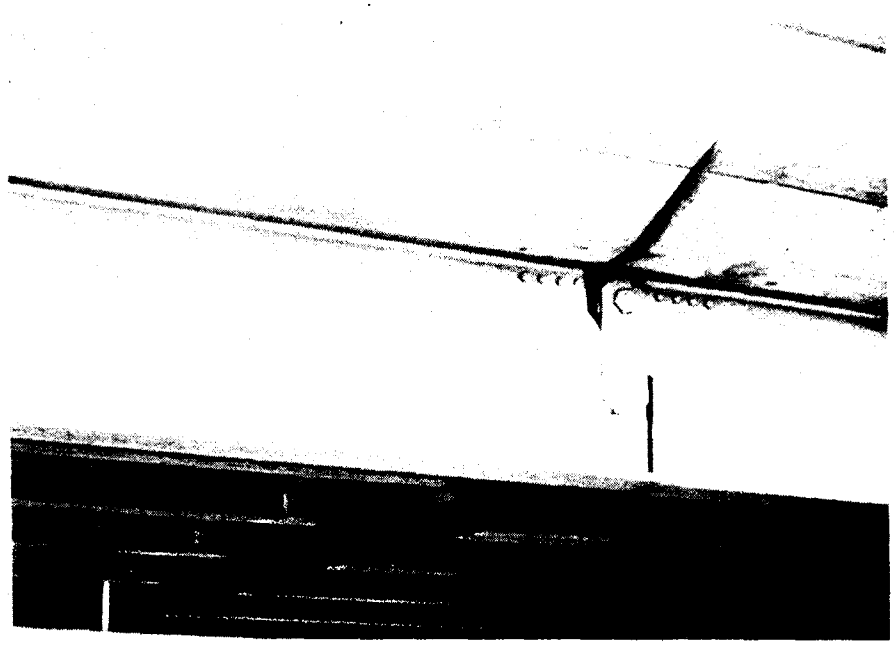


Figure 11-9 Pin and Link Bearing

11.2.5 Elastomeric Bearings

Elastomeric bearings include both plain and laminated neoprene pads, as well as isolation bearings.

Plain Neoprene Pads

A plain neoprene bearing consists of a rectangular pad of pure neoprene and is used primarily on short span, prestressed concrete structures. Neoprene bearings are becoming popular for steel beam bridges as well. Expansion is achieved through a shearing deformation of the neoprene.

Typically these bearings are of uniform thickness and are rectangular with parallel sides, but round, disc-shaped pads have also been used.

Various means are used to prevent the neoprene bearing from walking out of position from under a beam. An epoxy compound has been used to bond the pad to the beam and the bridge seat, but it has not always been successful.

Laminated Neoprene Pads

A laminated neoprene bearing is simply a stack of neoprene pads with steel or fiberglass plates separating them (see Figure 11-10). The plates are not visible if the entire bearing is encased in neoprene. Laminated bearing pads are used on longer structures where the expansion and contraction requirements and the superstructure loads are greater.

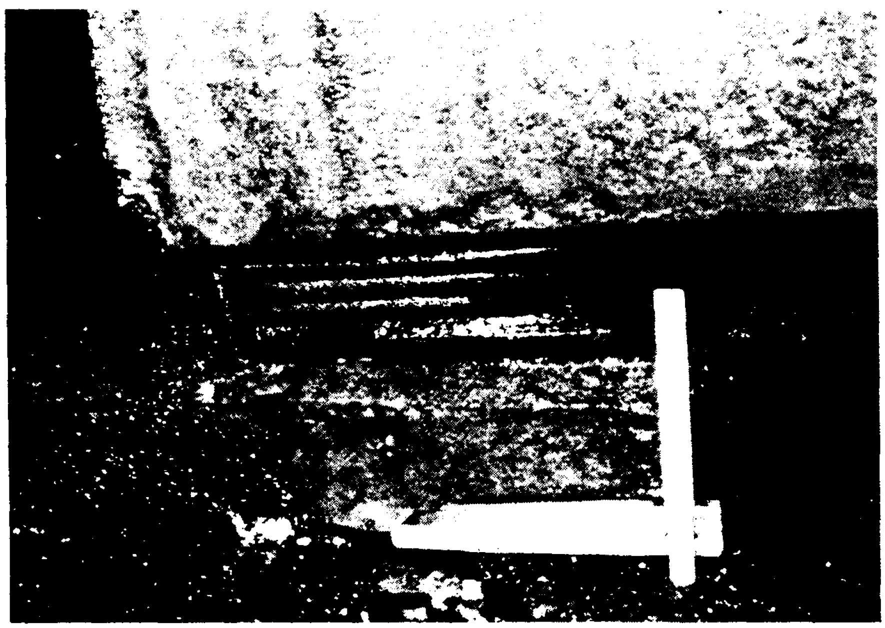


Figure 11-10 Laminated Neoprene Bearing

Although a single, thicker pad could conceivably do the job of the laminated bearing, excess bulging and wearing of the pad would dramatically decrease its useful life. The laminated bearing eliminates this excess bulging and allows the expansion and contraction without excessive wear.

Isolation Bearings

The isolation bearing was developed to protect structures against earthquake damage. It is similar to the laminated bearing in that it is a sandwich of neoprene and steel plates. It also contains a lead core that is used primarily for seismic loads. A cover of neoprene protects the steel plates but the top of the lead core remains exposed (see Figure 11-11).

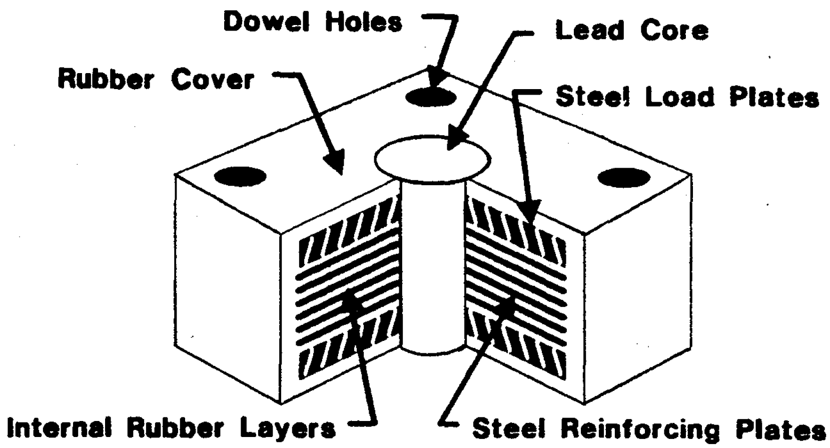


Figure 11-11 Lead Core Isolation Bearing

The isolation bearing behaves like a laminated bearing when exposed to normal bridge loading. The lead core stiffens the bearing and helps it to resist these loads. However, under seismic loading, the lead core is designed to fail. This failure makes the bearing more flexible and allows it to isolate the bridge from the effects of earthquake motion.

11.2.6 Pot Bearings

Pot bearings allow for the multi-dimensional rotations of a structure (see Figure 11-12). There are two different pot bearing configurations: neoprene and spherical.

Neoprene Pot Bearings

A neoprene pot bearing has a plate of stainless steel that is attached to the sole plate. This plate slides on a disc of PTFE. The PTFE disc is attached to a steel piston which rests on a neoprene pad, allowing for the rotation of the structure. The pad rests in a shallow steel cylinder that is attached to the substructure. This cylinder is referred to as the pot. Guide bars in the expansion pot bearing restrict movement. A fixed bearing version of this configuration does not possess the stainless steel plate or the PTFE disc.

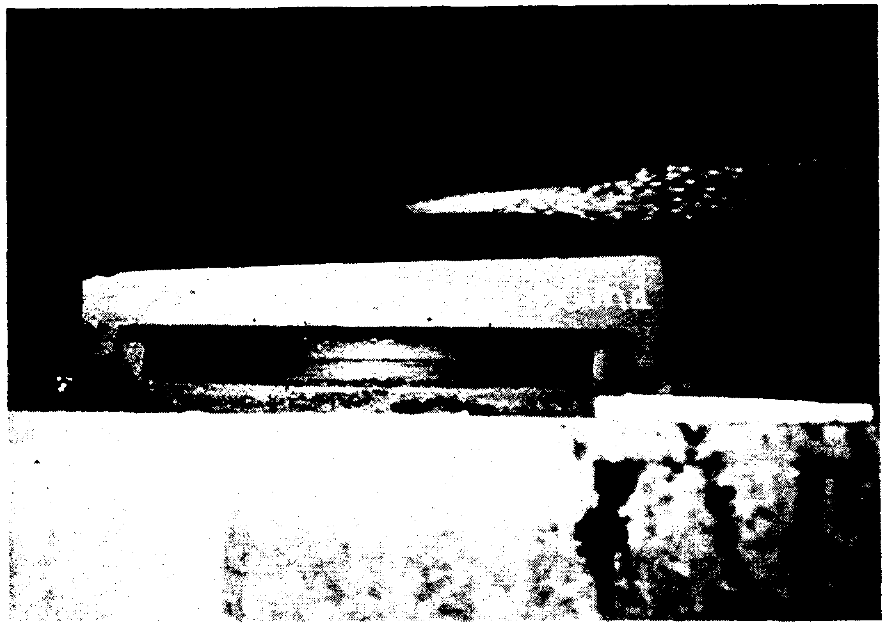


Figure 11-12 Pot Bearing

Spherical Pot Bearings

A spherical pot bearing has a plate of stainless steel that is attached to the sole plate. This plate slides on a disc of PTFE that is bonded to an aluminum alloy casting. The casting has a flat top and a spherical bottom. The bottom of the casting fits into another PTFE-coated aluminum alloy casting. The spherical shaped castings allow for the rotation of the structure. A fixed bearing version of this configuration has the upper aluminum casting attached to the sole plate. There is no stainless steel plate sliding on the PTFE disc.

11.2.7 Restraining Bearings

Restraining bearings serve to hold a bridge down in the case of uplift. Uplift usually occurs on cantilever anchor spans. The devices used to resist uplift can be as simple as long bolts running through the bearings on short span bridges (see Figure 11-13) or as complex as chains of eyebars on larger structures. Lock nuts are used with bolted restraining devices to resist uplift. Pin and link members are also used as restraining devices. The type of restraining device used depends on the magnitude of the uplift force.

11.3 Inspection of Bearings

When inspecting a bearing, the inspector must first determine if the bearing was initially intended to be fixed or expansion. If the bearing was designed to allow for translation or movement of the superstructure, then it is an expansion bearing; if not, then it is a fixed bearing. The inspector should refer to the design plans if available. It is critical that the inspector assess whether expansion bearings still allow for translation or movement.

All bearings must have a suitable support. A distance of several inches should exist between the edge of the masonry plate and the edge of the supporting member, abutment, or pier. Note any loss of section to the supporting member near the bearing (e.g., spalling of a concrete bridge seat).

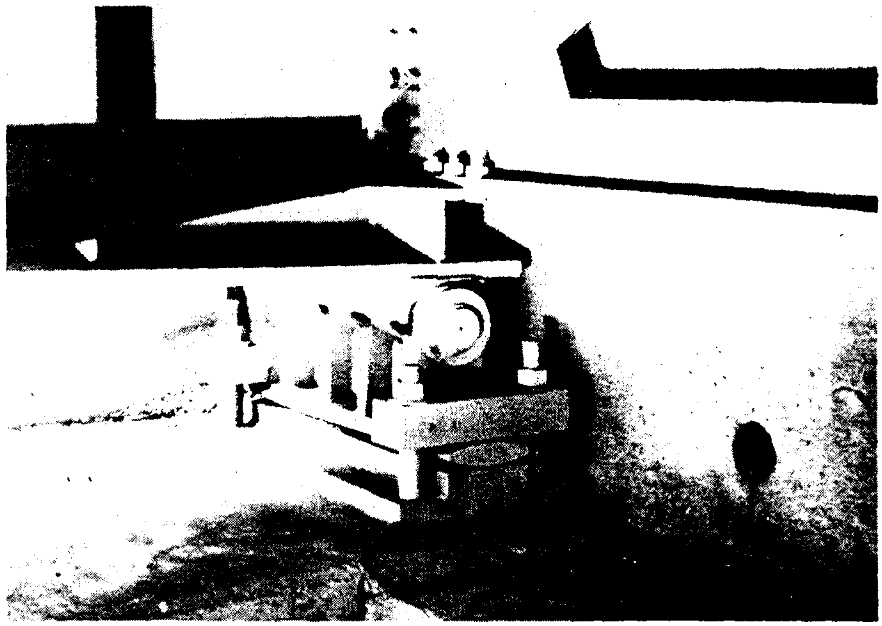


Figure 11-13 Restraining Bearing

Although there are many different types of bearings, bearing inspection can be broken down into two major categories based upon the basic materials from which they are made:

- Metal bearings
- Elastomeric bearings

Various metallic materials have been used in bearings, including steel, bronze, aluminum, lead, and cast iron. However, steel is by far the most prominent and the most susceptible to deterioration, while the others mentioned are either noncorrosive or corrosion-resistant. Consequently, the following discussions will concentrate on the most common materials: steel bearings and elastomeric bearings.

11.3.1 Inspection of Steel Bearings

Some inspection items are common to all steel bearings. For example, steel bearings are subject to the same corrosive forces as steel beams or girders.

Frozen bearings can occur when deterioration and debris buildup cause the bearing to bind up, thereby preventing free movement. Evidence of a frozen bearing includes bending, buckling, improper alignment of members, or cracks in the bearing seat.

Bearings should be properly aligned, and bearing surfaces should be clean and in full contact with each other. If only partial contact is made, damage can occur to the bearing device, superstructure, or substructure.

This damage can occur when a girder has moved horizontally so that the sole plate rests on only a portion of the masonry plate. The full load of the superstructure is therefore being applied to a smaller area on the substructure. This results in a higher stress that could crush the bridge seat. Also such redistribution of the load may cause buckling to occur in the girder web.

The bearing should not be loose. Looseness can be identified by noise at the bearing or by visually detectable movement in the bearing when the bridge is subjected to live loads. Loosening can be caused by any of the following:

- Settlement or movement of the bearing support away from the portion of the bridge being supported
- Excessive rust or corrosion which results in a loss of material in the bearing itself
- Excessive deflection or vibration in the bridge
- Loose or missing fasteners that are used to attach the bearing to either the superstructure or the support
- Worn bearing elements
- Uplift in curved bridge superstructures

Examine for broken or cracked welds and missing or sheared fasteners.

Bearings and lateral shear keys on skewed bridges should be inspected for binding and damage due to the creep effect of the bridge (i.e., the tendency of the bridge to move laterally along the skew).

Specific inspection items for the various types of steel bearings are discussed in the following paragraphs.

Sliding Plate Bearings

When a bridge is constructed, the upper and lower plates of the sliding plate bearing are placed such that they are centered with respect to each other at a certain temperature, usually 68°F. Any movement of the bearing can be measured based on this initial alignment.

For plates of equal size, the amount of expansion or longitudinal movement that has occurred is the distance from the front or back of the top plate to the front or back of the bottom plate or, alternatively, the distance between the centers of the top and bottom plates (see Figure 11-14). For plates of unequal size, the amount of expansion is one half of the difference between the front and back distances between the top and bottom plates. These dimensions should be measured to the nearest 1/8 inch, and the temperature at the time of inspection should be recorded.

Bearings employing bronze sliding plates with steel masonry plates on bridges exposed to a salt air environment should be examined for signs of electrolytic corrosion between the bronze and steel plates. Electrolytic corrosion can also occur between aluminum and steel plates.

Roller Bearings

Roller bearings are similar to sliding plate bearings in that the roller unit should be centered on the masonry plate at its design erection temperature. Therefore, the expansion (or contraction) is one half of the difference between the front of plate-to-roller distance and the back of plate-to-roller distance (see Figure 11-6). Alternatively, and perhaps easier to measure, the expansion (or contraction) is also the distance between the center of the roller (where it contacts the masonry plate) and the center of the masonry plate. Again, the temperature at the time of inspection should be recorded.

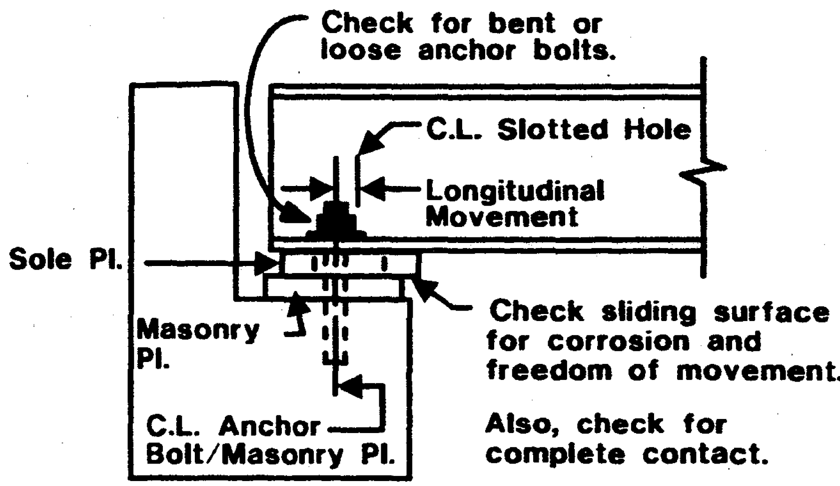


Figure 11-14 Sliding Plate Bearing Inspection Checklist Items

Rollers and masonry plates should be clean and free of corrosion in order to remain operable. They should be inspected for signs of wear.

The position of the roller should also be examined to see if the pintles are exposed or missing. Such conditions may indicate excessive superstructure expansion or contraction movement or undesirable substructure movement.

Rocker Bearings

Some rocker bearings have markings on the rocker and masonry plates. With no expansion or contraction, these marks should line up perfectly vertically. The amount of longitudinal movement can be determined by measuring the distance along the masonry plate between the two marks.

If the bearing has no markings, the expansion can be determined by measuring the distance between the current point of contact between the rocker and the masonry plate and the original point of contact, which is assumed to be the midpoint along the rocker's curved surface (see Figure 11-7).

Measurements should be to the nearest 1/8 inch, and the inspection temperature should be recorded.

Rockers should be inspected for proper tilt (see Figure 11-15). In warmer temperatures (above 68°F), the rockers should be tilted forward in the expanded direction; in colder temperatures, the rockers should be tilted backward in the contracted position. Also check for exposure of the pintles if any are known to be present.

Pins and other contact surfaces should be examined for wear and freedom of movement.

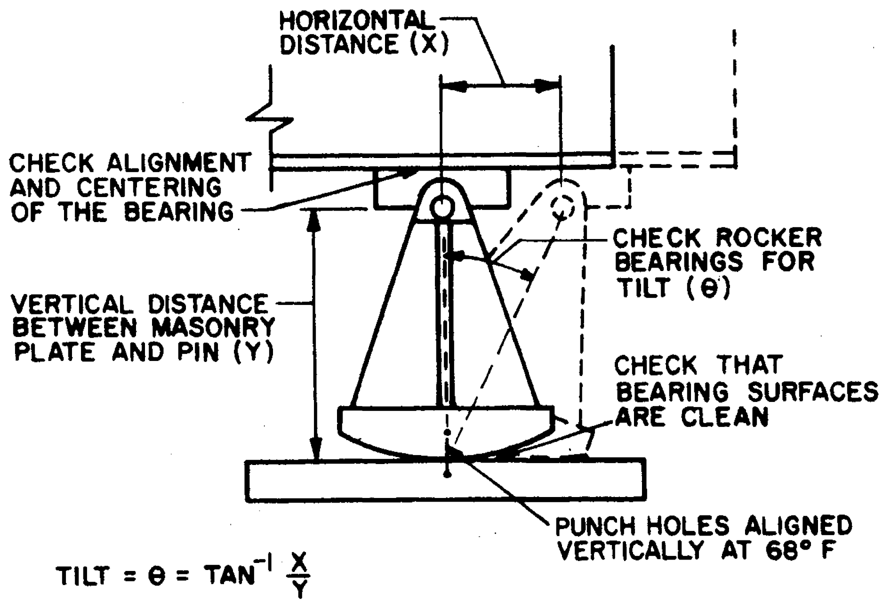


Figure 11-15 Rocker Bearing Inspection Checklist Items

Pin and Link Bearings

Inspection of pin and link bearings is essentially the same as that described for pins and hangers in Chapter 10. The amount of corrosion and ability of the connection to move freely is of critical concern, especially for suspended span bridges (see Figure 11-9).

The amount of corrosion on the pin and the interior portion of the link adjacent to it is impossible to detect visually. Ultrasonic testing or disassembly of the connection is required to determine the actual extent of deterioration. For a discussion of ultrasonic testing, refer to Chapter 15 and Section 18.4. Since disassembly is impractical during normal periodic bridge inspections, the inspector must closely examine all exposed portions of the pin and link for signs of corrosion, wear, stress, cracks, bending, and misalignment. If warranted, the inspector should recommend further action (i.e., special testing or disassembly of the pin and link).

Also examine the hanger/link for proper amount of tilt using a plumb line or level, record the opening between the ends of the girders, and record the inspection temperatures.

Pot Bearings

Pot bearing longitudinal movement can be measured in the same way as for a sliding plate bearing. The movement is one half of the difference between the front and back distances of the top and bottom plates. If the pot bearing allows movement in two directions, the inspector should investigate lateral movement as well. The inspection temperature at which the measurements are taken should also be recorded.

Although not normally required, pot bearing rotation should also be measured if it appears to be excessive. The top and bottom plates of a pot bearing are usually designed to be parallel if no rotation has taken place. Rotation can therefore be determined by measuring the length of the bottom plate and the distance between the two plates at the front and back of the bearing. The angle of rotation, measured from the horizontal, can be calculated using the following equation (see Figure 11-16):

$$\text{Rotation (Degrees)} = \tan^{-1} [(\text{Height}_1\text{-Height}_2)/\text{Plate Length}]$$

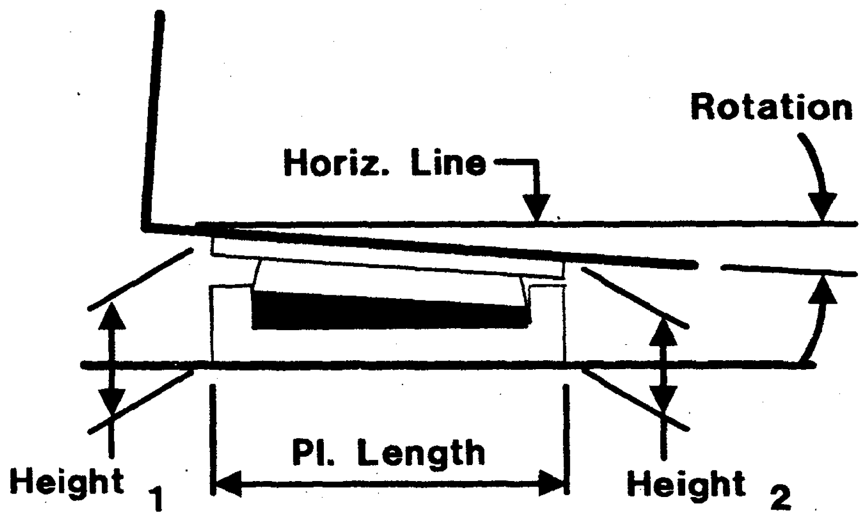


Figure 11-16 Angle of Rotation for Pot Bearing

Since the pot bearing allows multidirectional rotation, the inspector should check rotation along both sides of the bearing (see Figure 11-12).

Examine pot bearings for proper seating of the various elements with respect to one another. That is, check to see that the neoprene pad is properly seated within the pot and that the top plate is located properly over the elements below. Determine if the neoprene element is being extruded from the pot. Inspect guide bars for wear, binding, and deterioration.

Investigate welds for cracks, and examine for any separation between the PTFE and the steel surface to which it is bonded. Although they are usually hidden from view, check any exposed portions of the neoprene elements for splitting or tearing. Look for any buildup of dirt and debris in and around the bearing that would affect the smooth operation of the bearing.

Restraining Bearings

Inspection of restraining bearings is very similar to that for pin and link bearings in that the condition of the main tension elements (i.e., hanger plates, eyebars, and anchor rods/bolts) and pins is the main concern. Where these elements encompass a normal bridge bearing (see Figure 11-13), the inspection of the bearing assembly itself follows the procedures normally used for that particular type of bearing.

The elements that make up the restraining portion of the bearing should be investigated for deterioration, misalignment, or other defects that could affect the normal operation of the bearing.

11.3.2 Inspection of Elastomeric Bearings

Inspection of elastomeric bearings is somewhat more simple than the steel bearings previously discussed since there are usually fewer elements to inspect. However, certain defects in elastomeric bearings are rather difficult to detect. Elements that are common to both steel bearings and elastomeric bearings, such as sole plates, masonry plates, and anchor bolts, are described in the preceding section of this chapter. Only the elastomeric elements or elements specific to elastomeric bearings will be discussed here.

Neoprene Bearings

Neoprene bearing pads should be inspected for excessive bulging. This indicates that the bearing might be too tall for the application and therefore improperly designed. As expansion and contraction of the structure takes place, the bulge will tend to roll on the beam or bridge seat.

The bearing pad should be inspected for any splitting or tearing. Close attention should be paid to laminated neoprene bearings. Improper manufacturing can sometimes cause a failure in the area where the neoprene and interior steel shims are bonded together.

The pad should also be inspected for variable thickness other than that attributable to normal rotation of the bearing.

The plain (unlaminated) pad should be examined for any apparent growth in the length of the pad at the masonry plate. This growth indicates excessive strain in the pad. This is not a normal condition and usually indicates a problem with the design or manufacturing of the bearing. If this condition persists, the pad will eventually experience a shearing failure. Pad growth is not usually a problem with laminated bearings.

Close attention should be given to the area where the pad is bonded to the sole and masonry plates (see Figure 11-10). This is where a neoprene bearing frequently fails. Therefore, some agencies prohibit bonding of the bearing. Sometimes the pad tends to "walk" out from under the beam or girder. Some agencies prohibit painting of the contact surface between the neoprene and the sole plate for this reason.

The longitudinal movement of a neoprene bearing pad is measured in nearly the same manner as for a sliding plate bearing (see Figure 11-17). The longitudinal movement is the horizontal offset (in the longitudinal direction) between the top edge of the pad and the bottom edge of the pad.

The rotation on a neoprene bearing is measured the same way as for a pot bearing (see Figure 11-16). The top and bottom of the pad are normally parallel if no rotation has taken place. The inspector should measure the length of the pad and the height of the pad at the front and rear of the bearing. The equation presented in the pot bearing section can then be used to calculate the rotation. If a beveled pad is used to accommodate a bridge on grade, then the original dimensions of the pad must be known in order to determine the bearing rotation.

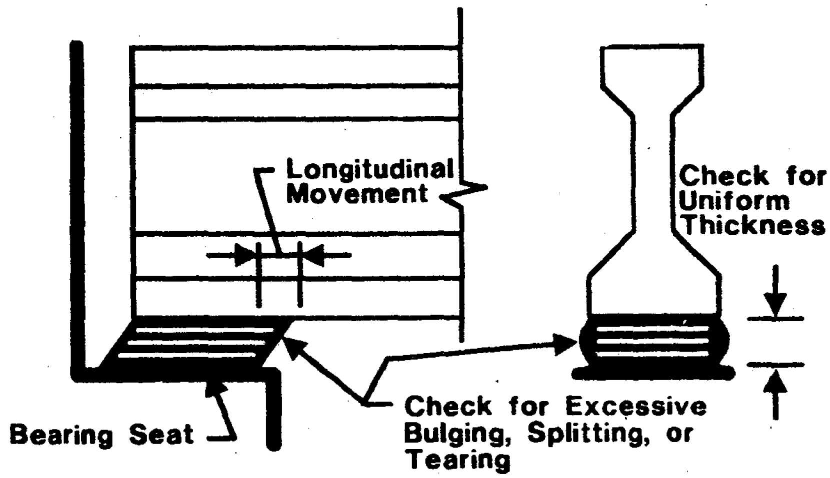


Figure 11-17 Elastomeric Bearing Inspection Checklist Items

Isolation Bearings

Isolation bearings are similar to neoprene bearing pads. They are composed of alternating layers of rubber and thin steel plates bonded together to form a unit. A lead core is tightly fitted into a preformed hole to provide rigidity (under low lateral loads such as wind and braking forces) and energy dissipation (under seismic loads). These bearings also use steel dowels to transfer shear forces.

The inspection items for isolation bearings are essentially the same as those for plain or laminated neoprene bearings. The only elements unique to isolation bearings are the lead core and steel dowels, both of which are hidden from view and can not be inspected.

11.4 Evaluation of Bearings

Bearings are considered a part, or element, of the superstructure. However, the most important point to remember about the inspection of bearings is that they will not influence the superstructure condition rating except in extreme situations. Bearings are an important inspection item, however, since small maintenance-type problems with bearings can grow progressively worse if ignored, eventually causing major problems for the bridge. If deterioration of the bearing area prevents the bearing from functioning as it should, then excessive stress can be transferred to the superstructure or substructure.

Serious situations could be created for a bridge superstructure if one of the following occurs:

- Horizontal failure of several bearings that could allow the superstructure to pull off the substructure
- Failure of a tie-down (restraining) device which could allow a span to overstress and potentially collapse

- Failure of a pin and link hanger in a two-girder structure, that could cause a section of the bridge to collapse

If such a problem existed, then the bearings would have a significant impact on the superstructure condition rating. Otherwise, the bearings affect the rating very little.

12

Inspection and Evaluation of Substructures

12

Inspection and Evaluation of Substructures

12.1 Introduction

The substructure is that component of a bridge which includes all elements supporting the superstructure. Its purpose is to transfer the loads from the superstructure to the foundation soil or rock.

This chapter describes the characteristics of three major types of substructure units:

- Abutments
- Piers and bents
- Wingwalls

The description of the characteristics includes the most common types, the primary construction materials, and the basic elements of each substructure unit. This chapter also describes the inspection locations and procedures for each substructure unit type, including the most common structural problems, their causes, and the various inspection procedures to detect those problems.

An element that can be common to each of the three major types of substructure units is the pile. Piles are structural members that transmit loads from the footing to the underlying soil or rock. Piles are constructed of timber, reinforced concrete, prestressed concrete, or steel. They can also be constructed from steel and concrete (e.g., a concrete-filled steel pipe pile). Piles may be driven vertically or battered, depending on the direction of the load to be resisted. Piles are generally completely buried and therefore can not be visually inspected. However, piles which are exposed due to soil erosion or other factors should be inspected for corrosion and for bending. Refer to Section 3.5.6 for additional information about pile foundations.

12.2 Abutments

12.2.1 Design Characteristics

An abutment is a substructure unit located at the end of a bridge. Its function is to provide end support for the bridge and to retain the approach embankment.

Abutment Types

Abutments are classified according to their locations with respect to the approach embankment. The most common abutment types are presented in Table 12-1 and in Figure 12-1.

Full height or closed types: • Gravity • Counterfort • Cantilever • Timber bent • Crib • Mechanically-stabilized earth Stub, semi-stub, or shelf type Open or spill-through type: • Curtain wall Integral type

Table 12-1 Common Abutment Types

Most structures have an expansion joint in the superstructure at the abutment. However, integral abutments supported by a single row of piles are becoming popular. In this design, the superstructure and substructure are integral and act as one unit without an expansion joint (see Figure 12-1).

Primary Materials

The primary materials used in abutment construction are plain cement concrete, reinforced concrete, stone masonry, steel (although not very common), timber, or a combination of these materials.

Varying reinforcing steel patterns are used in concrete abutments, depending on the abutment type (see Figure 12-2). In a concrete cantilever abutment, there are generally vertical bars in the rear face of the stem and backwall, transverse bars in the bottom of the footing (toe steel), and transverse bars in the top of the footing (heel steel). In a concrete spill-through abutment, there are generally vertical bars in the rear face of the backwall, horizontal bars in the bottom face of the cap beam, vertical bars in all faces of the columns, and horizontal bars in the bottom of the footing. All other bars are shear stirrups or temperature and shrinkage reinforcement.

Abutment Elements

The primary abutment elements are:

- Bridge seat
- Backwall
- Cheek wall
- Breastwall
- Footing
- Piles

The bridge seat provides a bearing area which supports the bridge superstructure.

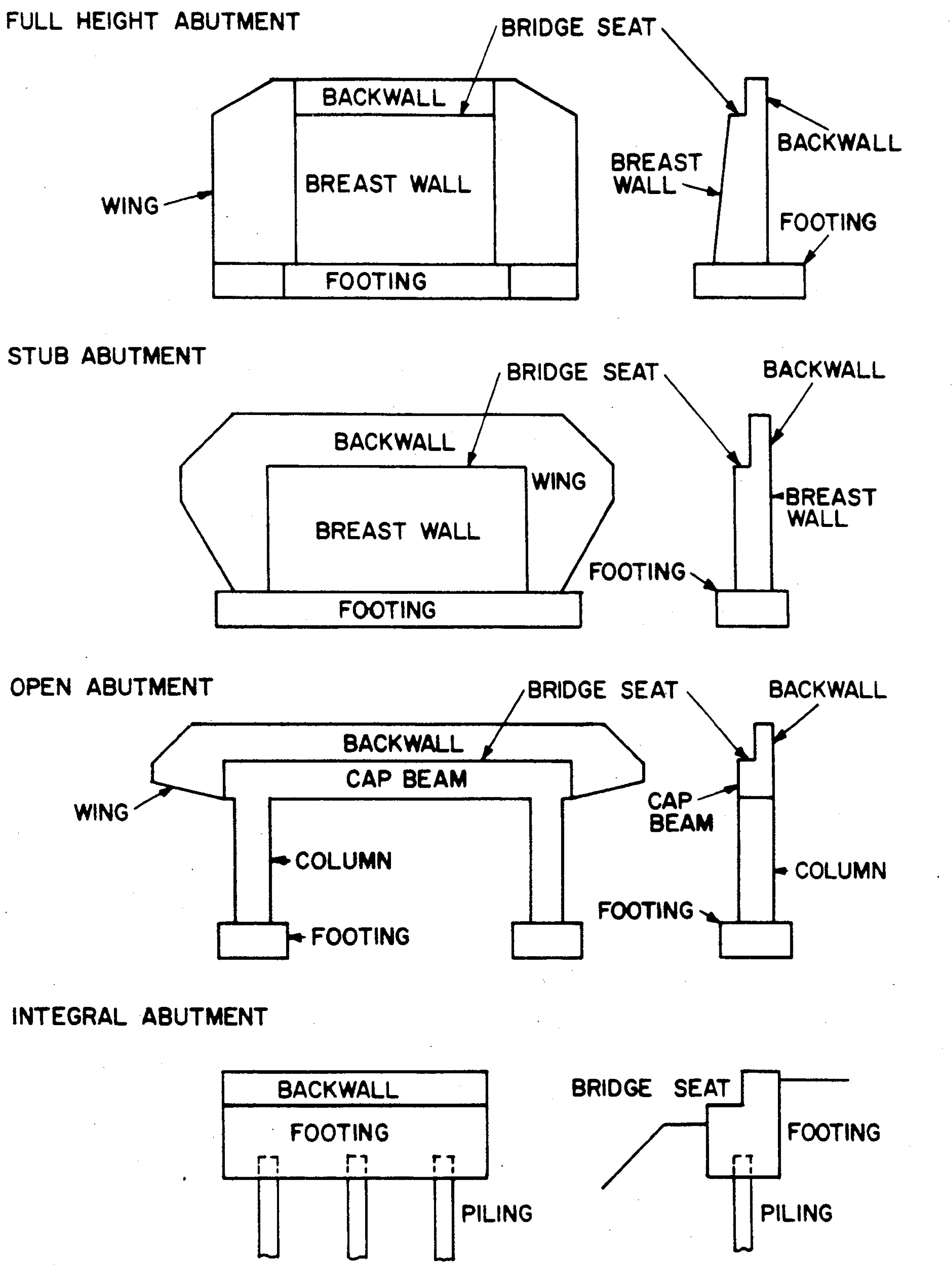


Figure 12-1 Common Abutment Types

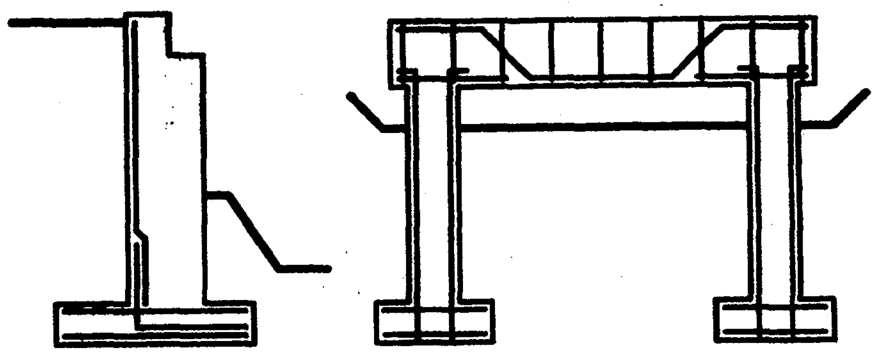


Figure 12-2 Primary Reinforcing Steel in Abutments

The backwall retains the soil and keeps it from sliding onto the bridge seat. It also provides support for the approach slab and for the expansion joint, if one is present.

The cheek wall protects the end bearings from the elements and the buildup of dirt and debris. A cheek wall is not always present.

The breastwall retains the soil behind the abutment. Stems and webwalls are forms of breastwalls.

The footing transmits the weight of the abutment, the soil loads, and the bridge reactions to the supporting soil or rock when piles are not used. It also provides stability against overturning and sliding forces. The portion of the footing in front of the wall is called the toe, and the portion behind the wall, which resists the overturning weight of the approach embankment, is called the heel.

Piles carry structure loads through the soil. They are not always present, but are generally used when the foundation soil is not adequate to resist the applied pressures of the abutment.

12.2.2 Inspection Locations and Procedures

The most common problems observed during the inspection of abutments are:

- Vertical movement
- Lateral movement
- Scour
- Rotational movement
- Failure of material

Vertical Movement

Vertical movement can occur in the form of uniform settlement or differential settlement. A uniform settlement of all bridge substructure units, including abutments, will have little effect on the structure. Uniform settlements of 1 foot have been detected on small bridges with no signs of distress.

However, differential settlement can produce serious distress in a bridge. Differential settlement may occur between different substructure units causing damage of varying magnitude depending on span length and bridge type (see Figure 12-3). It may also occur under a single substructure unit (see Figure 12-4). This may cause an opening of the expansion joint between the abutment and wingwall, or it may cause cracking or tipping of the abutment, pier, or wall.

The most common causes of vertical movement are soil bearing failure, consolidation of soil, scour, and deterioration of the abutment foundation material.

Inspection for vertical movement, or settlement, should include:

- Inspect the joint opening between the end of the approach slab and the deck. In some cases, pavement expansion or approach fill expansion could conceivably cause vertical movement in the approach slab.
- Investigate existing and new cracks for signs of settlement.
- Examine the superstructure for evidence of settlement.
- Check for scour around the abutment footing or foundation.
- Inspect the joint that separates the wingwall and abutment.

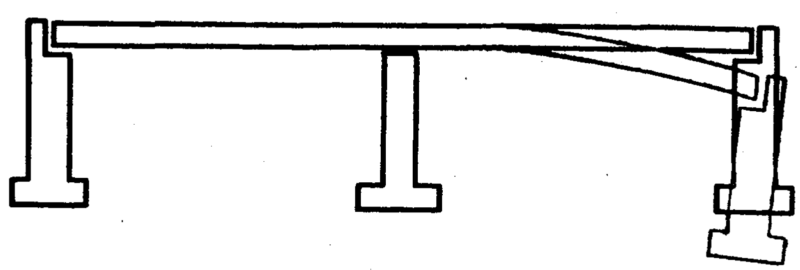


Figure 12-3 Differential Settlement Between Different Substructure Units

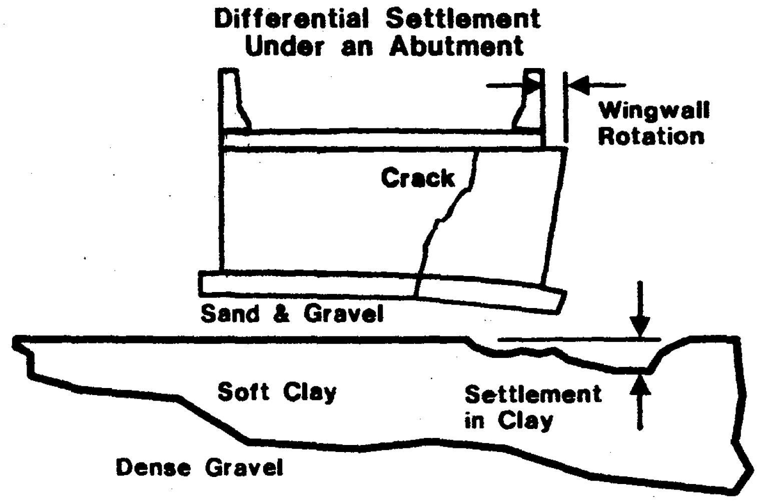


Figure 12-4 Differential Settlement Under an Abutment

Lateral Movement

Earth retaining structures, such as abutments and retaining walls, are susceptible to lateral movements, or sliding (see Figure 12-5). Lateral movement occurs when the lateral forces acting on the wall exceed the vertical forces which hold the structure in place.

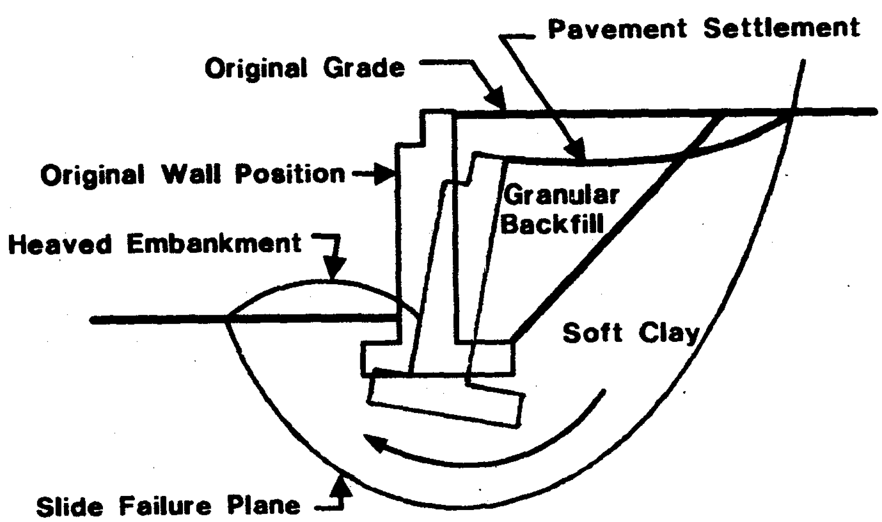


Figure 12-5 Lateral Movement of an Abutment Due to Slope Failure

The most common causes of lateral movement are slope failure, seepage, changes in soil characteristics (e.g., frost action and ice) and time consolidation of the original soil.

Inspection for lateral movement, or sliding, should include:

- Inspect the general alignment of the abutment.
- Check the bearings for evidence of lateral displacement.
- Examine the opening in the construction joint between the wingwall and the abutment.
- Investigate the joint opening between the deck and the approach slab.
- Check the distance between the end of the superstructure and the backwall.
- Examine for clogged drains.
- Inspect for erosion of the embankment material in front of the abutment.

Scour

Scour is the removal of material from a streambed as the result of the erosive action of running water (see Figure 12-6). Scour can cause undermining of abutments by streams or rivers flowing adjacent to them. Refer to Section 13.3.4 for a more detailed description of the various types of scour.

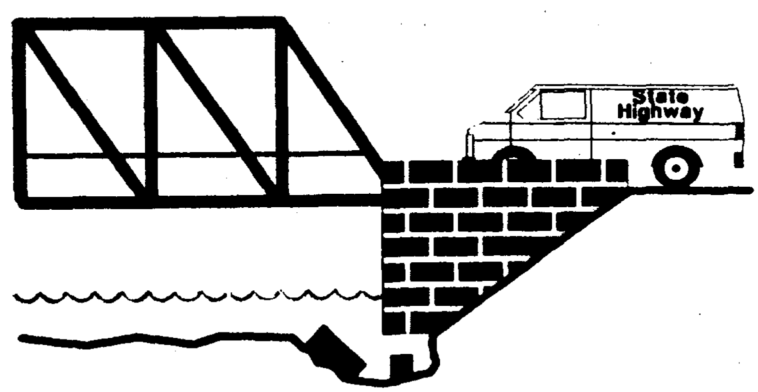


Figure 12-6 Abutment With Scour and Undermining

Inspection for scour should include probing around the abutment for signs of undermining.

Rotational Movement

Rotational movement, or tipping, of substructure units is generally the result of unsymmetrical settlements or lateral movements (see Figure 12-7). Piers, abutments, and walls are all subject to this type of movement.

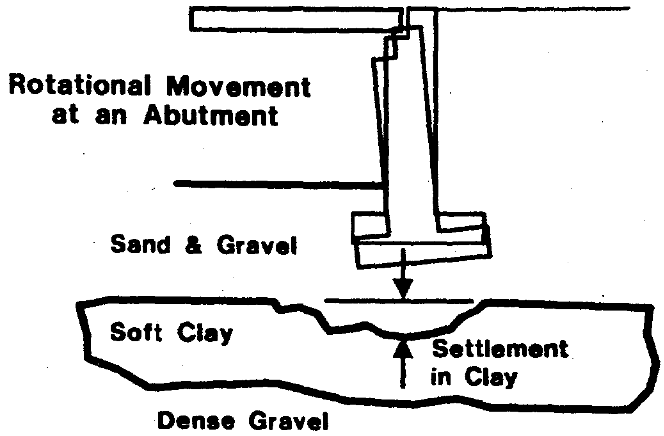


Figure 12-7 Rotational Movement of an Abutment

The most common causes of rotational movement are scouring, saturation of backfill, erosion of backfill along the sides of the abutment, and improper design.

Inspection for rotational movement, or tipping, should include:

- Check the vertical alignment of the abutment using a plumb bob; keep in mind that some abutments are constructed with a battered or sloped front face.
- Examine the clearance between the beams and the backwall.
- Inspect for clogged drains or weep holes.
- Investigate for cracks, and record the width, length, and direction.

Failure of Material

Another common problem observed during the inspection of abutments is failure of the construction material. Table 12-2 presents the most common forms of failure for various materials used in substructure units.

Refer to Chapter 4 for a more detailed description of the types and causes of deterioration observed in these construction materials.

Inspection for failure of concrete and stone masonry in abutments should include:

- Examine the bearing seats for cracking and spalling, particularly near the edges; this is particularly critical where concrete beams bear directly on the abutment seat.
- Inspect for the presence of debris and standing water on the bearing seats.
- Investigate for deteriorated concrete in areas that are exposed to roadway drainage, particularly below the joint between the backwall and the abutment (see Figure 12-8).

- Check the backwall for cracking and possible movement.
- Examine the construction joint between the backwall and the abutment.
- Inspect stone masonry for mortar cracks or loss of mortar in the joints.
- Examine stone masonry for vegetation, water seepage through cracks, loose or missing stones, weathering, and spalled or loose blocks.
- Check weep holes to see that they are clear and functioning.

Concrete: • Cracking • Spalling • Scaling • Crushing • Exposed reinforcement	Steel: • Corrosion • Cracking • Buckling
Stone masonry: • Weathering • Spalling • Cracking • Splitting • Mortar cracking and deterioration	Timber: • Decay • Insects • Marine borers • Caddisflies • Vermin damage • Weathering • Fire damage

Table 12-2 Types of Material Failure in Substructure Units

Figure 12-8 Deteriorated Concrete in an Abutment Backwall

Although a steel abutment is uncommon, the following items should be inspected if one is encountered:

- Examine bearing seat area for buildup of dirt and debris.
- After cleaning, check bearing seat area for corrosion and section loss.
- Inspect cap beam, piles, and any other steel elements for corrosion, cracking, and section loss.
- Investigate piles closely at the ground line.
- Check for scour and erosion around the piles.
- Examine all fasteners and connections for corrosion and tightness.

Inspection for failure of timber in abutments should include:

- Examine bearing seat for accumulated dirt and debris and prolonged exposure to moisture.
- Inspect for decay, insect damage, and crushing of the cap beam.
- Investigate for local failures in lagging or piles due to lateral movement.
- Check timber lagging and piles for splits, cracks, decay, insect damage, and fire damage.
- Inspect for scour around the piles.
- Examine piles very closely for decay at or near the ground line or waterline.
- Investigate splices and connections for tightness and for loose bolts.
- In marine environments, examine piles for the presence of marine borers and caddisflies.

12.3 Piers and Bents

12.3.1 Design Characteristics

A pier or bent is an intermediate substructure unit located between the ends of a bridge. Its function is to support the bridge at intermediate intervals with minimal obstruction to the flow of traffic or water. The difference between a pier and a bent is simply in physical appearance, and there is no functional difference between them.

Pier and Bent Types

The most common pier and bent types are:

- Solid shaft pier
- Column pier
- Column pier with a web wall
- Cantilever pier or hammerhead pier
- Column bent or open bent
- Pile bent

While there are many different types of piers and bents, they all function in essentially the same manner.

Primary Materials

The primary materials used in pier and bent construction are plain cement concrete, reinforced concrete, stone masonry, steel, timber, or a combination of these materials.

Varying reinforcing steel patterns are used in concrete piers and bents, depending on the type. In a concrete solid shaft pier, column pier, or column pier with a web wall, there are generally vertical bars in the stem or column, and horizontal bars in the bottom of the footing (see Figure 12-9). In a concrete cantilever or hammerhead pier, there are generally horizontal bars in the top face of the cap, vertical bars in the stem, and horizontal bars in the bottom of the footing (see Figure 12-10). In a concrete column bent or open pier, there are generally horizontal bars in the bottom face of the cap between columns, vertical bars in the columns, and horizontal bars in the bottom of the footing (see Figure 12-11). In a concrete pile bent, there are generally horizontal bars in the bottom face of the cap between columns, vertical bars in the concrete piles, and a footing is usually not present. All other bars are shear stirrups or temperature and shrinkage reinforcement.

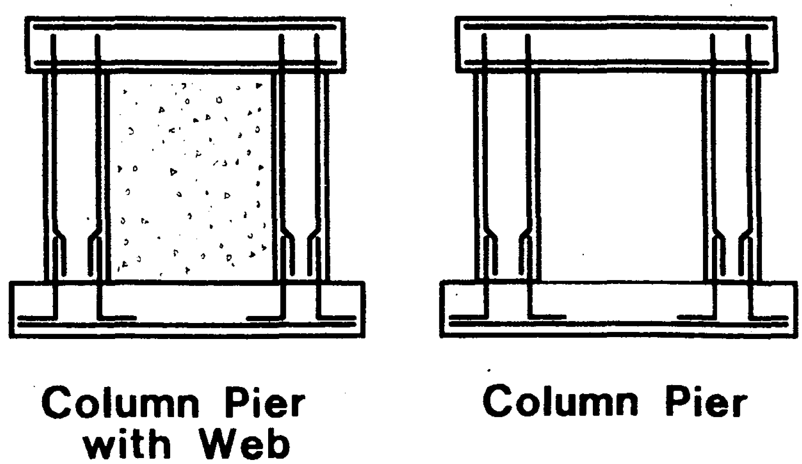


Figure 12-9 Primary Reinforcing Steel in Column Pier With Web and in Column Pier

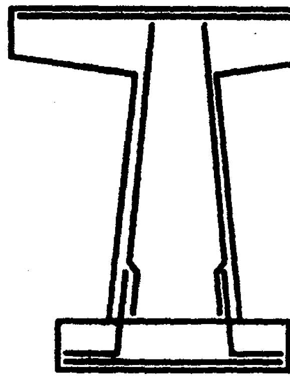


Figure 12-10 Primary Reinforcing Steel in Hammerhead Pier

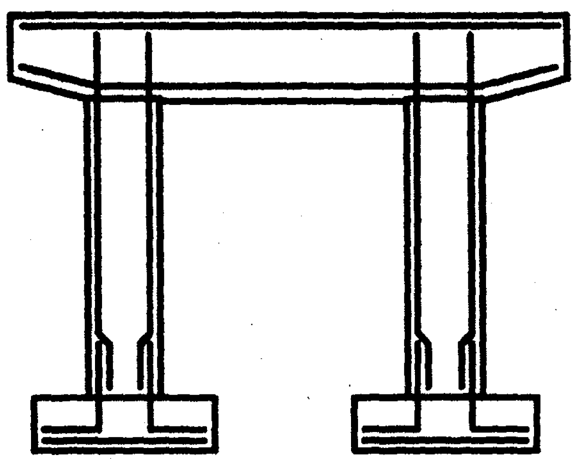


Figure 12-11 Primary Reinforcing Steel in Column Bents

Pier and Bent Elements

The primary pier and bent elements are:

- Pile or bent cap
- Pier wall or stem
- Column
- Footing
- Piles

The pile or bent cap provides support for the bearings and the superstructure.

The pier wall or stem transmits loads from the pier cap to the footing.

When columns are used, they also transmit loads from the pier cap to the footing.

The footing transmits the weight of piers or bents, the soil loads, and the bridge reactions to the supporting soil or rock when piles are not used. The footing also provides stability to the pier or bent against overturning and sliding forces.

Piles are vertical or inclined members that are driven, jacked, or cast into the ground. Their purpose is to transmit loads from the substructure through the soil. They are not always present but are generally used when the foundation soil is not adequate to resist the applied pressures of the pier or bent.

Pier Protection

Pier protection can be provided by using a collision wall pier, dolphins, or fenders. The pier shaft of a collision wall pier is encased by a solid wall of concrete to protect it from vehicular, train, or marine collisions, as well as ice flows. Dolphins are single, large diameter, sand-filled, sheet pile cylinders; clusters of timber piles or steel tubes; or large concrete blocks placed in front of a pier to protect it from marine or other traffic. Fenders are protective fences surrounding a pier to protect it from marine traffic. They may consist of timber bent arrangements, steel or concrete frames, or cofferdam sheets.

12.3.2 Inspection Locations and Procedures

The most common problems observed during the inspection of piers and bents are:

- Vertical movement
- Scour
- Rotational movement and lateral movement
- Failure of material

Vertical Movement

Differential settlement at piers can cause serious problems in a bridge. Deck joints can close up completely at piers and open excessively at abutments. Local deterioration, such as spalling, cracking, and buckling, can also occur.

The most common causes of vertical movement are soil bearing failure, soil consolidation, scour, and deterioration of the foundation material.

Inspection for vertical movement, or settlement, should include:

- For bridges with multiple simple spans, examine the joint in the deck above the pier as well as at adjacent piers and at the abutments.
- Check for any new or unusual cracking in the pier or bent.
- Investigate for buckling in steel columns of the pier or bent.
- Check the superstructure for evidence of settlement.
- Investigate for scour around the pier footing.
- In some cases, a check of bearing or top of pier elevations using surveying equipment may be necessary.

Scour

Scour is the removal of material from a streambed as the result of the erosive action of running water (see Figure 12-12). Scour around piers has been the cause of several fatal bridge collapses. Refer to Section 13.3.4 for a more detailed description of the various types of scour.

Figure 12-12 Pier Movement and Superstructure Damage Due to Scour

Inspection for scour should include:

- Probe around the pier or bent for undermining.
- Underwater inspection by divers may be required (refer to Chapter 17).
- Remote sensing using ground-probing radar.

Rotational Movement and Lateral Movement

Rotational movement (tipping) and lateral movement of piers may be caused by unsymmetrical settlement or excessive longitudinal or transverse forces, such as those experienced during an earthquake.

Inspection for rotational movement, or tipping, should include:

- Check vertical alignment of the pier using a plumb bob.
- Investigate the clearance between the ends of beams at piers and between beams and backwall.
- Inspect for cracking or spalling that may otherwise be unexplained; in the case of inspections after earthquakes, such damage will be readily apparent.

Inspection for lateral movement should include checking the linear alignment of the bridge railing or barrier.

Failure of Material

Another common problem encountered during the inspection of piers and bents is failure of the construction material. Table 12-2 presents the most common forms of failure for various materials used in substructure units. Refer to Chapter 4 for a more detailed description of the types and causes of deterioration observed in these construction materials.

Inspection for failure of concrete and stone masonry in piers and bents should include:

- Inspect for disintegration of the concrete, especially in the splash zone, at the waterline, at the ground line, and wherever concrete is exposed to roadway drainage.
- Examine the pier columns and the pier bent caps for cracks (see Figure 12-13).
- Check the bearing seats for cracking and spalling.
- Examine grout pads and pedestals for cracks, spalls, and deterioration.
- Investigate any significant changes in clearance for pier movement.
- Check all pier and bent members for structural damage caused by collision or overstress.
- Determine whether any earth or rock fills have been piled against piers, causing loads which were not provided for in the original design and producing unstable conditions.
- Check stone masonry piers for mortar cracks, water and vegetation in the cracks, and for spalled, split, loose, or missing stones.

Inspection for failure of steel in piers and bents should include:

- Check the pile bents for the presence of corrosion, especially at the ground line.
- Over water crossings, investigate the splash zone (i.e., up to 2 feet above high tide or mean water level) and the submerged part of the piles for indications of corrosion (see Figure 12-14).
- Check for debris around the pile or pier bents; debris will retain moisture and promote corrosion.
- Examine the steel caps for rotation due to eccentric connections.
- Inspect the bracing for broken connections and loose rivets or bolts.
- Check the condition of the web stiffeners, if present.
- Check the pier columns and pier caps for cracks.
- When there are any significant changes in clearance, visually inspect and measure for pier movement.

- Examine all pier and bent members for structural damage caused by collision, buckling, or overstress.
- Where a steel cap girder and continuous longitudinal beams are framed together, inspect the top flanges, welds, and webs for cracking.

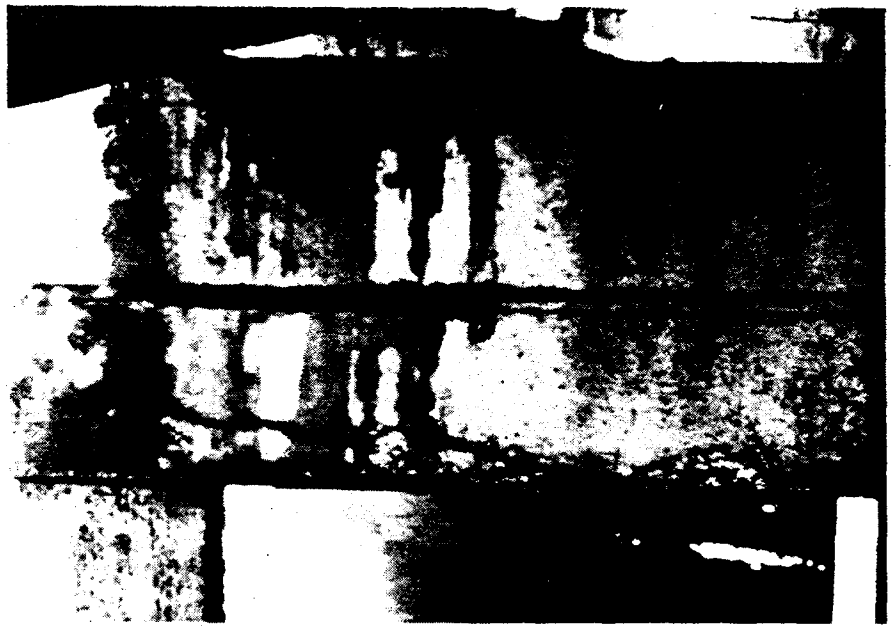


Figure 12-13 Crack in a Concrete Pier Bent Cap

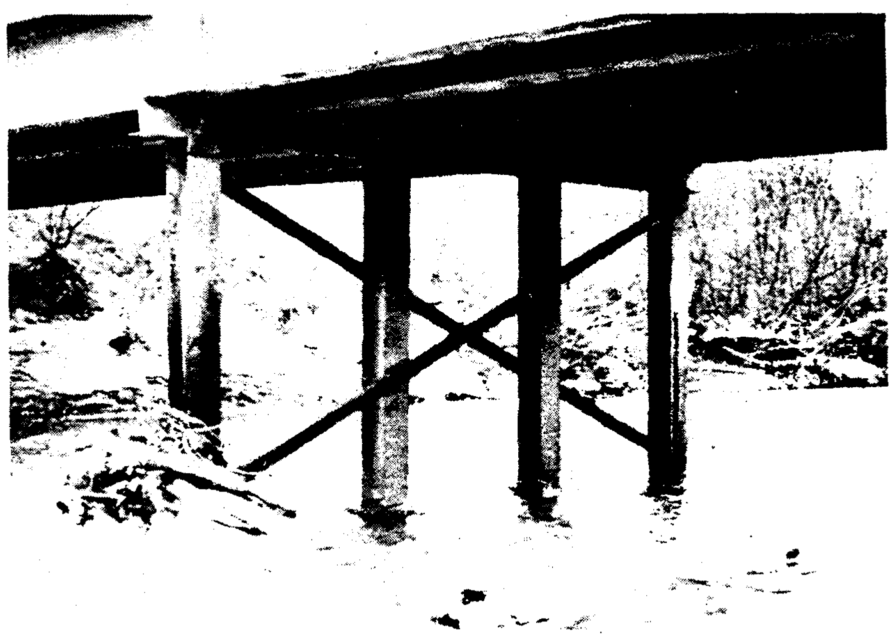


Figure 12-14 Corrosion and Debris at a Steel Pile Bent

Inspection for failure of timber in piers and bents should include:

- Check for decay in the piles, caps, and bracing. The presence of decay can be determined by tapping with a hammer or by test boring the timber. Inspect particularly at the ground line or waterline, and at joints and splices, since decay usually begins in these areas.
- Examine splices and connections for tightness and for loose bolts.
- Investigate the condition of the cap at those locations where the beams bear directly upon it and where the cap bears directly upon the piles. Note particularly any splitting or crushing of the timber in these areas.
- Observe caps that are under heavy loads for excessive deflection.
- In marine environments, check for the presence of marine borers, shipworms, and caddisflies.
- Check timber pile bents in salt water for damage caused by marine borers; common locations of damage are at checks in the wood, bolt holes, caps, or other connections.

Dolphins and Fenders

The condition of dolphins and fenders should be checked in a manner similar to that used for inspecting the main substructure elements. In concrete pier protection members, check for spalling and cracking of concrete or corrosion of the reinforcing steel. Investigate for hour-glass shaping of piles at the waterline, and check for structural damage caused by marine traffic.

In steel pier protection members, observe the splash zone (i.e., up to 2 feet above high tide or mean water level) carefully for severe corrosion. Also examine all other steel parts for corrosion, and check for structural damage.

In timber pier protection members, observe the upper portions lying between the high waterline and the mud line for marine borers, caddisflies, and decay, and check for structural damage.

12.4 Wingwalls

12.4.1 Design Characteristics

Wingwalls are the walls on the sides of an abutment which enclose the approach fill. Wingwalls are generally considered to be retaining walls since they are designed to maintain a difference in ground surface elevations on the two sides of the wall.

A wingwall is similar to an abutment except that it is not required to carry any vertical loads. The absence of the vertical superstructure load usually necessitates a wider footing to resist the overturning moment.

Wingwalls may be constructed of concrete, stone masonry, steel, or timber. In a concrete cantilever wingwall, the primary reinforcing steel consists of vertical bars in the rear face of the stem, horizontal bars in the bottom of the footing (toe steel), and horizontal bars in the top of the footing (heel steel). All other bars are temperature and shrinkage reinforcement.

There are several geometrical classifications of wingwalls, and their use is dependent on the design requirements of the structure:

- Straight - extensions of the abutment wall
- Flared - form an acute angle with the bridge roadway
- U-wings - parallel to the bridge roadway

There are also several construction classifications of wingwalls:

- Integral - cast monolithically with the abutment
- Independent - cast separately from the abutment; usually an expansion joint separates them from the abutment breastwall

12.4.2 Inspection Locations and Procedures

The inspection locations and procedures for most wingwalls are similar to those for an abutment. Many of the problems that occur in abutments are common in wingwalls also, including:

- Vertical movement
- Lateral movement
- Scour
- Rotational movement
- Failure of material (see Figure 12-15)

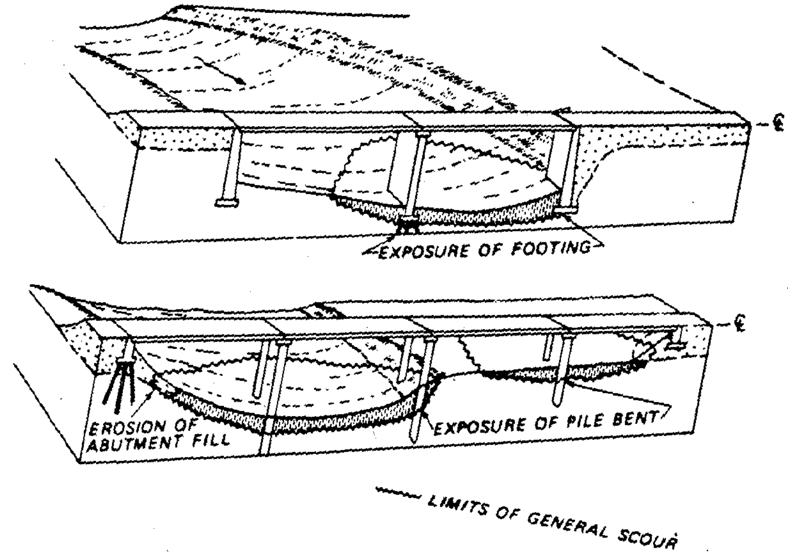
Figure 12-15 Deteriorated Concrete Wingwall

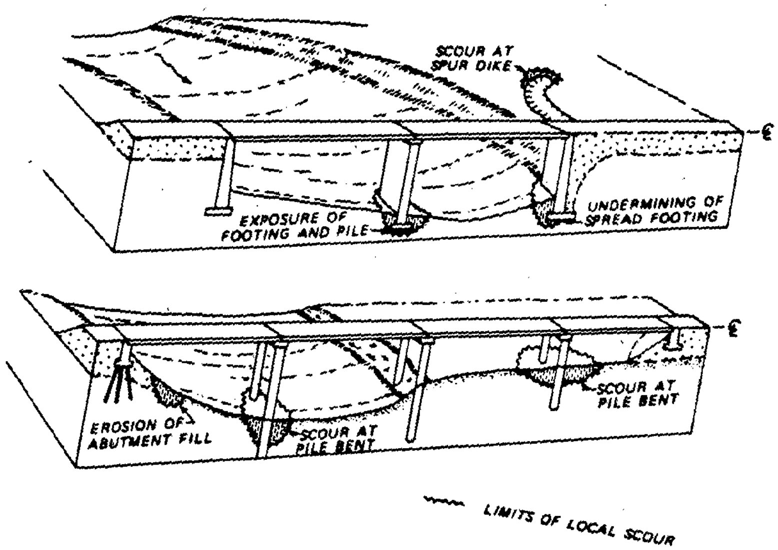
Refer to Section 12.2.2 for a more detailed description of these common wingwall problems.

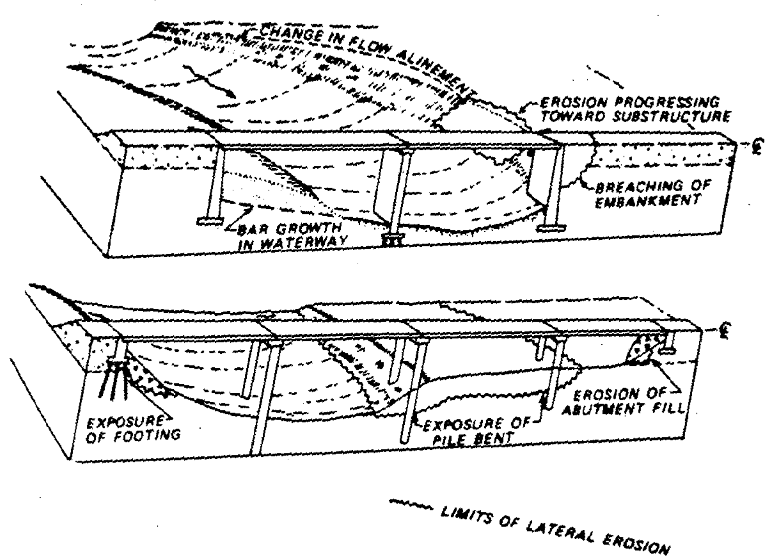
Independent wingwalls should be inspected with the abutments but their condition does not affect the evaluation and condition rating of the substructure. Integral wingwalls are included in the substructure evaluation and rating, but only that portion up to the first construction or expansion joint is considered.

13

Inspection and Evaluation of Waterways


℄
EXPOSURE OF FOOTING
EROSION OF ABUTMENT FILL
EXPOSURE OF PILE BENT
LIMITS OF GENERAL SCOUR


SCOUR AT SPUR DIKE
℄
EXPOSURE OF FOOTING AND PILE
UNDERMINING OF SPREAD FOOTING
EROSION OF ABUTMENT FILL
SCOUR AT PILE BENT
SCOUR AT PILE BENT
LIMITS OF LOCAL SCOUR


CHANGE IN FLOW ALINEMENT
EROSION PROGRESSING TOWARD SUBSTRUCTURE
℄
BREACHING OF EMBANKMENT
BAR GROWTH IN WATERWAY
EXPOSURE OF FOOTING
EXPOSURE OF PILE BENT
EROSION OF ABUTMENT FILL
LIMITS OF LATERAL EROSION

13

Inspection and Evaluation of Waterways

13.1 Introduction

An issue of major concern in bridge inspection is the safety of bridges that span active waterways. The inspection of these structures is highly dependent upon:

- The physical characteristics of the waterway
- The physical characteristics of the bridge
- The geomorphic history of the waterway (history of changes in the location, shape, and elevation of the channel)
- The hydraulic conditions imposed on the bridge by the waterway
- Changes in the river channel or flow due to development projects (such as dams, diversions, and channel stabilization) or natural phenomena
- The characteristics of the bed material of the river
- The characteristics of the bank material
- The physical interaction between the abutments, piers, and footings supporting the bridge and the impact of hydraulic conditions on general scour and local scour (i.e., erosion of the channel bed)
- Continuing analysis of the history of the bridge and its interaction with the waterway
- The physical condition of the riprap, revetments, spurs, and other structural devices that may have been utilized to help protect the bridge and adjacent channel

Rivers are the most dynamic geomorphic system that engineers must cope with in design and maintenance of bridges. The geomorphic features of the river can change dramatically with time. During major floods, significant changes can occur in a short period of time. While rivers are dynamic, bridges do not move other than in keeping with planned structural deflections resulting from anticipated static and dynamic loading of the structure.

There are several ways in which channels can change and thereby jeopardize the stability and safety of bridges. The channel bed can erode (degrade) so that bed elevations become lower, undermining the foundation of the piers and abutments. Deposition of sediment on the channel bed (aggradation) can reduce conveyance capacity through the bridge opening. Flood waters are then forced around the bridge, attacking roadway approaches, channel banks, and flood plains. Another consequence of aggradation is that the river stage may be increased to where it exerts lateral thrust and lift on the deck and girders of the bridge. The other primary way in which bridges can be adversely affected by a waterway is that bank erosion or avulsion can occur, causing the channel to shift laterally. These phenomena of aggradation, degradation or scour, bank erosion, and lateral migration can be a result of natural or induced causes and can adversely affect the bridge. This chapter describes what the inspector should look for in evaluating bridges with respect to waterways.

Refer to Chapter 17 for a detailed description of underwater inspections.

13.2 Types of Waterway Channels

Knowledge of the type and profile of a stream is essential to understand the hydraulics of the channel and its potential for change. The type of river may dictate certain tendencies or responses that may be more adverse than others. To aid in this understanding, various key river forms are briefly explained. Rivers can be broadly classified into four categories:

- Meandering rivers
- Braided rivers
- Straight rivers
- Steep mountain streams

Meandering Rivers

Meandering rivers consist of a series of bends connected by crossings. In general, pools exist in the bends. The dimensions of these pools vary with the size of the river, flow conditions, radius of the curvature of the bends, and type of bed and bank material. Such rivers are fairly predictable and experience relatively small velocities. They change plan form at a relatively slow rate and in a predictable manner, except during catastrophic flood events. Figure 13-1 illustrates channel change due to natural conditions, and it illustrates the major characteristics of a meandering river.

Braided Rivers

Braided rivers consist of multiple channels that are intertwined in braided form. At flood stages, the appearance of braiding is less noticeable. The bars dividing the multiple channels may become submerged, and the river will appear to be relatively straight. When compared with other forms of rivers, this type of channel:

- Has a steeper slope
- Experiences higher velocities
- Transports larger quantities of sediments
- Causes larger scour or erosion problems
- Is more difficult to train
- Requires careful engineering and continual maintenance of bridges subjected to this environment

Such rivers can change local plan form rapidly, causing different velocity distributions, partial blockages of portions of the waterway beneath bridges, and larger quantities of debris that can be a hazard to bridges. Figure 13-2 illustrates the plan view of typical rivers, including meandering, straight, and braided. This figure also relates form of river to channel type based on sediment load and relative stability of river type.

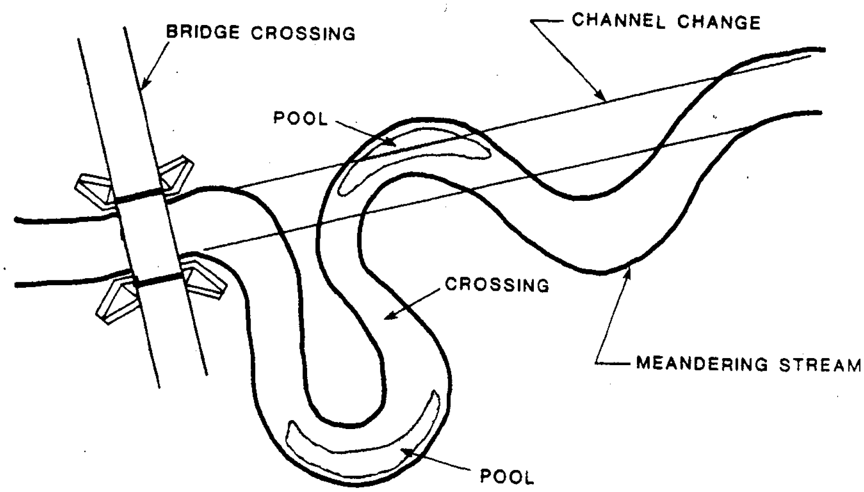


Figure 13-1 Channel Change

Straight Rivers

Straight rivers are something of an anomaly. Most straight rivers are in a transition between meandering and braided types. In straight rivers, any development that would flatten the gradient would accelerate change from a straight system to a meandering system. Conversely, if the gradient were increased, the channel may become braided. Therefore, in order to maintain the straight alignment over a normal range of hydrologic conditions, it may become necessary to utilize channel control measures, such as riprap or spurs. The characteristics of straight rivers are identified in Figure 13-2.

Steep Mountain Streams

Steep mountain streams are controlled by geologic formations, rock falls, and waterfalls. They experience very small changes in either plan form or profile when subjected to the normal range of discharges. The bed material of such river systems can consist of gravel, cobbles, and boulders, or some mixture of these different sizes. Even though these rivers are relatively stable, they can experience significant changes during episodic flood events.

13.3 Changes in Waterways Contributing to Bridge Instability or Failure

13.3.1 Bank Erosion

Erosion of channel banks, indicating a potential for channel movement of a river, is generally indicated by raw soil banks devoid of any vegetation or by active slumping and undercutting of bank material. Where such phenomena are evident and where erosion appears active, rapid, and ongoing, channel bank protection may be required.

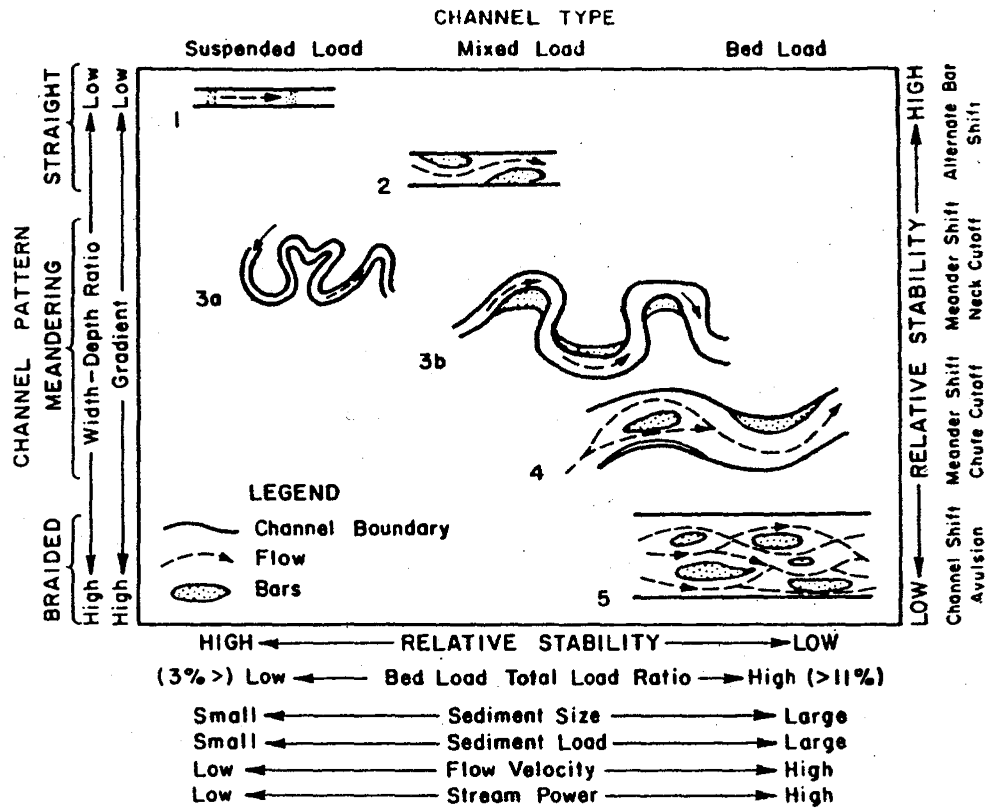


Figure 13-2 Plan View of Rivers (Source: 87)

To provide protection for bridges against lateral migration of the channel and against high velocity flows and scour, structural methods are often utilized. Common structural elements are illustrated in Figure 13-3. These flow control structures may be utilized either at the bridge, upstream from the bridge, or downstream from the bridge, and they include:

- Riprap
- Gabions
- Other types of protection

Riprap

Riprap consists of properly sized and graded rock. Riprap is protected against subsurface erosion by filters formed either of properly graded sand/gravel or of synthetic fabrics developed and utilized to replace the natural sand/gravel filter system. Such riprap must be of suitable dimensions and of proper gradation. It must be placed on an adequately flat slope to be able to resist the forces of the flowing water and of gravity. This generally requires placement of the riprap on side-slopes that range between one and a half to one and three to one, depending upon the design criteria followed. However, flatter side-slopes of two to one or three to one are preferable.

Gabions

Gabions consist of rock-filled baskets anchored together and generally anchored to the surface which they are designed to protect. Gabions may be placed on steeper slopes than riprap or may even be stacked vertically, depending upon the design procedure and the objectives of the placement of the gabions.

Other Types of Protection

Numerous other types of protection, both commercially manufactured and constructed of available materials, are often used. These provide protection to critical elements of bridges such as the approaches to the bridge, the abutments, and the piers. The manufacturers of such protection usually provide design criteria and specifications for placement and maintenance. Such erosion protection systems might include articulated concrete mats, concrete filled bags or mattresses, jacks, and other systems. Spur dikes are used to prevent erosion of the highway embankment at the abutments.

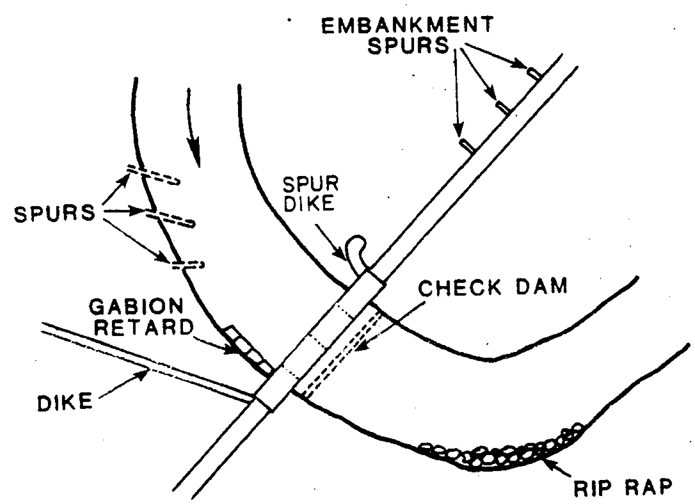


Figure 13-3 Placement of Flow Control Structures (Source: 85)

Inspection of Channel Protection

When inspecting rock riprap, gabions, and other types of surficial protection, look for:

- Separation of joints
- Exposure of underlying erodible material
- Steepening of the surface upon which these materials are placed
- Slippage of the materials downslope into the river
- Oversteepening of the protective material
- Actual loss of portions of the materials

It is essential to identify any change that is observable, including changes in the gradation of riprap. It is also essential to carefully inspect the integrity of the wire basket where gabions have been used.

In examining the condition of various types of channel protection works, a number of important factors must be considered, including:

- Separation of the protective works in such a way as to expose the underlying natural materials
- Any downslope slippage or movement of the protective materials that may indicate underwater erosion at the toe which, in turn, may have caused destabilization of the protective works
- Any increase in the slope of the protective works, which also may be indicative of excessive toe erosion beneath the water surface
- Mass wasting of the bank

Disturbance or loss of embankment and embankment protection material is usually obvious from close scrutiny of the embankment. Unevenness of the surface protection is often an indicator of the loss of embankment material from beneath the protective works. However, loss of embankment material may not be obvious in the early stages of failure. The inspector should also look for irregularities in the embankment slope.

It is even more difficult to determine conditions of the protective works beneath the water surface. In shallow water, evidence of failure or partial failure of protective works can usually be observed. However, with deeper flows and sediment-laden flows, it will be necessary for the inspector to probe or sound for physical evidence to identify whether failure or partial failure exists.

13.3.2 Channel Misalignment

Significant bank erosion or avulsions lead to a misalignment between the bridge and the new flow path. It has been pointed out that rivers are dynamic. The magnitude of change depends upon the type of river and the magnitude and duration of floods that the system has experienced. To evaluate misalignment, it is essential to refer to the original conditions at the bridge site at the time of construction. In addition, the bridge diary developed since construction should indicate changes in the characteristics of the waterway in relationship to the bridge. Evaluation of aerial photos over time is extremely useful in assessing changes in channel alignment. Figure 13-4 illustrates typical changes in flow alignment relative to the bridge opening, the abutments, and the piers. Local scour around piers and abutments is influenced by the shape of the pier and how these elements are skewed relative to water discharge.

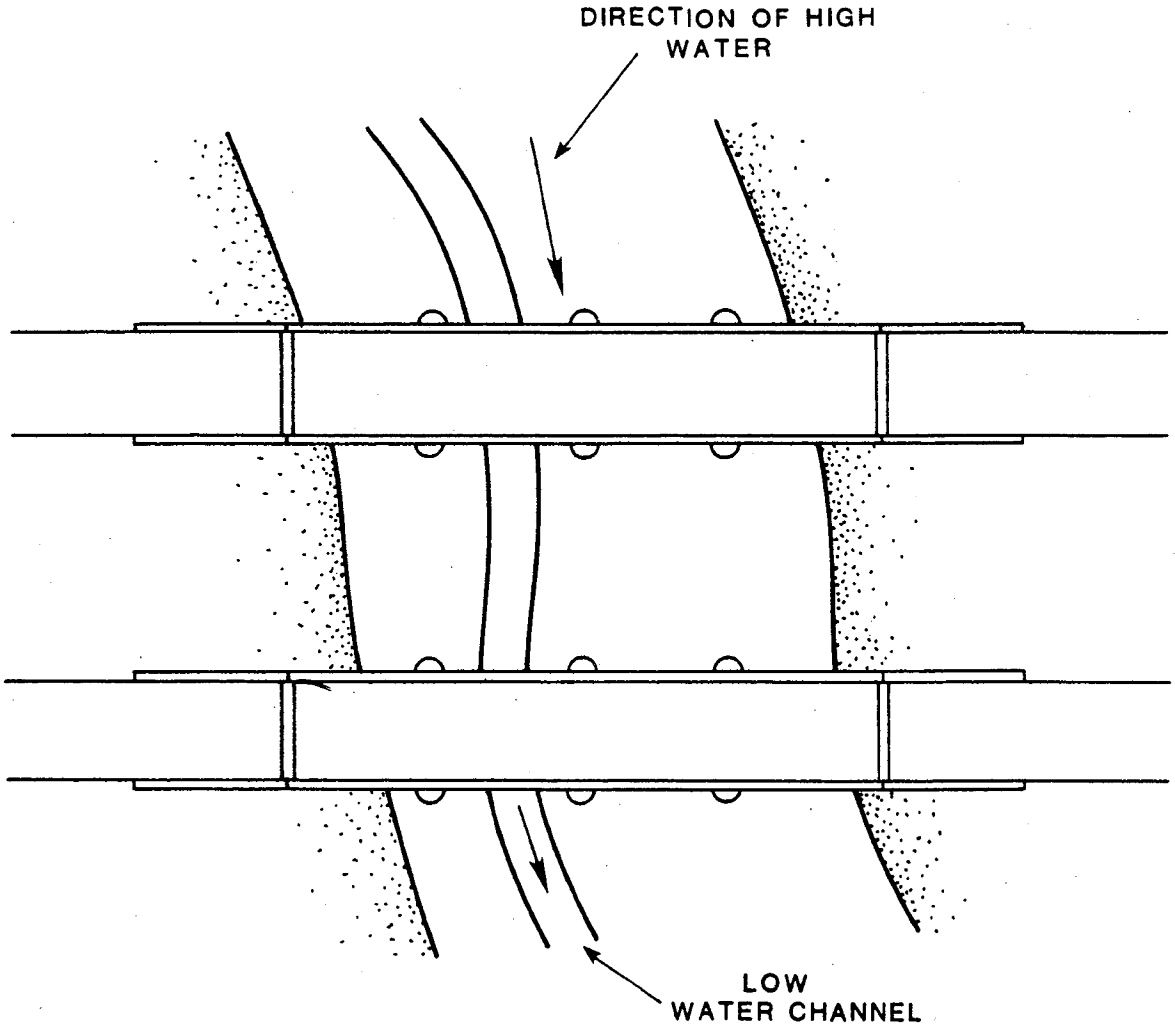


Figure 13-4 Typical Changes in Flow Alignment During High Water Causing Local Scour Around Piers

Inspection of Channel Misalignment

In general, bridges are designed so that the flow passes through the waterway parallel to the axes of the abutments and the piers. If the path of flow shifts in direction so that it approaches the abutments and the piers at a significant skew angle, the capacity of the waterway can be reduced. More significantly, both local and general scour will be increased and may lead to the failure of the structure. This depends upon the original design conditions and the degree of change resulting in misalignment in the flow with the critical elements supporting the structure. Any change in direction of the approach of the flow to the bridge and any change in the angle at which the flow hits or impinges on the abutments and piers should be carefully noted. Observations of local change in flow directions and surveys of changes in bed and bank elevations must also be made. All of this information may be utilized to rate the severity of increasing misalignment in the flow on bridge safety.

Example of channel misalignment: If the approaching flow impinges on rectangular piers at an angle of 45 degrees versus flowing parallel to the axis of the piers, the depth of scour may be increased by a factor of two or more. The actual factor of increase depends upon the characteristics of the bed material, the pier type, and the duration of the flood.

13.3.3 Hydraulic Opening

It is necessary to consider the adequacy of the hydraulic opening (the cross-sectional area under the bridge) to convey anticipated flows, including the design flood, without damage to the bridge. It is important to maintain a bridge diary for each bridge which documents the following:

- Original conditions in the waterway at the time the bridge was constructed
- Subsequent changes in the cross-sectional area of the channel under the bridge
- The accumulation of sediments, debris, or significant growth of vegetation that may block or partially block the waterway opening

Inspection of Hydraulic Opening

The primary method of assessing loss of cross-sectional area due to aggradation of the channel bed is to determine channel bed elevation changes. This can be determined by a periodic survey of the channel bed or by taking soundings from the bridge. About 20 to 25 survey or sounding points spaced across the bridge opening are adequate in determining changes in cross-sectional area. The lateral location of these surveyed points should be noted so that as subsequent inspections are conducted, the survey points can be repeated to maintain consistency. Photographs from key locations can be used to document debris and vegetation that can block the bridge opening.

Stream gages in the vicinity of the bridge may be useful in evaluating the adequacy of the waterway in relationship to changing hydraulic conditions. For example, stage-discharge curves based on discharge measurements by the United States Geological Survey (USGS) or other agencies and shifts in rating curves may indicate changes in channel bed elevation and cross section.

13.3.4 Scour

There are three forms of scour that must be considered in evaluating the safety of bridges:

- General scour
- Contraction scour
- Local scour

General scour is the general degradation of the bed along some considerable length of the river. Contraction scour results from contraction of channel width near the highway embankment. Local scour is the erosion of material adjacent to the abutments and around the piers. These three forms of scour must be considered in evaluating the safety of bridges.

Figure 13-5 is a schematic of contraction scour and local scour. General scour is similar to contraction scour in that it lowers the channel bed by erosion. Unlike contraction scour, which is limited to the bridge area only, general scour can extend both upstream and downstream of the bridge for a long distance.

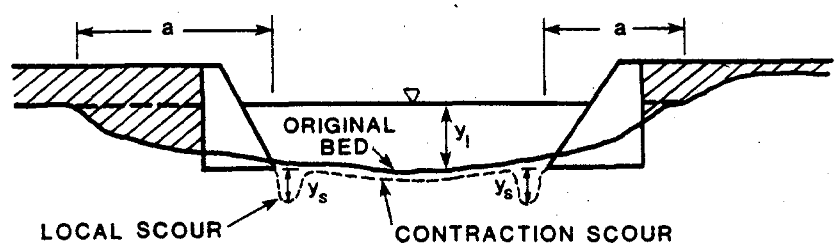


Figure 13-5 Contraction Scour and Local Scour (Source: 86)

General Scour

General scour of a river bed may be a result of the natural erosion and downcutting process that rivers experience through the years. General scour may be accelerated by natural cutoffs in a meandering river which steepens the channel gradient, increasing both the velocity of flow and hence scour. General scour may also be accelerated by various types of development or river modification, such as:

- Dam construction
- Dredging
- Straightening or narrowing of the river channel

Changes in downstream elevation, such as when a river drains into another river which is undergoing general scour of its own, can cause general scour in the upstream river. Since general scour involves degradation of the channel bed along some considerable distance of channel, major facilities are sometimes used to control erosion. These facilities can include a series of drop structures (small dam-like structures) or other erosion protection of the river bed. Presence of such structures may be indicative that the channel is experiencing scour.

Inspection of General Scour

Factors that may cause changes in general scour include:

- Water resources development, such as upstream diversions and upstream dams
- Changes in channel alignment
- Changes in channel dimensions
- Urbanization of the watershed (conversion of a more natural or agricultural area to a city)
- Other land use changes

These changing conditions may cause aggradation, loss of waterway cross section, or general scour. This may reduce the degree of safety required for the abutments and the piers considering the changed hydraulic conditions and the changed channel geometry. In this case, it is essential to refer to the bridge diary and study historical changes that have occurred in the general bed elevation through the waterway. If possible, these changes should be related to specific causes to assess the present safety of the bridge. These changes also provide insight as to future conditions that may be imposed by changed flow conditions, watershed development, or other conditions affecting the safety of the bridge.

Contraction Scour

Contraction scour results from the acceleration of flow due to either a natural contraction, a bridge contraction, or both (see Figure 13-5). Contraction scour occurs whenever the length of the bridge contracts the flow. Structural contraction of the channel width is usually dictated by savings in cost of the bridge but may be offset by increased foundation costs. Whenever the natural width of the channel is constricted by the bridge, contraction scour must be considered in the design and maintenance of the bridge.

Inspection of Contraction Scour

Inspect for constriction and contraction scour by comparing the width of the bridge opening to the width of the river upstream and downstream of the bridge.

Local Scour

In general, to reduce the cost of bridge structures, some degree of contraction is imposed upon the stream channel. This results in a narrower width of flow, further reduced by the piers, increased depth, possible reduction in resistance to flow, and increased velocities. As the water and sediment approaches the contracted section, the ability of the flow within the contracted system to transport sediments increases. Hence, the contracted flow results in a general degradation of the bed through the contraction until a new equilibrium is achieved. The magnitude of this general scour must be determined by considering the characteristics of the bed material, the erosive forces of the water, the supply of sediment from upstream, and the hydraulic characteristics of the flow. Using such an approach, an estimate of expected general scour can be computed and considered in the design of the bridge.

Local scour also occurs at piers or abutments as a result of the pier or abutment obstructing the flow. These obstructions accelerate the flow and create vortices (turbulences) that remove the sedimentary particles from around them. Generally, scour depths resulting from local scour are much larger than those from general scour, often by a factor of ten. However, if there are major changes in hydrologic conditions resulting from such factors as construction of large dams and water resources development, the long-term bed elevation changes classified as general scour can be the larger element in the total scour.

Bridges in tidal situations are particularly vulnerable to local scour. A strong tidal current whose direction reverses periodically causes a complex local scour around a bridge pier. This local scour is caused by an imbalance between the input and output sediment transport rates around the pier, and it has a negative influence on the stability of the bridge.

Three basic methods are used to protect structures from damage due to local scour:

- Place the foundations of structures at such depths that the deepest scour hole will not threaten the stability of the structure
- Prevent erosive vortices from developing
- Provide protection against local scour at some level at or below the stream bed to arrest the development of the scour hole

The first method is the recommended procedure for design unless risk analysis, cost, and engineering judgment indicate that a lesser depth could be used. Figure 13-6 illustrates local scour and common methods of reducing local scour. Wide footings or rock aprons beneath the bed level tend to reduce scour by deflecting downward currents. A projecting foundation, on the other hand, will tend to increase depth of local scour.

Inspection of Local Scour

To properly evaluate local scour and impacts of changes in hydrologic and hydraulic conditions on local scour, it is essential to develop and refer to that component of the bridge diary which deals with local scour. With each inspection, critical supporting elements of the bridge should be subjected to careful survey to determine the degree of local scour that has developed over time. By referring to this history of change in local scour, it can be determined whether or not the maximum local scour has occurred and the relationship of this maximum local scour to bridge safety.

If the survey of the magnitude of local scour indicates increased local scour with time and furthermore verifies that the local scour exceeds the anticipated maximum local scour when the bridge was designed, remedial measures must be taken to protect the bridge. Surveys of local scour along the abutments and around the piers are most often done during periods of low flow when detailed measurements can be made by wading and probing, by probing from a boat, or by sonic methods. The pattern of survey should be established and remain the same during the history of the bridge, following either a fixed radial or a rectangular grid. Changes in magnitude of local scour can then be compared at specific points over time.

The greatest problem associated with determining the magnitude of local scour relates to maximum local scour occurring at flows near flood peak followed by a period of deposition of sediments in the scour hole after the flood peak has passed and during low-flow periods. Consequently, a bridge rating should be based upon maximum scour that occurred during floods but not based upon examination of bed levels around abutments and piers during low-flow periods. Hence, it is necessary to use a variety of techniques to differentiate between maximum scour that may have occurred during flood periods and apparent scour after periods of low flow.

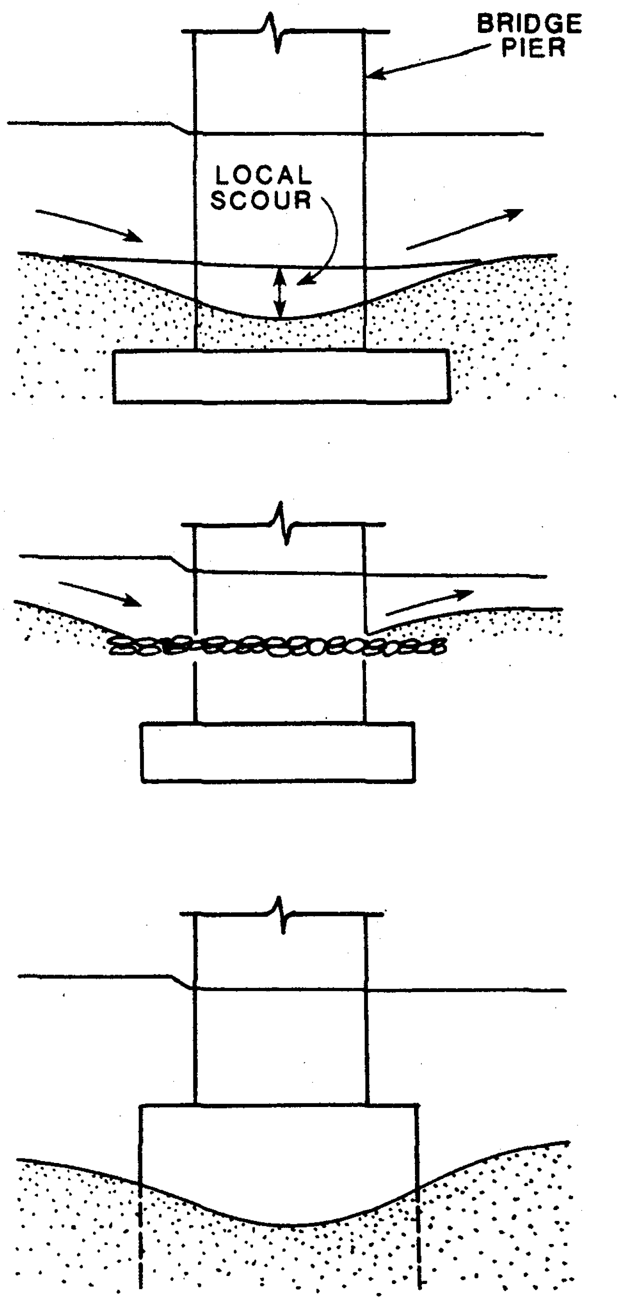


Figure 13-6 Local Scour and Local Scour Reduction at Bridge Piers

The inspector should consider utilizing probing rods and core samples to differentiate between backfill in the scour hole and the bottom of the scour hole. It may be possible to use geotechnical means as another alternative to differentiate between materials that have deposited in the scour hole and the bottom of the scour hole. It may also be necessary to use underwater surveys using divers, perhaps even diverting the water away from critical elements to allow removal of loose backfill material. The inspector can then determine the true level of maximum scour in relationship to the bridge's supporting structural elements.

The problem of accurately determining maximum local scour and rate of change of local scour over time is one of the most difficult aspects of bridge inspection and is one of the most important aspects of evaluating bridge safety. Additional research is being conducted to provide better guidelines for investigating local scour in relationship to bridge safety. (88)

13.4 Undermining of Structural Elements

The undermining of structural elements is basically an extreme form of general scour and local scour, which are the two most important variables. It is essential to determine whether or not undermining has a potential to develop, as well as whether it has already occurred. Undermining can pose an immediate threat to safety and must be dealt with immediately.

With small bridges, L-shaped rods can be used to probe at the base of abutments and around exposed footings to determine possible undermining. On the other hand, undermining may be very difficult to identify due to the redeposition of sediments during periods of low flow after undermining has occurred. However, in those channels where the bed is formed of coarse rock and the sediment supply to the bridge crossing is small, it is possible to inspect the footings and abutments because the backfill with fine sediments during periods of low flow generally does not occur. For these types of systems, an L-shaped rod can be used to identify that there has been some undermining and that critical conditions may exist in terms of bridge safety.

For areas not accessible to effective probing, it is essential to use underwater survey techniques utilizing divers and underwater cameras. In addition, where conditions permit, the inspector can also use detailed surveys of the aerial extent and depth of the cavities that have been eroded under these key supporting elements of bridges. Refer to Chapter 17 for a more detailed description of underwater inspections.

13.5 Material Defects

As an integral part of the waterway inspection, careful consideration should be given to the identification of material defects. A loss of quality and quantity of materials required to provide bridge safety may occur in a variety of ways. Again, a careful record of changes in characteristics of materials should be recorded in the bridge diary. Using this procedure, changes over time can be compared and any decision concerning maintenance requirements or replacement becomes more straightforward with such historic information available.

Inspection of Material Defects

A careful survey of the quality of the concrete, timber, and other materials utilized in the abutments and piers should be conducted. Reinforced and unreinforced concrete are the materials most commonly encountered in substructure construction, but stone masonry, steel, and timber have also been used. Check all elements for evidence of tilting, splitting, or vertical or lateral movement. Also, look for signs of material deterioration. For concrete, check for map cracking, delamination, and spalling. For stone masonry, check the stones and the joints for deterioration, noting any missing stones.

Footings and piles are visible after exposure due to erosion of supporting material. When visible, look for signs of footing deterioration, such as map cracking, delamination, and spalling in the concrete. Also, look for signs of distress in the form of large cracks or splitting. Check exposed piling for deterioration or buckling.

13.6 Inspection

13.6.1 Preparation for Inspection

It is necessary to identify and assemble the equipment required to conduct the waterway inspection. The required equipment will depend upon the characteristics of the river, the characteristics of the bridge, and the accessibility of the site. Documents, supplies, and equipment that might be utilized include:

- Site map
- Bridge diary (history of the bridge)
- Maps and drawings of the bridge site
- Truck, car, or trailer
- Boat, oars, motor, and anchor
- Surveying equipment (level or transit)
- Boots and wet suits
- Survey tapes and chains
- Level rod
- Compass
- Camera and film
- Video equipment and tapes
- Forms for recording information
- Past climatic and hydrologic records
- Stopwatch

Refer to Section 5.5 for a more detailed list and description of inspection equipment.

Considering the complexity of the inspection and the equipment and materials needed to execute the inspection, the inspector should develop a detailed plan of investigation, as well as forms for recording observations. A systematic procedure should be used each time that the bridge is surveyed to provide a means of accurately identifying changes that have occurred at the bridge site which may affect the safety of the bridge.

13.6.2 Inspection Procedures

The inspection of waterways should include the following general procedures:

- Record the flow conditions (e.g., low or high).
- Record the direction and distribution of flow between piers and between piers and abutments.
- Estimate velocities utilizing floats.
- Take photographs to document conditions of abutments and piers, conditions of bank protection works, and anything that appears unusual.
- Examine the stability of any river training and bank protection works to determine their stability and condition (e.g., the stability of rock riprap, spurs, and gabions); in particular, look for any gaps or spreading that may have occurred in the protective works, any changes in sizes of rock riprap, any increases in slope of protected embankments, and any evidence of slippage of protective works.
- Determine cross-sectional area of bridge opening by survey or soundings.
- Examine piers and abutments for evidence of deterioration or erosion.
- Investigate the configuration of the channel bed in the vicinity of the abutments and piers.
- Document any exposure of footings, pilings, or abutment foundations.
- Map, in detail, configurations of scour holes by wading and measuring depths on an adopted grid system, either radial or rectangular, in such a manner that the site can be resurveyed in an identical manner in subsequent inspections.
- Measure the depths of any scour holes using a wading rod, surveying rod, or sonic equipment.
- Use an L-shaped rod to check for possible undermining of exposed abutments and pier footings.
- Use straight steel or aluminum rods to probe loose sediments deposited along abutments and around footings; if sediment is finer than average bed material sizes or if the sediment is easily penetrated by the rod, it is indicative that the present sediment has accumulated in the scour hole and local scour is more severe than indicated by present accumulations of sediments.
- On the face of the piers, look for accumulations of organic debris or ice damage.
- Look for deposits of sediments upstream and downstream of piers; the size and extent of such accumulations may be indicative of the degree of scour.
- Indicate degree of urgency for removal of debris and deposits.
- Report any recent construction activity (e.g., causeways, fishing piers, and stranded vessels) which may affect stream flow under the bridge.

14

Bridge Inspection Reporting System

Abbreviations for Field Inspection Notes

Abut. = Abutment
Adj. = Adjacent
Betw. = Between
Bot. = Bottom
B.S. = Both Sides
[= Channel
Col. = Column
Conc. = Concrete
Cond. = Condition
Conn. = Connection
Cr. = Crack
Delam. = Delamination, Delaminated
Deter. = Deterioration
Diag. = Diagonal
Diam. = Diameter
Diaph. = Diaphragm
D.S. = Downstream
E = East
Eff. = Efflorescence
Elev. = Elevation
Expan. = Expansion
F.B. = Floorbeam
F.L. = Full Length
Flg. = Flange
F.S. = Far Side
Ft. = Feet
Gus. = Gusset
H.L. = Hairline
Horz. = Horizontal
Hvy. = Heavy
Int. = Interior
Lac. = Lacing
Lat. = Lateral
Lat. Br. = Lateral Brace
Len. = Length
Low. = Lower
Lt. = Light
Med. = Medium
Mid. = Middle
N = North
No Vis. Def. = No Visible Defects
N.S. = Near Side
Pl. = Plate
S = South
S.I.P. = Stay-in-Place Forms
Sq. Ft. = Square Feet
Stiff. = Stiffener
Str. = Stringer
T. Welds = Tack Welds
Typ. = Typical
U = Upper
U.S. = Upstream
Vert. = Vertical
Vis. = Visible
Vis. S. = Visible Signs
W = West
∢ = Angle

14

Bridge Inspection Reporting System

14.1 Introduction

A good bridge inspection reporting system is essential in order to protect the lives of the public and to protect the public's investment in bridge structures. It is, therefore, essential that bridge inspection reports be clear and complete, since they are an integral part of the lifelong record file of the bridge.

Because of the requirements that must be fulfilled for the National Bridge Inspection Standards (NBIS), it is necessary to employ a uniform bridge inspection reporting system. A uniform reporting system is essential in evaluating correctly and efficiently the condition of a structure. Furthermore, it is a valuable aid in establishing maintenance priorities and replacement priorities, and in determining structure capacity and the cost of maintaining the nation's bridges. The information necessary to make these determinations must come largely from the bridge inspection reporting system. Consequently, the importance of the reporting system cannot be overemphasized. The success of any bridge inspection program is dependent upon its reporting system.

This chapter presents a bridge inspection reporting system, and it covers the following topics:

- Federal Highway Administration (FHWA) Structure Inventory, Condition, and Appraisal
- Recordkeeping and documentation
- Report preparation
- Importance of the inspection report
- Quality

14.2 FHWA Structure Inventory, Condition, and Appraisal

The FHWA *Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges* (*Coding Guide*) has been revised several times.

Each state is encouraged to use the codes and instructions in the *Coding Guide*. However, its direct use is optional; each state may use its own code scheme provided that the data is directly translatable into the format of the *Coding Guide*. In other words, the states are responsible for having the capability to obtain, store, and report certain information about bridges, whether or not the *Coding Guide* is used.

The Structure Inventory and Appraisal (SI&A) Sheet is a tabulation of pertinent information about an individual structure (see Figure 14-1). Any requests by the FHWA for submittals of SI&A data will be based on the definitions, explanations, and codes supplied in this manual, its supplements, and the *Coding Guide*.

It is important to note that the SI&A Sheet is not an inspection form. Rather, it is a summary sheet of bridge data required by the FHWA to effectively monitor and manage the National Bridge Inspection Program and the Highway Bridge Rehabilitation and Replacement Program.

14.2.1 Standard Forms

The NBIS requires that the findings and results of a bridge inspection be recorded on standard forms. The SI&A Sheet is not a standard form. Rather, it is a list of bridge data that each state must report to the FHWA for each bridge in their inventory. A proper inspection will include gathering data beyond what is reported to the FHWA.

Many states have developed their own standard forms using the SI&A Sheet as a starting point. These forms generally list the major components and related elements, providing blank lines for narrative descriptions of the inspection findings. See Figure 14-2 for a sample inspection form.

The data and information required of states by the FHWA is listed on the SI&A Sheet. It is important to note that the items listed on this sheet apply to both the field and office personnel responsible for bridge inspections. The bridge inspector will not be required to obtain the data for all the items during every inspection of a bridge. Once a bridge has been inventoried, the majority of the SI&A items will remain unchanged.

The items on the SI&A Sheet are divided into three main categories:

- Inventory items
- Condition rating items
- Appraisal rating items

Structure Inventory and Appraisal Sheet

NATIONAL BRIDGE INVENTORY - - - - - - - STRUCTURE INVENTORY AND APPRAISAL MM/DD/YY

********** IDENTIFICATION **********************

(1) STATE NAME - ______________ CODE __
(8) STRUCTURE NUMBER #__________
(5) INVENTORY ROUTE (ON/UNDER) - ____ = ______
(2) STATE HIGHWAY DEPARTMENT DISTRICT __
(3) COUNTY CODE ___ (4) PLACE CODE _____
(6) FEATURES INTERSECTED - ______________
(7) FACILITY CARRIED - ______________
(9) LOCATION - ______________
(11) MILEPOINT ___.___
(16) LATITUDE __ D __.__' (17) LONGITUDE ___ D __.__'
(98) BORDER BRIDGE STATE CODE ___ % SHARE __%
(99) BORDER BRIDGE STRUCTURE NO. #__________

********** STRUCTURE TYPE AND MATERIAL *********

(43) STRUCTURE TYPE MAIN: MATERIAL - __________
TYPE - ______________ CODE ___
(44) STRUCTURE TYPE APPR: MATERIAL - __________
TYPE - ______________ CODE ___
(45) NUMBER OF SPANS IN MAIN UNIT ___
(46) NUMBER OF APPROACH SPANS ___
(107) DECK STRUCTURE TYPE - __________ CODE _
(108) WEARING SURFACE / PROTECTIVE SYSTEM:
A) TYPE OF WEARING SURFACE - __________ CODE _
B) TYPE OF MEMBRANE - __________ CODE _
C) TYPE OF DECK PROTECTION - __________ CODE _

********** AGE AND SERVICE *********************

(27) YEAR BUILT ____
(106) YEAR RECONSTRUCTED ____
(42) TYPE OF SERVICE: ON - ______________
UNDER - ______________ CODE __
(28) LANES: ON STRUCTURE __ UNDER STRUCTURE __
(29) AVERAGE DAILY TRAFFIC ______
(30) YEAR OF ADT 19__ (109) TRUCK ADT __%
(19) BYPASS, DETOUR LENGTH __MI

********** GEOMETRIC DATA **********************

(48) LENGTH OF MAXIMUM SPAN ____ FT
(49) STRUCTURE LENGTH ______ FT
(50) CURB OR SIDEWALK: LEFT __.__ FT RIGHT __.__ FT
(51) BRIDGE ROADWAY WIDTH CURB TO CURB ___.__ FT
(52) DECK WIDTH OUT TO OUT ___.__ FT
(32) APPROACH ROADWAY WIDTH (W/SHOULDERS) ___ FT
(33) BRIDGE MEDIAN - ______________ CODE _
(34) SKEW __ DEG (35) STRUCTURE FLARED _
(10) INVENTORY ROUTE MIN VERT CLEAR __ FT __ IN
(47) INVENTORY ROUTE TOTAL HORIZ CLEAR __.__ FT
(53) MIN VERT CLEAR OVER BRIDGE RDWY __ FT __ IN
(54) MIN VERT UNDERCLEAR REF - ______ __ FT __ IN
(55) MIN LAT UNDERCLEAR RT REF - ______ __.__ FT
(56) MIN LAT UNDERCLEAR LT __.__ FT

********** NAVIGATION DATA *********************

(38) NAVIGATION CONTROL - ______________ CODE _
(111) PIER PROTECTION - ______________ CODE _
(39) NAVIGATION VERTICAL CLEARANCE ___ FT
(116) VERT-LIFT BRIDGE NAV MIN VERT CLEAR ___ FT
(40) NAVIGATION HORIZONTAL CLEARANCE ____ FT

****

SUFFICIENCY RATING = ____.__
STATUS = ______________

********** CLASSIFICATION ***************** CODE

(112) NBIS BRIDGE LENGTH - ___
(104) HIGHWAY SYSTEM - ______________ _
(26) FUNCTIONAL CLASS - ______________ __
(100) DEFENSE HIGHWAY - ______________ _
(101) PARALLEL STRUCTURE - ______________ _
(102) DIRECTION OF TRAFFIC - ______________ _
(103) TEMPORARY STRUCTURE - ______________ _
(110) DESIGNATED NATIONAL NETWORK - __________ _
(20) TOLL - ______________ _
(21) MAINTAIN - ______________ __
(22) OWNER - ______________ __
(37) HISTORICAL SIGNIFICANCE - __________ _

********** CONDITION ********************** CODE

(58) DECK _
(59) SUPERSTRUCTURE _
(60) SUBSTRUCTURE _
(61) CHANNEL & CHANNEL PROTECTION _
(62) CULVERTS _

********** LOAD RATING AND POSTING ******** CODE

(31) DESIGN LOAD - ______ _
(64) OPERATING RATING - ______ __
(66) INVENTORY RATING - ______ __
(70) BRIDGE POSTING - ______________ _
(41) STRUCTURE OPEN, POSTED OR CLOSED - _
DESCRIPTION - ______________

********** APPRAISAL ********************** CODE

(67) STRUCTURAL EVALUATION _
(68) DECK GEOMETRY _
(69) UNDERCLEARANCES, VERTICAL & HORIZONTAL _
(71) WATERWAY ADEQUACY _
(72) APPROACH ROADWAY ALIGNMENT _
(36) TRAFFIC SAFETY FEATURES ____
(113) SCOUR CRITICAL BRIDGES _

********** PROPOSED IMPROVEMENTS ***************

(75) TYPE OF WORK - ______________ CODE ___
(76) LENGTH OF STRUCTURE IMPROVEMENT ______ FT
(94) BRIDGE IMPROVEMENT COST $___,___,000
(95) ROADWAY IMPROVEMENT COST $___,___,000
(96) TOTAL PROJECT COST $___,___,000
(97) YEAR OF IMPROVEMENT COST ESTIMATE 19/20__
(114) FUTURE ADT ______
(115) YEAR OF FUTURE ADT 20__

********** INSPECTIONS *************************

(90) INSPECTION DATE __/__ (91) FREQUENCY __ MO
(92) CRITICAL FEATURE INSPECTION: (93) CFI DATE
A) FRACTURE CRIT DETAIL - ___ - __ MO A) __/__
B) UNDERWATER INSP - ___ - __ MO B) __/__
C) OTHER SPECIAL INSP - ___ - __ MO C) __/__

Figure 14-1 1988 FHWA SI&A Sheet (Source: 38)

BRIDGE INSPECTION FORM

Date	______	Structure Name	______
Temperature	______	Structure No.	______
Inspected By	______	Structure Type	______
Field Book No.	______	Location	______
District	______	Features Intersected	______
County	______	ADT/Year	______
Weather	______	Functional Classification	______

58 OVERALL DECK CONDITION RATING: N 9 8 7 6 5 4 3 2 1 0

Comments: ______

Deck Elements	Rating (Good/Fair/Poor/Not Applicable)				Remarks
Wearing Surface	G	F	P	N/A	______
Deck - Topside	G	F	P	N/A	______
Deck - Underside	G	F	P	N/A	______
SIP Forms	G	F	P	N/A	______
Curbs	G	F	P	N/A	______
Medians	G	F	P	N/A	______
Sidewalks	G	F	P	N/A	______
Parapets	G	F	P	N/A	______
Railing	G	F	P	N/A	______
Expansion Joints	G	F	P	N/A	______
Drainage System	G	F	P	N/A	______
Lighting	G	F	P	N/A	______
Utilities	G	F	P	N/A	______
______	G	F	P	N/A	______
______	G	F	P	N/A	______

Record Elevations

@ ______

@ ______

72 APPROACH ROADWAY ALIGNMENT APPRAISAL RATING: N 9 8 7 6 5 4 3 2 1 0

Comments: ______

Approach Elements	Rating				Remarks
Pavement Condition	G	F	P	N/A	______
Vertical Alignment (Abut. 1)	G	F	P	N/A	______
Horizontal Alignment (Abut. 1)	G	F	P	N/A	______
Vertical Alignment (Abut. 2)	G	F	P	N/A	______
Horizontal Alignment (Abut. 2)	G	F	P	N/A	______

Speed Limit = ______ MPH

Speed Limit Reduction: None Minor Substantial

Figure 14-2 Sample Inspection Form

59 OVERALL SUPERSTRUCTURE CONDITION RATING: N 9 8 7 6 5 4 3 2 1 0

Comments: ______________________________

Superstructure Elements	Rating				Remarks
Stringers	G	F	P	N/A	
Floorbeams	G	F	P	N/A	
Floor System Bracing	G	F	P	N/A	
Multibeams	G	F	P	N/A	
Girders	G	F	P	N/A	
Trusses - General	G	F	P	N/A	
Upper Chords	G	F	P	N/A	
Web Members	G	F	P	N/A	
Lower Chords	G	F	P	N/A	
Lateral Bracing	G	F	P	N/A	
Sway Bracing	G	F	P	N/A	
Portals	G	F	P	N/A	
Arches	G	F	P	N/A	
Cables	G	F	P	N/A	
Paint	G	F	P	N/A	
Bearing Devices	G	F	P	N/A	
Connections	G	F	P	N/A	
Welds	G	F	P	N/A	
________	G	F	P	N/A	
________	G	F	P	N/A	
________	G	F	P	N/A	

Timber Decay ______________________________
Concrete Deterioration ______________________________
Steel Corrosion ______________________________
Collision Damage ______________________________
LL Deflection ______________________________
Vibration ______________________________
Member Alignment ______________________________
Utilities ______________________________

60 OVERALL SUBSTRUCTURE CONDITION RATING: N 9 8 7 6 5 4 3 2 1 0

Comments: ______________________________

Substructure Elements	Rating				Remarks
Abutments	G	F	P	N/A	
Piles	G	F	P	N/A	
Footing	G	F	P	N/A	
Stem	G	F	P	N/A	
Bearing Seat	G	F	P	N/A	
Backwall	G	F	P	N/A	
Wingwalls	G	F	P	N/A	
Piers and Bents	G	F	P	N/A	
Piles	G	F	P	N/A	
Footing	G	F	P	N/A	
Column(s)/Stem	G	F	P	N/A	
Cap	G	F	P	N/A	
________	G	F	P	N/A	
________	G	F	P	N/A	
________	G	F	P	N/A	

Scour/Undermining ______________________________
Settlement ______________________________
Substructure Protection ______________________________
Fender System ______________________________
Collision Damage ______________________________
High-water Mark ______________________________
Timber Decay ______________________________
Concrete Deterioration ______________________________
Steel Corrosion ______________________________
Paint ______________________________

Figure 14-2 (cont.) Sample Inspection Form

61 OVERALL CHANNEL AND CHANNEL PROTECTION CONDITION RATING: N 9 8 7 6 5 4 3 2 1 0

Comments: ____

____

____

Channel Elements	Remarks
Channel	______________
Streambed (align., scour, etc.)	______________
Embankments (vegetation, etc.)	______________
Streamflow (velocity, etc.)	______________
Drift and Debris	______________

	Rating				Remarks
Channel Protection	G	F	P	N/A	______________
Riprap	G	F	P	N/A	______________
Guidebanks or Spur Dikes	G	F	P	N/A	______________
Gabions	G	F	P	N/A	______________
Slope Protection	G	F	P	N/A	______________
Footing Aprons	G	F	P	N/A	______________
______________	G	F	P	N/A	______________

71 WATERWAY ADEQUACY APPRAISAL RATING: N 9 8 7 6 5 4 3 2 1 0

Comments: ____

____

____

Waterway Elements	Remarks
Hydraulic Opening	______________
Freeboard	______________
Span	______________
Floodplain	______________
Chance of Overtopping	______________
Remote	______________
Slight	______________
Occasional	______________
Frequent	______________
Overtopping Traffic Delays	______________
Insignificant	______________
Significant	______________
Severe	______________

GEOMETRIC DATA

Structure Dimensions:

No. of Traffic Lanes ______; 1-way / 2-way
Curb-to-Curb Dimension: ___ ___ ___. ___feet
Deck Width, Out-to-Out: ___ ___ ___. ___feet
Curb or Sidewalk Width: ___ ___ ___. ___feet
Structure Length: ___ ___ ___. ___feet
Vertical Overclearance: ___ ___ ___. ___inches
Vertical Underclearance: ___ ___ ___. ___inches
Lateral Underclearance (Right): ___ ___ ___. ___feet
Lateral Underclearance (Left): ___ ___ ___. ___feet

Maintenance Comments: ____

____

____

____

____

Figure 14-2 (cont.) Sample Inspection Form

Bridge Signing:

Speed Limit = ____MPH
Weight Restrictions = ____Tons; ____ Tons/Comb.
Narrow Bridge; one truck at a time; paddle boards
Speed Reduction
Vertical Clearance - Overhead: ___Ft. __ In.; Under: ___Ft. ___In.

36A	BRIDGE RAILING	0	1	N	________
36B	TRANSITIONS	0	1	N	________
36C	APPROACH GUARDRAIL	0	1	N	________
36D	APPROACH GUARDRAIL ENDS	0	1	N	________

Comments: ____________________

Follow-Up Comments:

Underwater Inspection: ____________________
Fracture Critical Inspection: ____________________
NDT: ____________________
Load Rating: ____________________
Inspection Frequency: ____________________
Special Equipment: ____________________
General: ____________________

Additional comments or sketches:

Signature: ____________________

Figure 14-2 (cont.) Sample Inspection Form

14.2.2
Inventory Items

Inventory items pertain to a bridge's characteristics. For the most part, these items are permanent characteristics which only change when the bridge is altered in some way, such as reconstruction or load restriction. Inventory items are grouped as follows:

- Identification - identifies the structure using location codes and descriptions
- Structure type and material - categorizes the structure based on the material, design and construction, the number of spans, and wearing surface
- Geometric data - pertinent structural dimensions
- Navigation data - identifies the existence of navigation control, pier protection, and waterway clearance measurements
- Classification - classification of the structure and the facility carried by the structure are identified
- Age and service - information showing when the structure was constructed or reconstructed, features the structure carries and crosses, and traffic information
- Load rating and posting - identifies the load capacity of the bridge and the current posting status
- Proposed improvements - items for work proposed and estimated costs for all bridges eligible for funding
- Inspection - inspection dates, frequency, and special emphasis

All inventory items are explained in the *Coding Guide*. Although inventory items are usually provided from previous reports, the inspector must be able to verify and update the inventory data should it be required.

14.2.3
Condition Rating Items

The condition of an element, member, or component is an evaluation of its current physical state compared to the as-built (new) condition.

The inspector should evaluate each element of a given component and assign to it a descriptive condition rating of "good," "fair," or "poor," based on the deficiencies found on the individual element. The following guidelines should be used in establishing an element's condition rating:

- Good - element is limited to only minor problems
- Fair - structural capacity of element is not affected by minor deterioration, section loss, spalling, cracking, or other deficiency
- Poor - structural capacity of element is affected or jeopardized by advanced deterioration, section loss, spalling, cracking, or other deficiency

To ensure a comprehensive inspection and as a part of the requirements of recordkeeping and documentation, an inspector should record the type, size, quantity, and severity of deterioration and deficiencies for each element in a given component.

The following SI&A items receive an overall condition rating:

- Item No. 58 Deck
- Item No. 59 Superstructure
- Item No. 60 Substructure
- Item No. 61 Channel and Channel Protection
- Item No. 62 Culverts

Items 58 through 60 are considered major components of a bridge, and they are not included with Item 62. (The inspection of culverts is discussed in Chapter 19.) Item 61 is used only for structures over waterways.

The numerical condition ratings should characterize the general condition of the entire component being rated. They should not attempt to describe localized or nominally occurring instances of deterioration or disrepair. Correct assignment of a condition rating must, therefore, consider both the severity of the deterioration or disrepair and the extent to which it is widespread throughout the component being rated.

However, in some cases, a deficiency will occur on a single element or in a single location. If that one deficiency reduces the load carrying capacity or serviceability of the component, then the element can be considered a "weak link" in the structure, and the rating of the component should be reduced accordingly.

The following general condition rating guidelines (obtained from the 1988 version of the *Coding Guide*) are to be used in the evaluation of the deck, superstructure, and substructure.

Code	Description
N	NOT APPLICABLE
9	EXCELLENT CONDITION
8	VERY GOOD CONDITION - no problems noted.
7	GOOD CONDITION - some minor problems.
6	SATISFACTORY CONDITION - structural elements show some minor deterioration.
5	FAIR CONDITION - all primary structural elements are sound but may have minor section loss, cracking, spalling, or scour.
4	POOR CONDITION - advanced section loss, deterioration, spalling, or scour.
3	SERIOUS CONDITION - loss of section, deterioration, spalling, or scour have seriously affected primary structural components. Local failures are possible. Fatigue cracks in steel or shear cracks in concrete may be present.
2	CRITICAL CONDITION - advanced deterioration of primary structural elements. Fatigue cracks in steel or shear cracks in concrete may be present or scour may have removed substructure support. Unless closely monitored it may be necessary to close the bridge until corrective action is taken.
1	"IMMINENT" FAILURE CONDITION - major deterioration or section loss present in critical structural components, or obvious vertical or horizontal movement affecting structure stability. Bridge is closed to traffic but corrective action may put bridge back in light service.
0	FAILED CONDITION - out of service; beyond corrective action.

A bridge's load-carrying capacity is not to be used in the condition rating process. The fact that a bridge was designed for less than current legal loads, and may even be posted, should have no influence upon the condition rating.

Structural capacity is defined as the designed strength of the member. However, structural capacity is different than load-carrying capacity. Load-carrying capacity refers to the ability of the member to carry the legal loads of the highway system of which the bridge is a part. Therefore, a bridge could possibly have good structural capacity yet be load posted because it is unable to carry the legal loads.

The condition rating of a bridge is a reflection of the bridge's structural capacity, not its load-carrying capacity. The load-carrying capacity is reflected in the Structural Evaluation appraisal rating.

14.2.4 Appraisal Rating Items

The following SI&A items are known as appraisal rating items:

- Item No. 67 Structural Evaluation
- Item No. 68 Deck Geometry
- Item No. 69 Underclearances, Vertical and Horizontal
- Item No. 71 Waterway Adequacy
- Item No. 72 Approach Roadway Alignment

Appraisal rating items are used to evaluate a bridge in relation to the level of service which it provides on the highway system of which it is a part. The structure should be compared to a new one which is built to current standards for that particular type of road. The exception is Item 72, Approach Roadway Alignment. Rather than comparing the alignment to current standards, it is compared to the general existing alignment of the approach highway.

The level of service goals used to appraise bridge adequacy vary depending on the highway functional classification, traffic volume, and other factors. The goals are set with the recognition that widely varying traffic needs exist throughout highway systems. Many bridges on local roads can adequately serve traffic needs with lower load capacity and geometric standards than would be necessary for bridges on heavily traveled main highways.

If national uniformity and consistency are to be achieved, similar structure, roadway, and vehicle characteristics must be evaluated using identical standards. Therefore, tables and charts have been developed which must be used to evaluate the appraisal rating items for all bridges submitted to the National Bridge Inventory, regardless of individual state criteria used to evaluate bridges.

The tables appear in the *Coding Guide* and are specific enough that several states now program their computerized bridge management system to automatically calculate several of the appraisal rating items.

14.3 Recordkeeping and Documentation

When inspecting large or complex bridges it will be necessary to use a notebook, in addition to any standard inspection form. The inspection notebook should contain:

- A standard notation system for indicating the condition of the elements or members
- Sketches of elements or members showing typical and deteriorated conditions
- Standard nomenclature for the elements of members and the components made up of these members
- A log or index for photographs
- Brief narrative descriptions of general and component conditions

When the notebook format is selected for recording bridge inspection results, the information should be recorded systematically. The following describes a suggested content outline.

Title Page

The title page should contain the name of the structure, structure identification number, location, features intersected, district, and county. The back of the title page should be used to note the date, the names of the inspectors (indicating the team leader), the field book number, temperature, and weather conditions.

Table of Contents

The next sheet should be a table of contents to the notebook.

General Format

The left-hand page should contain the element identification, descriptive rating (i.e., good, fair, poor), and comments. The right-hand page should be reserved for sketches or drawings of the elements.

In most cases it will be possible to insert reproductions of portions of the plans in the notebook. However, in some instances, sketches will have to be drawn.

The first sketch should schematically portray the general layout of the bridge, illustrating the structure plan and elevation data. The immediate area, the stream or terrain obstacle layout, major utilities, and any other pertinent details should be included.

Deck sketches should include expansion joints, construction joints, curbs, sidewalks, parapets, and railings.

Superstructure units should be sketched both in cross section, plan, and elevation views. Items to be numbered include bearings, main supporting members, floorbeams, stringers, bracing, and diaphragms.

Sketches or drawings of each substructure unit should be included. In many cases, it is sufficient to draw typical units which identify the principal elements of the substructure. Each of the elements of a substructure unit should be numbered so that they can be cross referenced to the information appearing on the data page on the left-hand side of the sketch. Items to be numbered include piling, footings, vertical supports, lateral bracing of members, and caps.

Orientation

It is important that the orientation of each element be clearly established. For example:

- Identify substructure units and sides of floorbeams with near/far (e.g., north/south or east/west) designations; alternately, number the substructure units such as Abutment #1 and Pier #3
- Sides of members can be identified by direction (e.g., "south side of Floorbeam #2" or "northeast elevation of Beam #4")
- Span numbers and bay numbers should be used to identify general areas on the bridge
- Individual beams or stringers should be numbered left to right, looking in the direction of inventory
- Upstream or downstream designations can be assigned to structures over waterways (e.g., "upstream truss," "downstream girder," or "upstream arch")
- For truss elements, identify the member with joint designations

If the orientation used during the inspection differs in any way with that used in existing documents, these differences should be clearly stated in the inspection notebook.

Dimensions

Sufficient dimensions must be documented to establish the cross section and other pertinent dimensions of elements. These should include:

- Beam or slab sizes - length, width, and depth of each; spacing and span length
- Columns - width and depth (for rectangular shapes), diameter (for round columns), length, spacing, and pile batter and spacing (for pile bents)
- Caps and struts - width, depth, clear span, and cantilever span

Defect Identification

Defects should be identified by their specific types.

Defects that are likely to occur in timber elements include:

- Decay - caused by either fungi or insects
- Checks - partial depth
- Splits - full depth
- Knots
- Cracks
- Wear - caused by traffic or water

Typical concrete defects to look for include:

- Delaminations
- Spalls
- Scaling
- Cracks
- Exposed rebar or strands
- Corrosion or section loss to rebar or strands
- Collision damage

Some of the defects that may be encountered on steel and iron elements include:

- Corrosion and section loss
- Cracks
- Deformation
- Deficiencies

Defect Qualification

Documenting of defects by the inspector must describe the seriousness of a defect. For example:

- Crack sizes - record lengths and widths
- Section loss - record the remaining section dimensions

Defect Quantification

The inspector must also describe the quantity of a defect. For example:

- "27 square feet of delaminated concrete in Span 1 of the deck"
- "25% of east face of Pier 1 is spalled"

Defect Location

The exact position of the defect on the element or member is required if load capacity analysis is to be performed. For example:

- "Left side of web, top half, 3" from north bearing"
- "Top of top flange, from 3" to 6" west of Pier 2"

The use of permanent reference points is suggested. Reference points to avoid include:

- Expansion rocker faces
- Ground levels, especially those that may be exposed to water
- Water levels

The following figures (Figures 14-3 through 14-6) show some typical field notebook pages.

14.4 Report Preparation

The purpose of the bridge inspection reporting system is to have trained and experienced personnel record objective and subjective observations of all elements of a bridge and to make logical deductions and conclusions from their observations. The bridge inspection report should represent a systematic inventory of the current condition of all bridge members and their possible future weaknesses. Moreover, bridge reports form the basis of quantifying the manpower, equipment, materials, and funds that are necessary to maintain the integrity of the structure.

A bridge inspection is not complete until a new inspection report is written. A complete inspection report contains several parts, as outlined in this section. A sample bridge inspection report is presented in Appendix B.

14.4.1 Introduction

The introduction is a narrative presentation summarizing the qualitative condition of the bridge. The introduction must properly identify the bridge (e.g., name, number, and location) and the date of inspection. The introduction should also present any high priority repair items.

CORROSION CATEGORIES

R-1
- FAILURE OF PAINT SYSTEM.
- SPOTS OF SURFACE RUST
- NO SECTION LOSS

R-2
- SURFACE SCALE PRESENT
- NO SECTION LOSS

R-3
- MEASURABLE SECTION LOSS

R-4
- HOLES, 100% SECTION LOSS

CRACK WIDTH DESIGNATIONS

HL • HAIRLINE - LESS THAN 1/16" WIDE

N • NARROW - 1/16" TO 1/8"

M • MEDIUM - 1/8" TO 3/16"

W • WIDE - GREATER THAN 3/16"

MAP CRACKING - INTERCONNECTED CRACKS OF VARYING SIZE FROM BARELY VISIBLE HL CRACKS TO WELL-DEFINED OPENINGS

ELEMENT CONDITIONS

GOOD - ELEMENT IS LIMITED TO ONLY MINOR PROBLEMS.

FAIR - STRUCTURAL CAPACITY OF ELEMENT IS NOT AFFECTED BY MINOR DETERIORATION, SECTION LOSS, CRACKING, OR OTHER DEFICIENCY

POOR - STRUCTURAL CAPACITY OF ELEMENT IS AFFECTED OR JEOPARDIZED BY ADVANCED DETERIORATION, SECTION LOSS, SPALLING, CRACKING, OR OTHER DEFICIENCY

Figure 14-3 Example of Field Notebook Pages

CONCRETE DETERIORATION SYMBOLS

LS — LIGHT SCALE - LOSS OF SURFACE MORTAR UP TO 1/4" DEEP, WITH SURFACE EXPOSURE OF COARSE AGGREGATES.

MS — MEDIUM SCALE - LOSS OF SURFACE MORTAR FROM 1/4" TO 1/2" DEEP, WITH SOME ADDED MORTAR LOSS BETWEEN THE COARSE AGGREGATE.

HS — HEAVY SCALE - LOSS OF SURFACE MORTAR SURROUNDING AGGREGATE PARTICLES OF 1/2" TO 1" DEEP. AGGREGATES ARE CLEARLY EXPOSED AND STAND OUT FROM THE CONCRETE.

SS — SEVERE SCALE - LOSS OF COARSE AGGREGATE PARTICLES AS WELL AS SURFACE MORTAR AND THE MORTAR SURROUNDING THE AGGREGATES. DEPTH OF LOSS EXCEEDS 1".

DELAMINATION - AN AREA OF CONCRETE WHICH GIVES OFF A HOLLOW SOUND WHEN STRUCK WITH A HAMMER, INDICATING THE EXISTENCE OF A FRACTURE PLANE BELOW THE SURFACE WHICH WILL LEAD TO A SPALL.

SPALL - HORIZONTAL FRACTURE OF THE CONCRETE CAUSED BY THE EXPANSION OF CORROSION ON THE REINFORCING STEEL

HONEYCOMB - ROUGHNESS OF A CONCRETE SURFACE CAUSED BY THE CONCRETE HAVING SEGREGATED SO BADLY THAT THERE IS VERY LITTLE SAND AND CEMENT TO FILL THE GAPS BETWEEN THE COARSE AGGREGATE PARTICLES

Figure 14-3 (cont.) Example of Field Notebook Pages

DANIEL DAVID ST BRIDGE
DATE: 7/90 INSP. BY R.A.T. & Z.I.P.
DECK PLAN L_6L_7
TRUSS SPAN NO. 2
88° SUNNY

ELEM.	COND.	REMARKS
ROADWAY	POOR	• LARGE SPALL @ SOUTH EAST SIDE OF DECK. 9'-0" x 6'-0" x 3" w/ REBAR EXPOSED. WATER STAINS LOCATED ON UNDERSIDE OF DECK @ SAME AREA. • D-CRACKING (HL) @ CONST. JOINT • NARROW TO MEDIUM CRACK @ ℄ NORTH BOUND LANE • DEBRIS BUILD-UP ALONG BOTH GUTTER LINES
RAILING	FAIR	• COLLISION DAMAGE TO RAILING AND VERT. POST (NEEDS REPLACED)
		~ SEE SKETCH ~

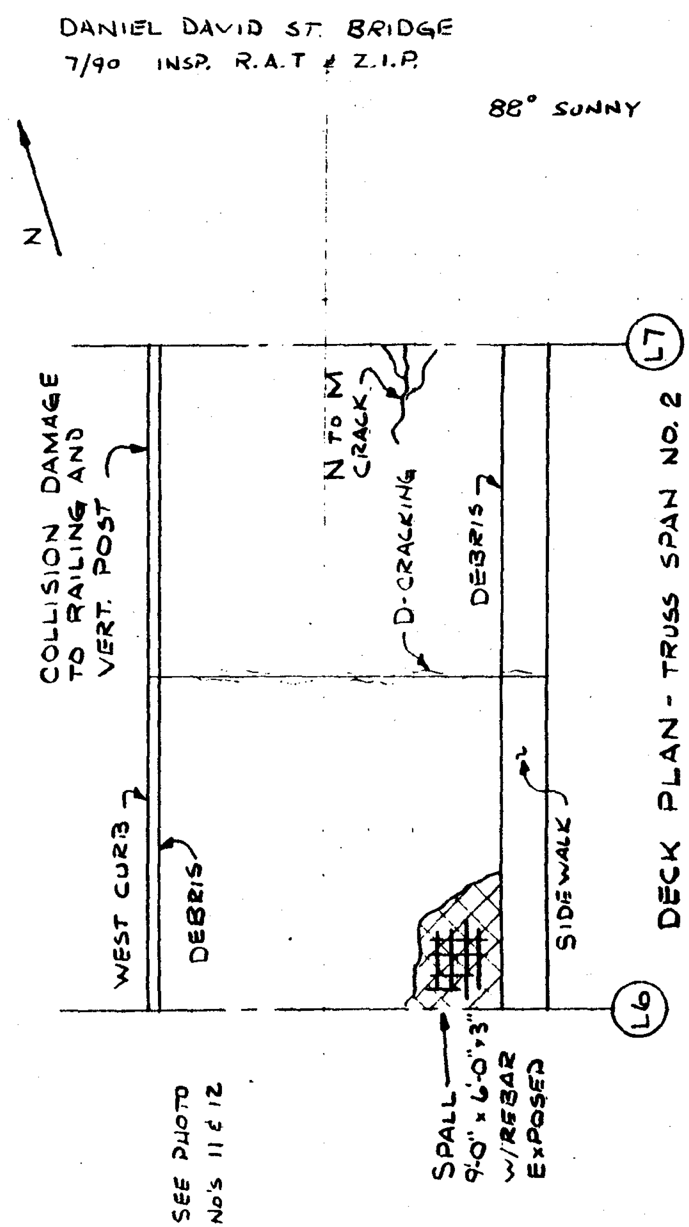


Figure 14-4 Example of Deck Inspection Notes

DANIEL DAVID ST. BRIDGE
DATE: 7/90 INSP. BY R.A.T. & Z.I.P.
TRUSS SPAN No. 2
FLOOR SYSTEM L_6 L_7 88° SUNNY

ELEM.	COND	REMARKS
S1	FAIR	• R3 1/16" FULL WIDTH OF COVER PL EDGE
S2	FAIR	• R2 SPOTS THROUGHOUT WEB AND BOTT. FLG.
S3	GOOD	• 2 LOOSE BOLTS @ STRINGER FL. BM CONN.
S4	GOOD	
S5	FAIR	• R3 1/16" TO 1/8" @ STRINGER FL. BM. CLIP ANGLE
FL. BM. 6	POOR	• R4 2" DIA. HOLE IN WEB BELOW STRINGER CONN. S5 (POSSIBLE PROBLEM AREA) • 1/4" RUST PACKING BTW STR. FL. BM. CONN. ANGLE @ S5

~ SEE SKETCH ~

DANIEL DAVID ST. BRIDGE
7/90 INSP. R.A.T & Z.I.P.
88° SUNNY

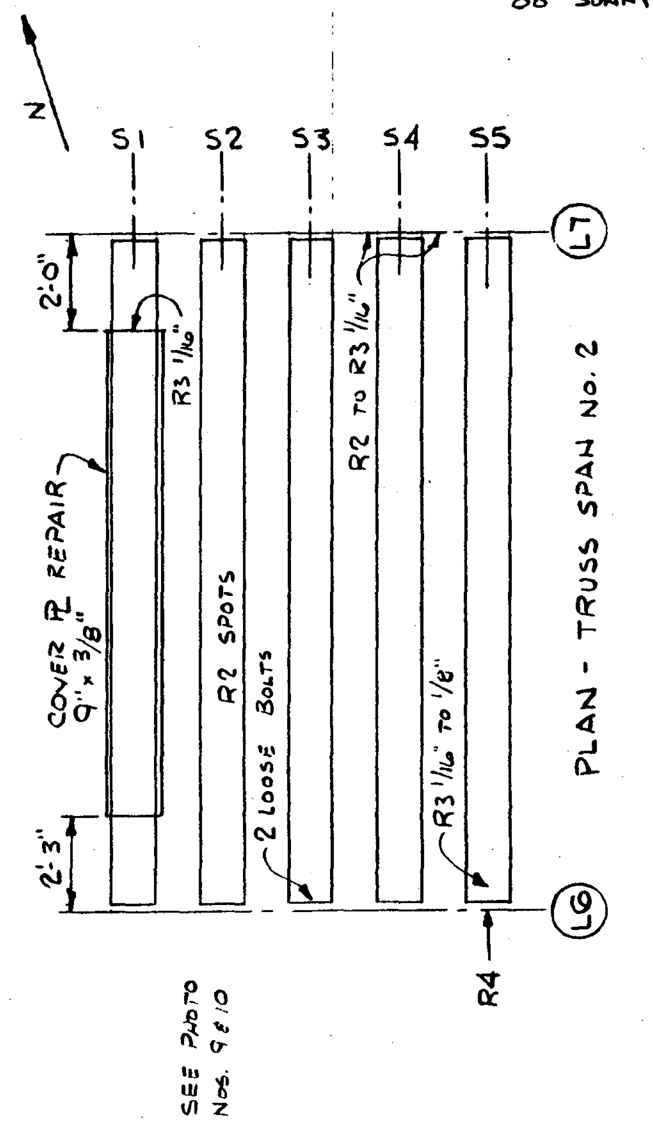
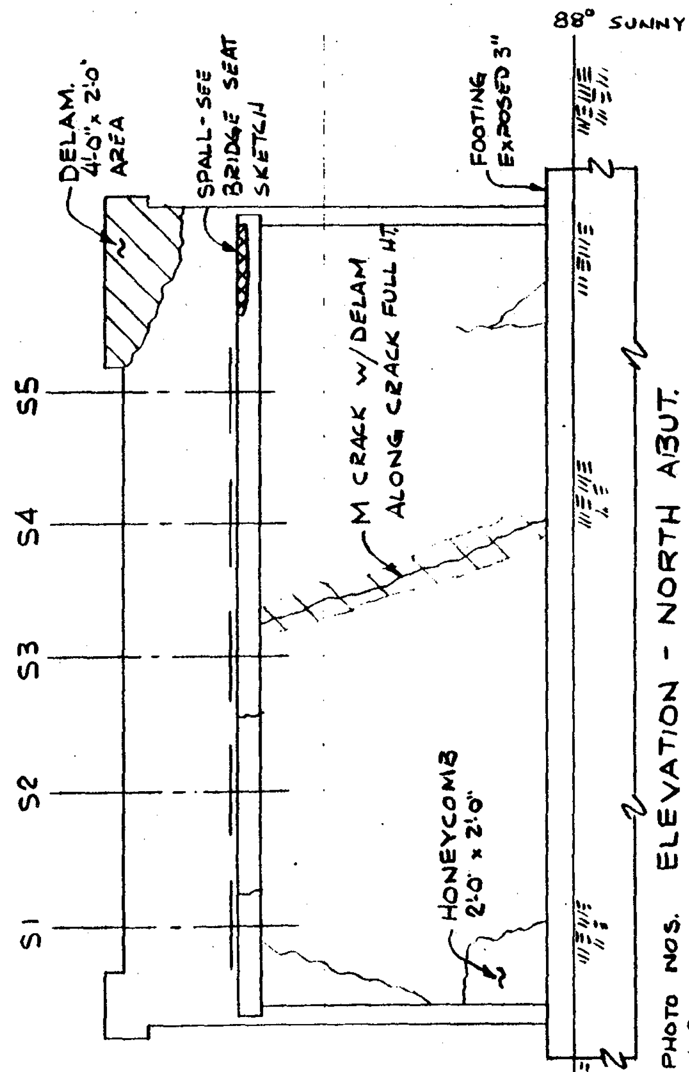


Figure 14-5 Example of Superstructure Inspection Notes

DANIEL DAVID ST. BRIDGE
DATE: 7/90 INSP. BY R.A.T. & Z.I.P.
NORTH ABUT. 88° SUNNY

ELEM.	COND.	REMARKS
FOOTING	GOOD	• EXP. 3" ABOVE GROUND LINE. NO VISIBLE SIGNS OF DEFECTS.
STEM	FAIR	• FULL HT. VERT. M CRACK W/ DELAM. ALONG OPENING • HONEYCOMB BOTT. LEFT - SEE SKETCH -
BACKWALL	FAIR	• DELAM. TOP RIGHT UNDER SIDEWALK - SEE SKETCH -
BRIDGE SEAT	FAIR	• SPALL RIGHT SIDE UNDER SIDEWALK • MS SCALING • DELAM. • H.L. CRACKS - SEE SKETCH -

DANIEL DAVID ST. BRIDGE
7/90 INSP. BY R.A.T. & Z.I.P.



• ALL CRACKS HL TO N UNLESS NOTED OTHERWISE

Figure 14-6 Example of Substructure Inspection Notes

14.4.2 Bridge Description and History

The bridge description and history section of the report should contain all pertinent data concerning the design, construction, and use of the bridge. The type of superstructure will generally be given first, followed by the type of abutments and piers, along with their foundations. If data is available, indicate the type of foundation soil, maximum bearing pressures, and pile capacities. The type of deck is also indicated.

Design Data

The design information should include a description of the:

- Skew angle
- Number of spans
- Span lengths
- Total length
- Roadway width
- Wearing surface
- Sidewalks
- Railing
- Traffic lanes
- Design live loading
- Waterway
- Other features intersected
- Clearances
- Encroachments
- Alignment

Construction Date

The construction history of the bridge should include the date it was originally built, as well as the dates and descriptions of any repairs or reconstruction projects. State what plans are available, where they are filed, and whether they are "as-built."

Service Data

State the average daily traffic (ADT) count, along with the date of record. This information should be updated approximately every five years. Any environmental conditions which may have an effect on the bridge, such as salt spray, industrial gases, bird droppings, and ship and railroad traffic, should be noted in the report.

14.4.3 Inspection Procedures

The procedures used to inspect the bridge should be explained. In most instances it is advantageous to inspect structures in the same sequence as the load path (i.e., the deck first, then the superstructure, and finally the substructure). This manual is organized and presented in that sequence.

However, many inspections cannot follow this sequence due to traffic and lane-closure restrictions. It is important to document whatever sequence was used during the inspection. This information will be useful in planning future inspections and will also serve as a checklist to make sure that all elements and components were inspected. The following information should be included:

- Component sequence (e.g., deck, superstructure, substructure, and channel)
- Equipment required (e.g., hammers and plumb bobs)
- Access equipment (e.g., rigging, ladders, and free climbing)
- Traffic restrictions (e.g., lane closures, flagmen, and hours of operation)
- Inspection methods (e.g., corings and ultrasonic)
- Personnel (e.g., number of inspectors, specialists, and boatmen)

When structure plans are not on file and a previous inspection report is not available, it may be necessary to prepare plans from field measurements to permit a stress analysis of the structure. This requirement could affect the inspection procedures.

14.4.4 Inspection Results

Narrative descriptions of the conditions should be clearly presented in the same order as the inspection sequence. Note all signs of distress, failure, or defects with sufficient accuracy so that another inspector at a future date can make a comparison of condition or rate of disintegration.

Note any load, speed, or traffic restrictions on the bridge. Include information about high water marks and unusual loadings. All work or repairs to the bridge since the last inspection should be listed. Verify or obtain new dimensions when some maintenance or improvement work has altered the dimensions of the structure. New streambed profiles should be taken with each inspection for scour detection.

The seriousness and amount of all deficiencies must be clearly stated. In emergency situations, the inspector should immediately contact the inspection supervisor and the representative of the bridge owner.

14.4.5 Conclusions

A good inspection report should explain in detail the type and extent of any deterioration found on the bridge and should point out any deviations or modifications that are contrary to the "as-built" construction plans. Not all conditions of deterioration are of equal importance. For example, a crack in a prestressed concrete box beam which allows water to enter the beam is much more serious than a vertical crack in the backwall or a spall in a corner of a slopewall.

The inspector, in formulating conclusions, must report the seriousness of the defect or deficiency involved. The inspector's experience and judgment are called upon when interpreting inspection results and arriving at reasonable and practical conclusions. The conclusions are the heart of the inspection report. Improper and misinformed conclusions will lead to improper recommendations. The inspector may need to play the role of a detective to conclude why, how, or when certain defects occurred. When the inspector cannot interpret the inspection findings, the advice of more experienced personnel should be sought.

14.4.6 Recommendations

The recommendations made by the inspector constitute the "focal point" of the operation of inspecting, recording, and reporting. A thorough, documented inspection is essential for making informed and practical recommendations to correct or preclude bridge defects or deficiencies.

All instructions for maintenance work, stress analysis, postings, further inspection, and repairs should be included. The inspector must carefully consider the benefits to be derived from making repairs and the consequences if the suggested repairs are not made. The inspector should list, in order of greatest urgency, any repairs that are necessary to maintain structural integrity and public safety.

Recommendations concerning repairs may be classified into two general categories:

- Urgent repairs
- Programmed repairs (i.e., those to be performed sometime later)

The inspector must decide whether a repair is urgent. Usually this is easily determined, but occasionally the experience and judgment of a professional engineer may be required to reach a proper decision. A large hole through the deck of a bridge obviously needs attention, and a recommendation for emergency repair is in order. By contrast, a slightly deteriorated gusset plate at a panel point of a truss may not be critical. A condition such as this would appropriately call for a recommendation for a programmed repair.

Most recommendations concerning repairs submitted by the bridge inspector will be in the category of programmed repairs (i.e., repairs that will be incorporated into preprogrammed repair and maintenance schedules). Whenever recommendations call for bridge repairs, the inspector must carefully describe the type of repairs that are needed, the scope of work to be done, and an estimate of the quantity of materials that will be required.

14.4.7 Appendices

The appendices should contain any back-up information that can be used to substantiate the inspector's conclusions and recommendations. As a minimum, the appendix should include photographs, drawings and sketches, and inspection forms. It can also include copies of any field notebooks used and specialist reports (e.g., underwater, nondestructive testing (NDT), and survey).

Photographs

Photographs will be of great assistance to anyone reviewing reports on bridge structures. It is recommended that pictures be taken of any problem areas that cannot be completely explained by a narrative description. It is better to take several photographs that may be unessential than to omit one that would preclude misinterpretation or misunderstanding of the report. At least two photographs of every structure should be taken. One of these should depict the structure from the roadway, while the other photo should be a view of the side elevation.

Drawings and Sketches

Sketches should be used freely as needed to illustrate and clarify conditions of structural elements. Clear diagrams are very helpful at future investigations in determining the progression of defects and to help determine any changes and their magnitude.

Channel profiles should be taken during each inspection of a structure.

Inspection Forms

The inspection forms should contain the actual field notes, as well as the numerical condition and appraisal ratings by the inspector. The inspection forms must be signed by the inspection team leader.

14.5 Importance of the Inspection Report

The bridge inspection report is an extremely valuable document when completed properly. A new inspection report should be made each time a bridge is inspected. To achieve maximum effectiveness, each report should be supplemented with sketches, photographs, or any other additional explanatory information. Reports and supplemental information must be accurate, and amplifying descriptions or explanations should be clear and concise.

A well prepared report will not only provide information on existing bridge conditions, but it also becomes an excellent reference source for future inspections, comparative analyses, and bridge study projects. Any conditions that are suspicious but unclear should be reported in a factual manner, avoiding speculation. Further action on such reports will be determined after review and consultation by more experienced personnel.

In preparing a report, keep in mind that rehabilitation funding may be allocated or repairs designed based on this information. Furthermore, the inspection report is a legal record which may form an important element in some future litigation. The language used in reports should be clear and concise and, in the interest of uniformity, the same phraseology should be used as much as possible to avoid ambiguity of meaning. The information contained in reports is obtained from field investigations, supplemented by reference to "as-built" or "field checked" plans. The source of all information contained in a report should be clearly stated.

14.5.1 Critical Areas

A primary purpose of the inspection report is to provide guidance for immediate follow-up inspections or action. The report provides information which may lead to decisions to limit the use of, or to close to traffic, any bridge which the inspection has revealed to be hazardous to public safety.

14.5.2 Maintenance

Another purpose of the inspection report is to provide useful information on the needs and effectiveness of routine maintenance activities. An active preventative maintenance program is vital to the long-term structural integrity of a bridge. The inspection report enables bridge maintenance to be programmed more effectively through early detection of structural defects or deficiencies, thus minimizing repair costs.

14.5.3 Load Rating Analysis

When an inspection report describes defects or deficiencies that may effect the load capacity of the structure, a revised stress analysis must be performed. The stress analysis is made to determine the safe load capacity for the current condition. It may then be necessary to restrict loads crossing the bridge so that its safe load capacity is not exceeded. It is important that the calculations for the revised load-carrying capacity analysis become part of the structure file.

14.5.4 Bridge Management

The final use of the inspection report is analysis by the states and the FHWA of the SI&A data. The intent of the analysis is to aid in the decisions for allocating and prioritizing resources.

The eligibility for federal funding is determined by a bridge's sufficiency rating. The sufficiency rating uses a scale of zero to 100. Deficient bridges receive low sufficiency ratings. Bridges scoring below 80 are eligible for rehabilitation funds, while bridges scoring below 50 are eligible for replacement funds.

The calculation of a bridge sufficiency rating is based on an empirical formula which assigns points on the basis of approximately 19 separate SI&A items.

The largest variable in the equation, up to 55 points, is determined by structural adequacy and safety. This is primarily governed by the lower of either the superstructure or substructure condition ratings.

The second variable in the sufficiency rating equation, up to 30 points, is for serviceability and functional obsolescence. This includes items such as deck condition, structural evaluation, deck geometry, underclearances, waterway adequacy, and approach roadway alignment.

Deficient bridges are divided into two categories: "structurally deficient" or "functionally obsolete." A structurally deficient bridge is weight restricted due to condition, in need of rehabilitation, or closed. A functionally obsolete bridge may be structurally sound but does not meet current standards due to inadequacies in deck geometry, clearances, or approach roadway alignment.

As previously discussed, the *Coding Guide* incorporates a level-of-service approach in the descriptions used for the appraisal rating of the nation's bridges. These items primarily affect the functional obsolescence of bridges.

The third variable of the equation is essentiality for public use, and it accounts for up to 15 points. This includes items such as detour length, average daily traffic, and defense highway designation.

The final variable of the equation is for special reductions, allowing the reduction of up to 13 points. This includes items such as detour length, traffic safety features, and structural type.

14.6 Quality

The accuracy and uniformity of information collected and recorded is vital to the management of a state's bridges for rehabilitation, maintenance, replacement, and, most importantly, public safety. Quality cannot be taken for granted. The responsibility of ensuring quality bridge inspections rests with each state. The operation of a quality review will be determined by the organization of the inspection teams. Two phrases are frequently used when discussing quality: quality control and quality assurance.

Quality Control

Quality control (QC) is the enforcement, by a supervisor, of procedures that are intended to maintain the quality of the inspection at or above a specific level. If a state's inspection program is decentralized, the individual districts are responsible for their own QC. If the inspection efforts are centralized, then the responsibility for QC is at the centralized level.

Quality Assurance

Quality assurance (QA) is the verification of the level of quality of the bridge inspection. This is accomplished by the reinspection of a sample of bridges by an independent inspection team. For decentralized state inspections, the QA program can be performed by the central staff or their agent (e.g., consultants). If the inspections are centralized within the state, then the QA program should be performed by consultants or a division separate and independent of the inspection organization.

The quality of the inspection and reports rests primarily with the inspection team leaders and team members and their knowledge and professionalism in developing a quality product. A QA/QC program is a means by which random inspections, reviews, and evaluations are performed in order to provide feedback concerning the quality and uniformity of the state's inspection program. The feedback is then used to improve the training of the bridge inspectors and the quality of the inspection report.

15

Advanced Inspection Techniques

Advanced Inspection Testing Techniques Described in this Chapter

Testing Technique	Destructive Nature		Primary Application		
	Nondestructive	Destructive	Timber	Concrete	Steel
Acoustic emissions testing	●				●
Acoustic wave sonic/ ultrasonic velocity measurements	●			●	
Boring or drilling		●	●		
Brinell hardness test		●			●
Carbonation		●		●	
Charpy impact test		●			●
Chemical analysis		●			●
Computer programs	●				●
Computer tomography	●				●
Concrete permeability		●		●	
Concrete strength		●		●	
Corrosion sensors	●				●
Delamination detection machinery	●			●	
Dye penetrant	●				●
Electrical methods	●			●	
Endoscopes		●		●	
Flat jack testing	●			●	
Ground-penetrating radar	●			●	
Impact-echo testing	●			●	
Infrared thermography	●			●	
Laser ultrasonic testing	●			●	
Magnetic field disturbance	●			●	
Magnetic flux leakage	●				●
Moisture content		●	●	●	
Neutron probe for detection of chlorides	●			●	
Nuclear methods	●			●	
Pachometer	●			●	
Pol-Tek	●		●		
Probing		●	●		
Radiographic testing	●				●
Rebound and penetration methods	●			●	
Reinforcing steel strength		●		●	
Robotic inspection	●				●
Shigometer		●	●		
Spectral analysis	●		●		
Tensile strength test		●			●
Ultrasonic testing	●		●	●	●

15

Advanced Inspection Techniques

15.1 Introduction

The advanced inspection techniques described in this chapter are to be used as a supplement to visual inspection and the other more common inspection techniques. Generally, advanced inspection techniques are used:

- To evaluate defects encountered during visual inspection
- To inspect components and elements that can not be readily inspected using visual inspection and the other more common inspection techniques
- To inspect components and elements that have presented problems in the past or have failed on bridges of similar design
- For sampling a certain percentage of critical elements (e.g., a 10% test sample of all cable sockets on a suspension bridge)
- For the complete evaluation of fracture critical members (FCMs) where impending failure is suspected (refer to Chapter 18)
- To perform rapid surveys of a large number of decks
- To monitor structure performance under service conditions

This chapter presents a brief description of several advanced inspection methods. These methods are grouped based on their primary application: timber, concrete, and steel. For each material, the methods are presented in two major categories: nondestructive and destructive.

Nondestructive methods permit inspection of the member without impairing its usefulness. Some common forms of nondestructive methods include ultrasonics, dye penetrant, X-ray, soundings, and radiography. In addition, several methods of instrumentation are presented.

As the name implies, destructive methods are those that, to some degree, affect or destroy the structural integrity of the member being tested. The effects of destructive testing may be slight, as in probing with a pick or knife; they may be moderate, as in taking a core sample; or they may be totally destructive, as in cutting a member and crushing it. Destructive methods should not be used without proper authorization. The references listed in the bibliography should be referred to for a more complete description of advanced inspection techniques.

The methods discussed in this chapter generally require extensive expertise in interpreting results, and most require expensive and complex electronic devices. They should be conducted using appropriate American Society for Testing and Materials (ASTM) specifications and American Association of State Highway and Transportation Officials (AASHTO) specifications. Therefore, most advanced inspection methods should be performed by a specially trained operator.

The techniques presented in this chapter are in varying stages of research, development, and use. The bridge inspector can look forward with anticipation to many new innovations that the future will bring.

For a description of underwater inspection equipment, refer to Chapter 17.

15.2 Timber

15.2.1 Nondestructive Testing

Pol-Tek

Pol-Tek is a sonic testing device that is used to detect rot or other low density regions in timber poles. (41) Starting about six inches below the ground line, probes are pressed on opposite sides of the timber member. A trigger trips a hammer that sends a sound wave down one probe, through the member, and up the other probe to a dial.

This method eliminates the need for making holes in good members. Members testing positive for rot are then drilled or cored to determine the nature of the defect. A dial reading that is low, compared with that of a good member of similar diameter, indicates rot or another low density region that delayed the sound wave within the member. However, several readings should be taken on the member since the readings are nearly instantaneous, and the Pol-Tek should be checked frequently for proper calibration.

Used by trained personnel, Pol-Tek works well with Douglas fir and western red cedar. However, it does not work as well with southern pine members because of the high incidence of ring shakes.

Spectral Analysis

Research is being conducted to develop a method to determine the bending strength of in situ wood members that involves a spectral analysis of stress-wave parameters using a multivariable sonic wave.

Ultrasonic Testing

Ultrasonic testing consists of high frequency sound waves introduced by a sending transducer (see Figure 15-1). Discontinuities in the specimen interrupt the sound wave and deflect it toward a receiving transducer. The magnitude of the return signal allows a measurement of the flaw size. The distance to the flaw can be estimated from the known properties of the sound wave and of the material being tested. Ultrasonic testing can be used to detect cracks, internal flaws, discontinuities, and surface damage.

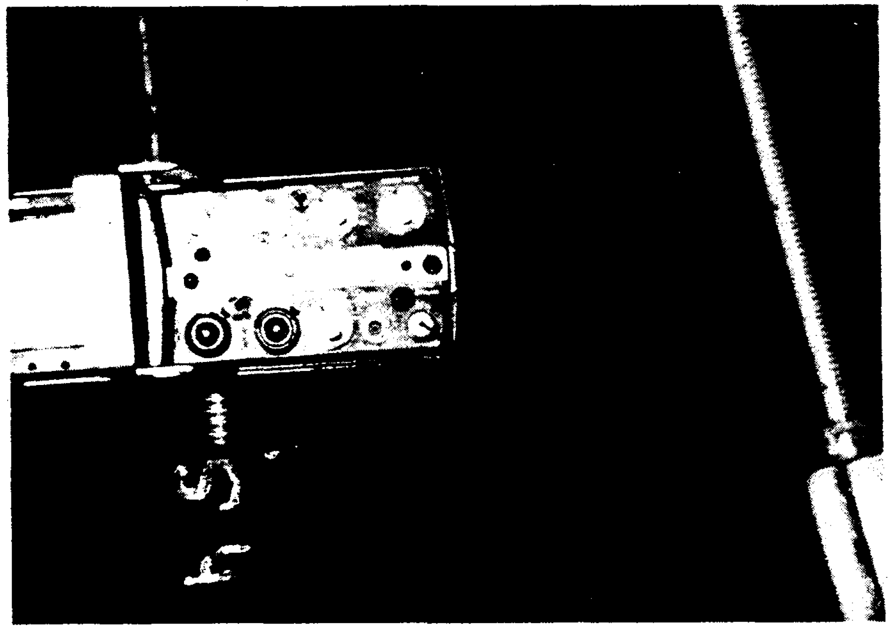


Figure 15-1 Ultrasonic Testing Equipment

In timber bridge members, ultrasonic testing can be used to determine the in-place strength of timber bridge members, both above and below water. The load carrying capacity of the member is correlated to the member's wave velocity normal to the grain and to its in-place unit weight.

15.2.2 Destructive Testing

Boring or Drilling

Boring is the most dependable and widely used method for detecting internal decay in timber. Boring permits direct examination of an actual sample from a questionable member. An increment borer is used to extract wood cores for examination (see Figure 15-2).

Drilling is performed using a rechargeable drill or a brace and bit. An abrupt decrease in drilling resistance indicates either rot or a void. However, wet wood and natural voids can falsely suggest rot. While samples are generally not attainable, observation of the wood particles removed during the drilling process can provide valuable information about the member. The depth of preservative penetration, if any, can be determined, and regions of discolored wood may indicate rot.

The use of increment cores for assessing the presence and damage due to bacterial and fungal decay requires special care. Cleaning of the increment borer is necessary after each core extraction to eliminate transfer of organisms; trichloroethane has been found to work well. (43) Core samples that do not show visible signs of decay can be cultured to detect the presence of potential decay hazards. Many laboratories can provide this service. Core samples are more commonly used to detect the presence of internal decay pockets and to measure the depth of preservative penetration and retention.

All bore holes can provide an entrance for bacterial and fungal decay to gain access to the member. As such, the holes must be treated with a preservative and must be plugged.

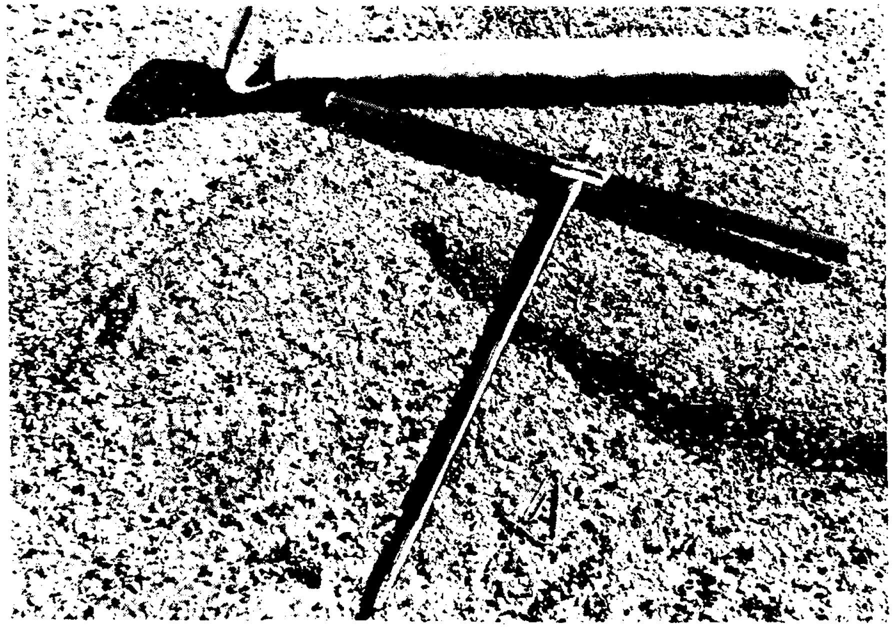


Figure 15-2 Increment Borer for Timber Inspection

Moisture Content

Moisture meters can be used to determine moisture content in a timber member. (41) Moisture contents exceeding 20% indicate the condition of the wood is conducive to decay. As a sliding hammer drives two electrodes into the wood, a ruler emerging from the top of the hammer measures the depth. These electrodes can measure moisture content to a depth of about 2 1/2 inches. Because the high moisture content of decaying wood causes steeper than normal moisture gradients in wood decaying internally, the meter is useful for determining the extent of decay.

Probing

Probing consists of inserting a pointed tool, such as an ice pick, into the wood and comparing its resistance with that of sound wood. Lack of resistance or excessive softness to probe penetration may reveal the presence of decay.

Two forms of probing are a pick test and a shell-thickness indicator. A pick test is a form of probing that is performed by removing a small piece of wood with a pick or pocket knife. If the wood splinters, it is probably sound wood, and if it breaks abruptly, it is probably decayed wood.

A shell-thickness indicator is a thin, metal, hooked rod used to determine the thickness of solid, but not necessarily sound, wood. The rod is inserted into a hole made by coring or drilling and is then pulled back with pressure against the side of the hole. The hook should attach to the edge of a rot pocket, making it possible to determine the depth of the rot and the solid wood.

Shigometer

The Shigometer measures electrical resistance to detect rot in timber members. (41) It should be used in wood with a moisture content of at least 27%, a value indicative of decaying wood. A probe is used consisting of two twisted, insulated wires with the insulation removed near the tip. This probe is inserted to various depths into a hole 3/32 inch in diameter. If the electrical resistance changes as the probe goes deeper, this indicates rot or a defect.

While this device effectively detects rot, it can also produce misleading readings on sound timber. Consequently, drilling or coring should be done on suspect members. Like the Pol-Tek, the Shigometer should be recalibrated frequently.

15.3 Concrete

15.3.1 Nondestructive Testing

A full evaluation of concrete decks can be accomplished with sonic/ultrasonic acoustic wave velocity measurements. This method delineates areas of internal cracking (including delaminations) and deteriorated concrete, including the quantification of strength characteristics (elastic moduli values). A mobile automated data acquisition device with an impact energy source and multiple sensors is the principle part of a computer-based monitoring and recording system for detailed evaluation of bridge decks. Bridge abutments and concrete support members are tested using the same recording system with a portable, hand-held sensor array. The system works directly on either bare concrete or through wearing surfaces such as asphalt. It can distinguish between debonded asphalt and delaminations, and it is effective for a detailed evaluation of large areas.

Acoustic Wave Sonic/ Ultrasonic Velocity Measurements

Delamination Detection Machinery

Delamination detection machinery is based on sonic responses and can be used to inspect concrete decks (see Figure 15-3). The portable electronic instrument consists of three components: a tapping device, a sonic receiver, and a signal interpreter. The instrument is moved across the deck as acoustic signals are passed through the deck. These signals are then received and electronically interpreted, and the output is used to generate a plan of the deck showing delaminated areas. This method can be used on asphalt covered surfaces, although accuracy decreases. (53)

Electrical Methods

Copper sulfate electrode (CSE) tests can be used to measure the concrete's ability to conduct electricity. Less electrical resistance indicates a high chloride content and establishes an estimate of corrosion activity on the reinforcing bars. Although most commonly used with bridge decks, this method has also been used with other bridge components, such as bents, to determine active corrosion. (53)

Flat Jack Testing

The flat jack method was originally developed to test the in situ stress and deformation of rock and is now being applied to masonry structures. A portion of the horizontal mortar joint is removed, and the flat jack (an envelope made of metal) is inserted and pressurized to determine the state of stress. For deformation testing, two flat jacks are inserted, one directly above the other and separated by five or six courses.

Figure 15-3 Delamination Detection Machinery

Ground-Penetrating Radar

Ground-penetrating radar is used to detect deterioration of bridge decks. This technique uses low-power, high-frequency pulsed radar. An important benefit of this method is the ability to measure the thickness of asphalt covering. It can also be used to examine the condition of the top flange of box beams that may otherwise be inaccessible. (53)

Impact-Echo Testing

The impact-echo technique has proven to be successful in detecting flaws in slabs and pavements and is now being applied to assess the condition of concrete beams and columns. Testing involves introducing a stress pulse into the concrete by mechanical impact. The pulse in the concrete is reflected by cracks, voids, and the boundaries of the structure. A transducer placed near the impact point monitors surface displacements caused by the reflections. The response can then be interpreted to detect flaws within the concrete.

Infrared Thermography

Infrared thermography is also used to detect deterioration of bridge decks. This technique uses an infrared camera to detect temperature differentials in a concrete surface. A "cold spot" indicates a delamination. Although subject to weather conditions, this technique is efficient for large surfaces. (53)

Laser Ultrasonic Testing

Laser ultrasonic testing provides information about flaws in concrete and about the position of steel reinforcement bars which cannot be obtained with the non-laser ultrasonic testing described in this section. Laser-generated acoustic wave measurements with high stress amplitudes provide information about the quality of the concrete at various depths from the surface. Reinforcing steel does not cause misleading results in laser ultrasonic testing as it does in non-laser ultrasonic testing.

Magnetic Field Disturbance

Advanced inspection techniques have been developed that can evaluate fatigue damage to steel reinforcement in concrete members. The device is known as the magnetic field disturbance (MFD) system and can be used on reinforced and prestressed concrete. The system maps the magnetic field across the bottom and sides of the beam. A discontinuity in magnetized steel, such as a fracture in a rebar or a broken wire in a steel strand, produces a unique magnetic signal. While the research has been encouraging for detecting fatigue-related damage due to the significantly different magnetic signals for corroded reinforcing, MFD has not yet been demonstrated for detecting in-service corrosion damage.

Neutron Probe for Detection of Chlorides

A neutron probe can be used to detect chlorides in construction materials. The materials are bombarded with neutrons from a small portable source. Measuring the gamma rays bouncing back provides a spectrum showing different elements, one of which is chloride. A major potential application that remains to be tested is measuring chlorides in reinforced concrete to determine corrosion hazard. Another potential application includes inspecting suspension bridge cables.

Nuclear Methods

The primary use of nuclear methods is to measure the moisture content in concrete by neutron absorption and scattering techniques. These moisture measurements are then used to determine if corrosion of reinforcement is likely to occur. A more direct measurement of the rate of corrosion would be more useful to the bridge inspector, and this method is therefore more research oriented than operational. (53)

Pachometer

A pachometer is a magnetic device used in determining the position of reinforcement. Magnetic methods do not detect concrete defects or deterioration directly. However, they can detect regions of inadequate cover, which is often associated with corrosion-induced deterioration. Magnetic methods can be used to measure cover in the range of 0 to 3 inches to an accuracy of about 1/4 inch. (53)

Rebound and Penetration Methods

Rebound and penetration methods measure the hardness of concrete and can be used to predict the strength of concrete. The Schmidt hammer (also known as the Swiss hammer) is probably the most commonly used device to measure the penetration resistance of hardened concrete. A spring-loaded device strikes the surface of the concrete, and based on the response, the compressive strength of the concrete can be determined. This inspection technique can be used to compare the quality of the concrete in different parts of concrete bridge components. However, only the surface of the concrete is being tested, and the strength value is relative.

Another common penetration device is called the Windsor probe. A pistol-like driving device fires a probe into the surface of the concrete. The probe is specifically designed to crack aggregate particles and to compress the concrete being tested.

Both of these tests are considered practical primarily with concrete that is less than one year old. However, when used in conjunction with core sampling, these tests can also be used to determine significant differences in concrete strength of older bridges. (53)

Ultrasonic Testing

Ultrasonic testing can provide valuable information regarding the condition of concrete bridge members. However, the method can be difficult to use with reinforced concrete members, and some skill is required to obtain usable results.

Large cracks and voids can be detected, since the path of the pulse will travel around any cavity in the concrete and time of transmission is therefore lengthened. The presence of steel parallel to the line of transmission provides a path along which the pulse can travel more rapidly, causing misleading results. Therefore, it is generally desirable to choose paths that avoid the influence of reinforcing steel. (53) Refer to Section 15.2.1 for further details about the principles of ultrasonic testing.

15.3.2 Destructive Testing

Core sampling is a destructive form of concrete inspection, and it can weaken a member. Cores can be used for many of the following destructive tests. Usable cores can normally be obtained only if the concrete is relatively sound. If possible, cores should have a diameter three times the maximum aggregate size. All core holes should be filled with non-shrink concrete grout.

Carbonation

Carbonation of concrete is the result of the reaction of carbon dioxide and other acidic gases in the air, and it can cause a loss of protection of the reinforcing steel against corrosion. The depth of carbonation in a concrete bridge member can be measured by exposing concrete samples to a solution. Uncarbonated concrete areas change color, while carbonated concrete areas remain colorless. (53)

Concrete Permeability

Air and water permeability can be measured by drilling a small hole into the concrete, sealing the top with liquid rubber, and inserting a hypodermic needle. Air permeability can then be determined by filling the hole with water and measuring the flow into the concrete at a pressure similar to that of rainfall. This method is seldom used in bridge inspections. (53)

Concrete Strength

Actual concrete strength and quality can be determined only by removing a concrete core and performing such laboratory tests as:

- Compressive strength
- Cement content
- Air voids
- Static modulus of elasticity
- Dynamic modulus of elasticity
- Splitting tensile strength

Endoscopes

Endoscopes are viewing tubes that can be inserted into holes drilled into a concrete bridge member. Light can be provided by glass fibers from an external source. Some applications of this method include the inspection of the inside of a box girder and the inspection of hollow post-tensioning ducts. Although this is a viewing method, it is considered to be a destructive method because some destruction is necessary for its proper use in concrete. (53)

Moisture Content

Moisture content in concrete serves as an indicator of corrosion activity. Moisture content can be determined using nuclear methods (refer to Section 15.3.1) or from concrete samples taken from the bridge and oven dried in a laboratory. (53)

Reinforcing Steel Strength

The actual properties of reinforcing steel can only be determined by removing test samples. Such removal of reinforcing steel can be detrimental to the capacity of the bridge and should be done only when such data is essential. (53)

15.4 Steel

15.4.1 Nondestructive Testing

Acoustic Emissions Testing

Acoustic emissions can be used to identify growing cracks. When cracks grow, they emit minute "sounds" which propagate outward from the source. Sensors placed on the surface of the member "listen" for these sounds. The bridge must be loaded so as to produce stress and cracking in the members when this test is used.

Computer Programs

Computer programs have been developed to maximize the value of bridge inspections. In the pre-inspection routine, the inspector enters data on the bridge design and previously detected flaws. The computer responds with a customized checklist for the inspector, flagging critical areas of the structure. In the post-inspection routine, the inspector enters data about the flaws encountered in the field, and the computer responds with information about if the crack is likely to propagate and how to repair the crack. This procedure allows the inspector to detect flaws early and to judge which ones need immediate repair.

Computer Tomography

Computer tomography uses X-ray and gamma radiation to render the interior defects of a steel member. The image is captured by a detector array, it is processed by a computer, and it is then reconstructed. This method is similar in many ways to medical CAT scans, and it has great potential for locating discontinuities of all types in steel members (as well as concrete members).

Corrosion Sensors

Corrosion sensors are being developed that use environmental variables such as dirt and duration of wetness to indicate the degree of corrosion of a steel structure.

Dye Penetrant

A dye penetrant can be used to define the extent and size of surface flaws in steel members (see Figure 15-4). The test area is cleaned to bare metal, a dye is applied and allowed to penetrate the surface, and excess penetrant is removed. When a developer is applied, this draws the dye out of the irregularities and defines the extent and size of surface flaws. This method is commonly used by bridge inspectors since it does not require extensive training or expensive equipment. A limitation of this method, however, is that it reveals neither the depth of cracks nor any subsurface flaws.

Figure 15-4 Detection of a Crack Using Dye Penetrant

Magnetic Flux Leakage

Magnetic flux leakage is useful in detecting surface gouges, cracks, and holes. It can also detect subsurface defects, such as voids, inclusions, and cracks, that lie near the surface. A magnetic field is induced into the member, and cracks or other irregularities in the surface of the member cause irregularities in the magnetic field. This technique is also referred to as magnetic field disturbance.

Radiographic Testing

Radiographic testing is used to detect and locate surface and subsurface cracks, voids, and inclusions, and to determine the thickness of a member. X-rays or gamma rays are passed through the member and are absorbed differently by the various flaws. When a piece of film is exposed to the rays, the defects appear as shadows on the film.

Robotic Inspection

Several companies are currently developing and marketing a system which uses high resolution video cameras on robotic arms attached to permanent falsework underneath the bridge. By remote telescanning, details can be visually monitored, with magnification if needed, without the inspector having to climb to gain access to a detail each time an inspection is desired. While the primary material application for robotic inspection is steel, it can also be used on timber and concrete bridges.

Ultrasonic Testing

Ultrasonic testing is frequently used in steel applications and can be used to detect cracks in flat, relatively smooth members, as well as pins (see Figure 15-5). It can also be used to measure the thickness of steel members, providing detailed information concerning loss of cross section. Ultrasonic testing also has many applications in the inspection of welds, detecting porosity, voids, inclusions, corrosion, cracks, and other discontinuities. Refer to Section 15.2.1 for further details about the principles of ultrasonic testing.

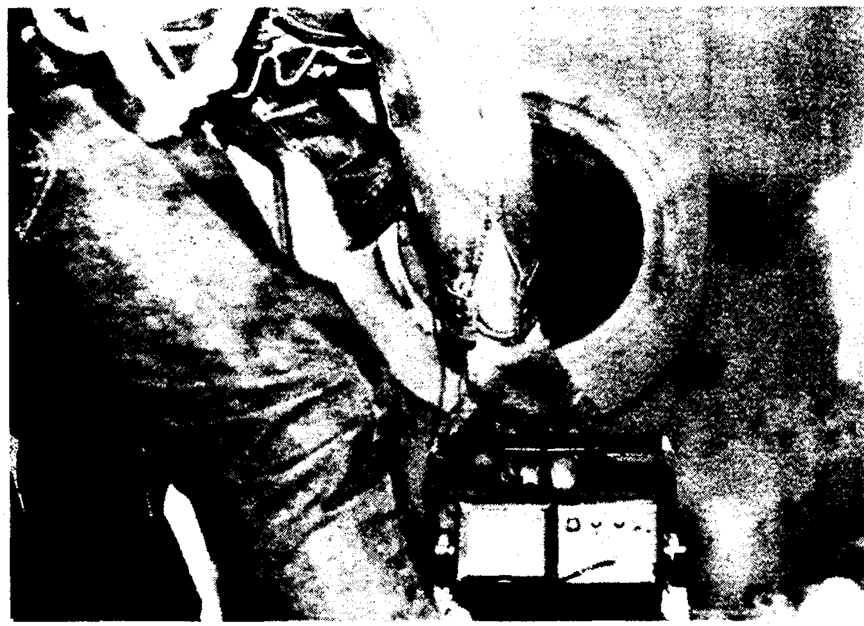


Figure 15-5 Ultrasonic Testing of a Pin

15.4.2 Destructive Testing

Strength tests are normally considered destructive tests since they usually involve tests conducted on pieces of steel removed from the bridge. Small steel pieces cut out of steel members are called test "coupons." Destructive tests may be necessary to determine the strength or other properties of existing iron or steel on bridges for which the steel type is unknown.

The following tests can be conducted only by the destructive technique of removing a sample and evaluating it in a laboratory.

Brinell Hardness Test

The Brinell hardness test measures the resistance to penetration of the steel. A hardened steel ball is pressed into the test coupon by a machine-applied load. The applied load and the surface area of the indentation are used to calculate the hardness of the steel. For a steel that has not been hardened by cold work, its hardness is directly related to its ultimate tensile strength.

Charpy Impact Test

An impact test determines the amount of energy required to fracture a specimen. A common impact test for steel coupons is the Charpy V-notch test (see Figure 15-6). A notched test coupon is placed in a vise, and a hammer is then released from an elevated position, swinging down and hitting the coupon. Since the force of the hammer is concentrated in a notch in the coupon, the stress goes into fracturing the specimen and not into strain. The energy required for fracture is determined based on the mass of the hammer and the distance that it fell. This test can be performed at different temperatures to determine if the steel is susceptible to brittle failure.

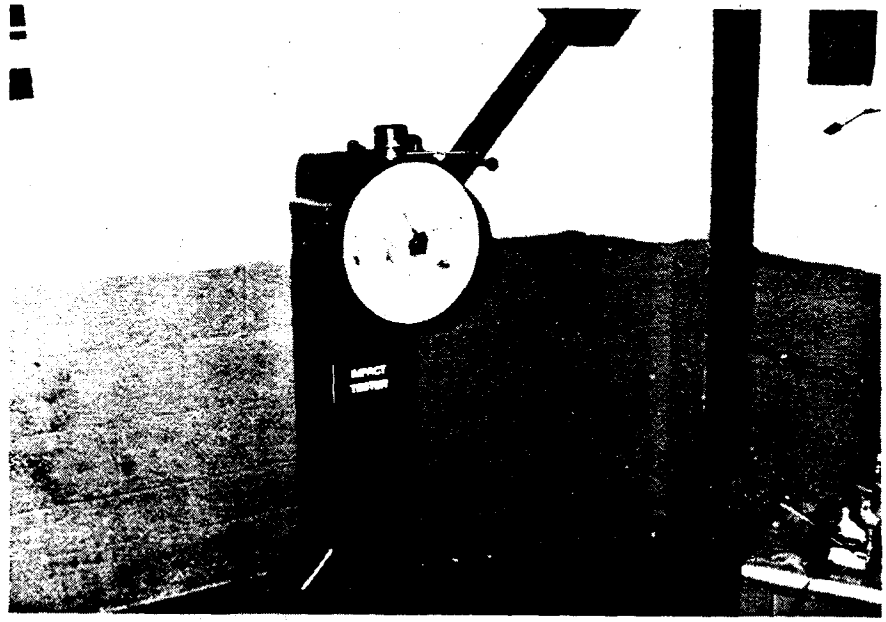


Figure 15-6 Charpy V-Notch Test

Chemical Analysis

The chemical composition of the steel is an important indication of whether a weld will crack, either from cold cracking or hot cracking. Tests can be performed on coupons to determine the chemical composition of the steel.

Cold, or delayed, cracking can be approximated using a carbon equivalent (C.E.) equation that is based on the chemical composition of the steel. One such equation, based on the relative proportions of various elements in the steel, is presented in the ASTM A706 rebar specification:

$$C.E. = C\% + \frac{Mn\%}{6} + \frac{Cu\%}{40} + \frac{Ni\%}{20} + \frac{Cr\%}{10} - \frac{Mo\%}{50} - \frac{V\%}{10}$$

When the C.E. is below 0.55, the steel is generally not susceptible to cold cracking, and no special precautions are required for welding. However, when the C.E. is above 0.55, the steel is susceptible to cold cracking, and special precautions are required for welding.

Hot cracking occurs as the weld begins to solidify. Hot cracks have almost been eliminated today due to the addition of chemicals to the welding material.

Tensile Strength Test

The tensile strength is the highest stress that can be applied to the coupon before it begins to rupture. Once the tensile strength has been exceeded, the coupon begins to elongate or "neck down" and eventually breaks if the load is not removed. The tensile strength of the steel can be easily determined.

The ends of the test coupon are placed in vises on a testing machine. The machine then applies a tensile load to the ends of the coupon. The machine measures the load at which the coupon fails or ruptures. This load and the cross-sectional area of the coupon determine the tensile strength of the steel.

15.5 Instrumentation

Detection and Warning of Bridge Collapse

Sophisticated sensing devices and electronic equipment can be used to warn motorists of an imminent bridge collapse. Such warning equipment includes radar monitoring, accelerometers attached to the bridge, frequency transmitters and receivers, and a mechanical spring-board device.

Laser Beam Line-of-Sight Detectors

When structures suffer fractures or cracks, the weak point sags more than allowed in the design. A laser beam can be directed towards a sensor strategically placed on the structure. As the weak point sags, the sensor moves. When this displacement is greater than the level of tolerance, an alarm is activated. A computer can record the magnitude and rate of change of the deformation. This method can be used to detect potential structural failures.

Strain Gauges

Strain gauges can be used to monitor the response of a member to a known live load. Foil mounted gauges can be used in the axial direction of flat members, and single wire filament, paper mounted gauges can be used on cables. Portable strain reading instruments can be used to monitor all gauges from a central location on or near the bridge.

Locations for strain gauges should be selected based on the condition of individual members, accessibility, and the objectives of the load testing program. Well designed strain gauge instrumentation can provide valuable information about:

- The actual transverse load distribution through the deck system
- The load sharing between elements of a multi-element member
- The effectiveness of the various members of the primary structural system
- The influence of deteriorated or defective members

Recently strain gauge instrumentation data has been interpreted to provide the weights of the vehicles crossing the bridge. This is known as a weighing-in-motion system.

System Identification

In recent years, an increasing number of bridges have been evaluated using measured response data. These have provided useful information and, in some instances, have revealed bridges which needed to be closed or restricted.

Using structural response data, the properties of the structure (e.g., areas and moments of inertia of structural members) can be calculated. The process of determining a structural model from response data is called system identification. The primary use of system identification in structural engineering has been for earthquake engineering research. The accuracy achieved indicates that system identification can also provide a valuable tool for detecting structural flaws.

System identification can be performed using a variety of response data, such as modal and time history response. For modal response, the frequencies and mode shapes of the structure are obtained either from ambient vibration data or from the results of harmonic excitation. A time history response is the response (i.e., displacements or acceleration) of one or more points on the structure as a function of time due to a known loading function. For either type of response data, the results are used to determine structural parameters representing the structural integrity of the bridge.

Initially, system identification is used to create a structural model which more accurately represents the structure than a model used for design. Subsequent analyses are then used to determine which parameters are changing. Since the parameters represent structural properties (e.g., areas and moments of inertia), the changes are indicative of structural decay.

Since bridge inspections focus on individual members, and system identification considers the entire structure, they are complementary processes. Therefore, system identification can be used to more accurately define the structural integrity of bridges. Using ambient vibrations to perform system identification creates the possibility of continuously monitoring bridges, even from a remote location.

Three-Dimensional Displacements and Strains

Current strain measurements are limited to point-determination or two-dimensional geometries. Research is being conducted to develop optical techniques to measure displacements and strains in three dimensions. The three-dimensional measurements will give a more accurate description of the interaction of bridge elements.

16

Protective Systems

Common Bridge Protective Systems

Timber Bridges

Water Repellents

Preservatives
- Coal tar-creosote
- Pentachlorophenol
- Chromated copper arsenate (CCA)
- Pole-fuming

Fire Retardants
- Pressure impregnated fire retardant salts
- Intumescent coatings (paints)

Paint
- Oil-based paint
- Latex paint

Concrete Bridges

Paint
- Oil-based paint
- Latex paint
- Epoxy paint
- Urethanes

Water Repellent Membranes (Sealers)
- Methyl methacrylate
- Silane
- Silicone

Steel Bridges

Paint
- Oil/alkyd paints
- Vinyl paints
- Epoxies
- Epoxy mastics
- Urethanes
- Zinc-rich primers
- Latex paints

Weathering Steel

16

Protective Systems

16.1 Introduction

Protective measures are an absolute necessity to protect all types of bridges from environmental forces that cause steel to corrode, concrete to deteriorate, and timber to decay. A variety of methods are used to protect timber, concrete, and steel bridges, each suited to the particular type of bridge construction material to be protected and the environment in which the bridge is to serve.

16.2 Protective Systems for Timber Bridges

16.2.1 Causes of Wood Degradation

Decay

Wood is composed of cells, each surrounded by a cell wall which provides structural strength. Mold, a fungal growth of microscopic plant life, invades wood, living on sugar in the wood cells or on cellulose in the cell walls. One type of mold grows only on the surface of wood, causing only surface blemishes. A second type of mold, however, penetrates deep into wood, breaking up the cell walls and thus structurally weakening the wood. This is the familiar wood decay, or rot.

Moisture

Wood is hygroscopic, meaning that it takes up or gives off water depending on its own moisture content and the temperature and humidity of its environment. This causes shrinking and swelling, causing stress leading to cracking of the wood. Wood with less than 20% moisture will generally not decay.

Insects

Insects weaken structural wood by burrowing through it. Termites, carpenter ants, and marine organisms can severely weaken timber structures in only a few years.

Fire

The heat of fire causes the solids in wood to convert to flammable gases. As long as an external heat source is applied, the wood will continue to degrade, even in the absence of a visible flame. Wood self-ignites at temperatures ranging from 378°F to 507°F, depending on the type of wood.

Weathering

Weathering is caused by the action of sunlight and moisture on unprotected wood. Ultraviolet rays in sunlight degrade lignin, an organic substance which holds wood cells together. Swelling and shrinking due to changing water content then cause cracks starting at the surface and extending deep into the wood.

16.2.2 Types and Characteristics of Wood Protectants

Water Repellents

Water repellents prevent water absorption, lowering the water content of wood. This helps to prevent decay by molds and to slow the weathering process. Laminated wood (plywood) is particularly susceptible to moisture variations which cause stress between plies due to swelling and shrinkage.

Preservatives

Wood preservatives prevent decay by molds which penetrate deep into timber. They are applied to wood by vacuum-pressure treatment. The lumber to be treated is placed in a sealed chamber up to 8 feet in diameter and 140 feet long. The chamber is evacuated, drawing the air from the wood pores and cells. The treatment chemical is then fed into the chamber and pressure up to 200 psi is applied, forcing the chemical into the wood (see Figure 16-1). The preservatives are the best means to prevent decay, but do not prevent weathering. A paint or water repellent coating is required for this.

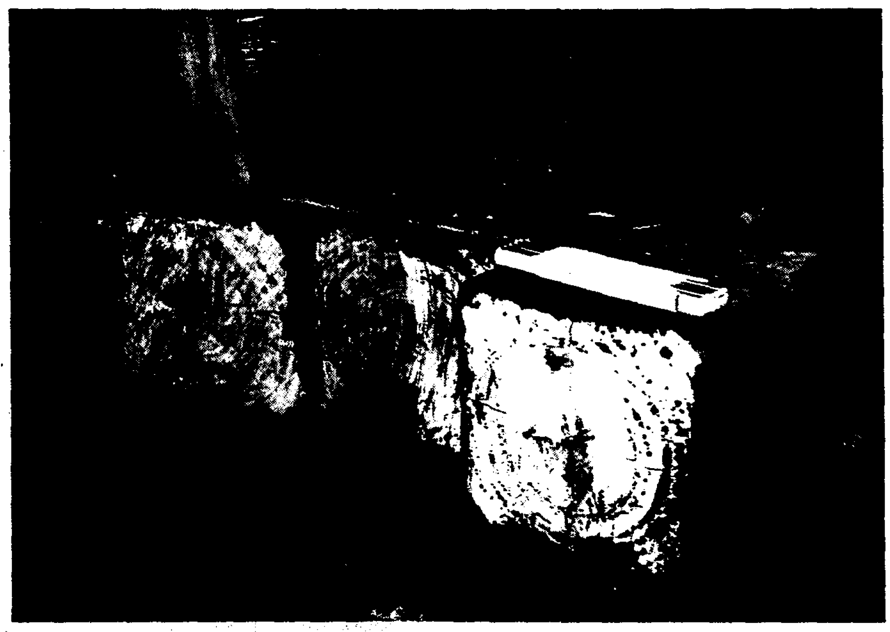


Figure 16-1 Bridge Timber Member Showing Penetration Depth of Preservative Treatment

Coal tar-creosote is a dark, oily protectant used in structural timber such as pilings and beams. Coal tar-creosote treated timber has a dark, oily appearance (see Figure 16-2). Unless it has weathered for several years, it cannot be painted, since paint adheres poorly to the oily surface, and the oils bleed through paint.

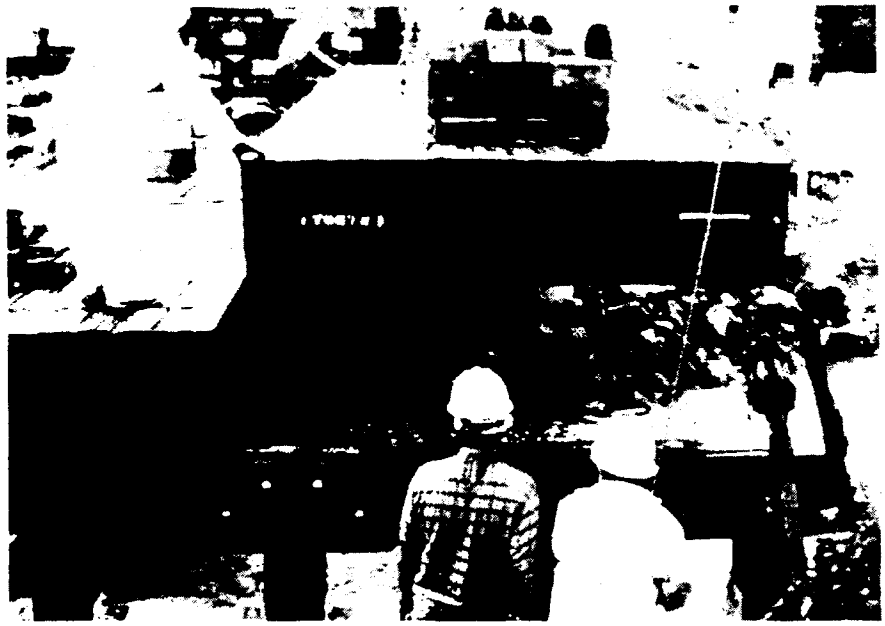


Figure 16-2 Coal-Tar Creosote Treated Timber Beams (Source: Barry Dickson, West Virginia University)

Pentachlorophenol (in a light oil solvent) is an organic solvent solution used as a decay inhibitor. It also leaves an oily surface, like creosote, but can be painted after all of the solvent has evaporated, usually in one or two years of normal service.

Chromated copper arsenate (CCA) is the most common of the waterborne salts applied by vacuum-pressure treatment. Lumber treated with CCA has a green appearance. It is the only pressure-applied preservative that readily accepts painting. CCA also provides limited protection against the ultraviolet rays in sunlight, and water repellence.

Pole-fuming is used to kill decay molds in timber pilings which are already in-service. The treatment chemical, injected through bore holes drilled into the piling, spreads along wood fibers for up to 9 feet from the injection site. It kills existing decay and prevents further decay for up to nine years.

Fire Retardants

Fire retardants will not indefinitely prevent wood from burning, but will retard the spread of fire and prolong the time to ignite wood. The two main classes of fire retardants are pressure impregnated fire retardant salts and intumescent coatings (paints). The intumescent paints expand upon intense heat exposure, forming a thick, puffy, charred coating which insulates the wood from the intense heat.

Paint

Paint protects wood from both moisture and weathering. By precluding moisture from wood, paint prevents decay. However, paint applied over unseasoned wood seals in moisture, accelerating, rather than retarding, decay. Oil-based paint and latex paint are both commonly used on wood bridges.

Oil-based paint provides the best shield from moisture. It is not, however, the most durable. It does not expand and contract as well as latex, and it is more prone to cracking. Oil/alkyd paints cure by air oxidation. These paints are low cost, with good durability, flexibility, and gloss retention. They are resistant to heat and solvents. Alkyd paints often contain lead pigments, known to cause numerous health hazards. The removal and disposal of lead paint is a regulated activity in all states.

Latex paint consists of a latex emulsion in water. Latex paint is often referred to as water-based paint. There are many types of latex paint, each formulated for a different application. They have excellent flexibility and color retention, with good adhesion, hardness, and resistance to chemicals.

16.2.3 Surface Preparation

Wood must be sufficiently dry to permit painting. A few months of weathering will satisfactorily dry new wood. The wood surface must be free of dirt and debris prior to painting. Old, poorly adherent paint must be removed and the edges of intact paint feathered for a smooth finish. Mildew shows up as green or black spots on bare wood or paint. It is a fungus which typically grows in warm, humid, shaded areas with low air movement. Mildew must be removed with a solution of sodium hypochlorite (bleach) and water.

There are several common methods to prepare wood for painting:

- Hand tool cleaning is the simplest but slowest method. Sandpaper, scrapers, and wire brushes are used to clean small areas.
- Power tool cleaning utilizes powerized versions of the hand tools. They are faster than hand tools, but care must be exercised not to damage the wood substrate.
- Heat application with an electric heat gun softens old paint for easier removal to bare wood.
- Solvent-based and caustic chemical paint removers can efficiently clean large areas quickly. Some of the chemicals may, however, present serious fire or exposure hazards. Extreme caution must be exercised when working around chemical paint removers.
- Open nozzle abrasive blast cleaning and water blast cleaning remove old paint and foreign material, leaving bare wood. However, they can easily damage wood unless used carefully.

16.2.4 Inspection of Timber Bridge Coating

When inspecting timber bridge coatings, keep in mind the environment surrounding the bridge and how this can cause coating failures leading to rapid decay of the underlying wood members.

Damage and Decay

Look for evidence of fire damage. This is best seen as dark, charred residue or bubbling of intumescent paint. Fire-damaged wood often has a characteristic pungent odor. Look for insect bore holes. Mildew can be distinguished from dirt with a simple bleach test. One or two drops of a fresh solution of liquid bleach will destroy the mildew and thereby remove the dark color. Discoloration that does not bleach is probably dirt.

Substrate decay is assessed by probing with a knife or ice pick, or by drilling bore holes into the timber. Either a core bit which removes a narrow (3/16 to 1/4 inch) cylinder of wood, or a standard drill bit can be used. The bit moves much faster through decay than through solid wood. Decay can also be distinguished from sawdust generated by the drill bit by its softer texture and darker color.

Care must be exercised, when boring timbers to test for decay, not to contaminate undecayed timber. Since decay is caused by mold which is microscopic plant life, a drill bit which is contaminated with mold from a decaying timber will "infect" the next piece of wood that is bored. The drill bit or corer must be cleaned between each use and preferably disinfected with a chemical, such as liquid bleach, that kills mold. All drilled holes must be plugged with treated plugs.

Areas to Inspect

While inspecting, pay close attention to the following areas:

- The ends of boards and beams. The porous ends of wood members can be difficult to coat. Since paint easily soaks into the grain, especially on weathered wood, a tight seal is not formed. Paint failure often starts at the ends.
- The upper surfaces of substructure members where water and debris accumulate.
- Areas that are hard to reach and may have been missed during painting.
- All areas exposed to rain, wind-blown sand or debris, and hail.
- All areas exposed to flying stones or road salt propelled by passing traffic.
- Shaded areas retain moisture, allowing mold and mildew to grow. This, coupled with the shrink and swell due to moisture, promotes cracking of the paint and wood.

Paint Adhesion

Probe the paint with the point of a knife to test paint adhesion to wood. Attempt to lift the paint. Adhesion failure may occur between wood and paint or between layers of paint.

A more quantitative paint adhesion assessment is performed in accordance with American Society for Testing and Materials (ASTM) D-3359 "Measuring Adhesion by Tape Test". An "X" is cut through the paint to the wood surface. Adhesive test tape is applied over the "X" and removed in a continuous motion. The amount of paint (if any) removed is noted. Adhesion is rated on a scale of 0 to 5. Refer to ASTM D-3359 for the rating criteria.

While examining the paint, also inspect the condition of the wood substrate. Check for erosion of the wood surface and for shallow and deep cracks in wood that usually follow the grain. Probe with the point of a knife or ice pick for decay. Inspect for delamination of plywood.

Paint Dry Film Thickness

Paint dry film thickness is measured with a Tooke Gage (see Figure 16-3). With this instrument, a groove is cut at a known angle through the paint, with the grain, to expose the wood substrate. The thickness of each layer of paint is measured through a 50-power microscope built into the gage.

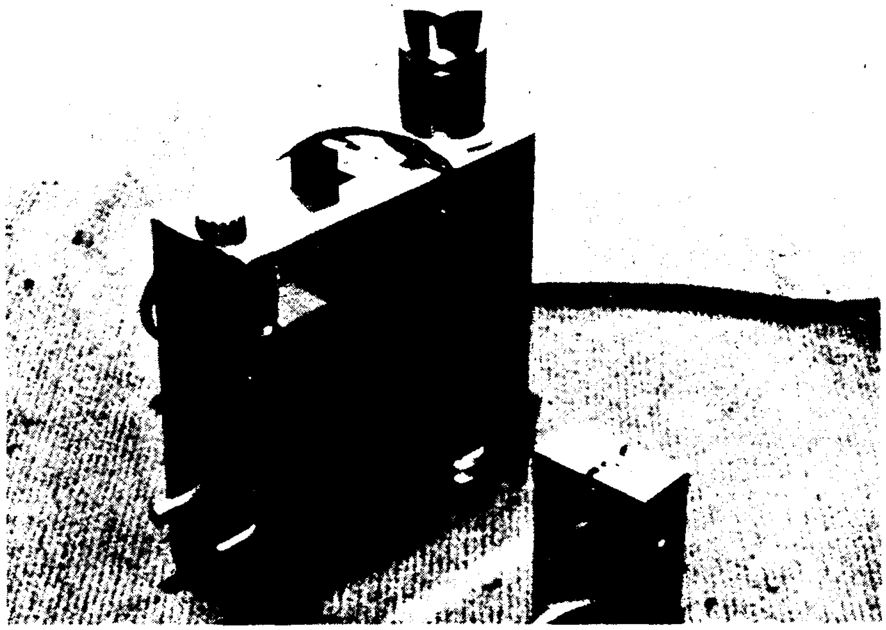


Figure 16-3 Tooke Gage Used to Measure Coating Dry Film Thickness

Repainting

If the coating is to be repainted, type of paint in the existing topcoat must be known, since paints of different type may not adhere well to each other. Two methods to determine the type of existing paint are:

- Check historical records of previous painting
- Obtain paint samples from the bridge for laboratory analysis

Alternately, a test patch may be coated with new paint over intact existing paint. After the paint thoroughly dries in accordance with the manufacturer's specification, inspect the appearance and adhesion of the new paint.

16.2.5 Coating Failures

The following failures are characteristic of paint on wood:

- Cracking and peeling extend with the grain of the wood. They are caused by different shrink and swell rates of expansion and contraction between earlywood (the lighter colored, wider spaces between the "rings" which grow in springtime) and denser latewood (the darker, narrower rings which grow in hotter, drier summer).
- Blistering is caused by paint applied over an improperly cleaned surface. Water, oil, or grease typically are responsible for blistering.
- Chalking is a degradation of the paint, usually by the ultraviolet rays of sunlight, leaving a powdery residue.
- Erosion is general thinning of the paint due to chalking, weathering, or abrasion.
- Mold penetrates through cracks in the paint to cause wood to decay. Mold is a type of fungus.

- Mildew, also a fungus, grows on the surface of paint and wood, usually in warm, humid, shaded areas with low air flow. It appears as small green or black spots.

16.3 Protective Systems for Concrete Bridges

16.3.1 Deterioration of Concrete

When one thinks of the causes of concrete deterioration, corrosion is generally not on the list. In fact, however, corrosion is the dominant cause of concrete failures. Concrete is a porous material, and water and chlorides from road deicing salt or seawater spray penetrate through concrete to corrode the steel reinforcing bars (rebars). The corrosion products (rust) occupy up to 10 times the volume of the corroded steel which it replaces. This expansion of rebars places tremendous stresses on the concrete, causing cracking, delamination, and spalling. The purpose of concrete protective systems is to prevent rebar corrosion. For a discussion of the corrosion mechanism, refer to Section 16.4.1.

16.3.2 Types and Characteristics of Concrete Coatings

Coatings form a protective barrier film on the surface of concrete to preclude entry of water and chlorides into the porous concrete. The practice of coating the concrete surface varies with each agency. Two primary concrete coatings are paint and water repellent membranes.

Paint

Paint is applied in one or two layers. The first layer fills the voids in a rough concrete surface. The second layer forms a protective film over the first. On smooth concrete surfaces, only one layer may be necessary.

Several classes of paint are coated on concrete:

- Oil-based paint
- Latex paint
- Epoxy paint
- Urethanes

Oil-Based Paint

Oil-based paint is declining in use, but is still found on some older concrete structures. Oil paint is subject to saponification failure in wet areas. Saponification is a chemical attack on the coating caused by the inherent alkalinity of the concrete. The moisture may be from humidity in the atmosphere, rain runoff, or ground water entering the porous concrete from below. Saponification does not occur over dry concrete, or occurs at a greatly reduced rate.

Latex Paint

Latex paint consists of a resin emulsion. Latexes can contain a variety of synthetic polymer binding agents. Latex paint resists attack by the alkaline concrete. Acrylic or vinyl latexes provide better overall performance, in that they are more resistant to alkaline attack than oil-based paint. Latex paints, however, are susceptible to efflorescence. Efflorescing is a process in which water-soluble salts pass outward through concrete and are deposited at the concrete/paint interface. This can cause loss of coating adhesion. If the paint is also permeable to water, the salts are deposited on the paint surface as the water evaporates.

Acrylics do not chalk as rapidly as other latexes and have good resistance to ultraviolet rays in sunlight. Polyvinyl acetate latexes are the most sensitive to attack by alkalies.

Epoxy Paint

Epoxy paint uses a cross-linking polymer binder, in which the epoxy resin in the paint undergoes a chemical reaction as the paint cures, forming a tough, cross-linked paint layer. Epoxies have excellent resistance to chemicals, water, and atmospheric moisture. Most epoxies are sensitive to the concrete's moisture content during painting. Polyamide-cured and water-base epoxy systems, however, have substantially overcome the moisture intolerance problem. For other epoxy systems, the concrete moisture should be measured prior to painting.

Urethanes

Urethanes are usually applied over an epoxy primer. They provide excellent adhesion, hardness, flexibility, and resistance to sunlight, water, harmful chemicals, and abrasion. They are, however, sensitive to temperature and humidity during application. The urethanes used on concrete require moisture to cure. In high humidity, the paint cures too quickly, leaving a bubbly appearance.

Many states now apply moisture-cured urethane anti-graffiti coatings on accessible concrete structures (see Figure 16-4). These are smooth, clear coatings applied without a primer coat. Spray paint and indelible marker ink adhere poorly to the smooth urethane, permitting easier cleaning than if they were applied to porous concrete.

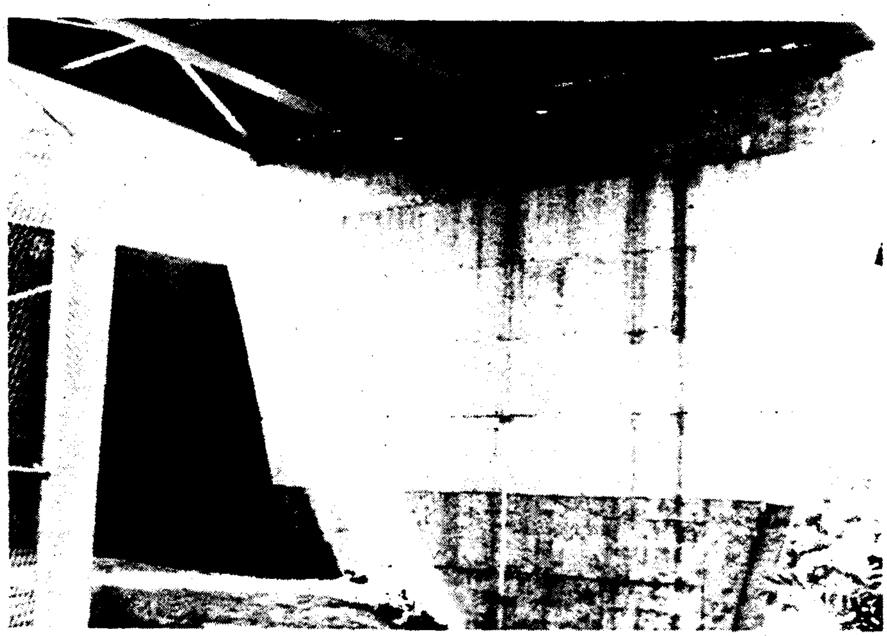


Figure 16-4 Anti-Graffiti Coating on Lower Area of Bridge Piers

Water Repellent Membranes

Water repellent membranes (sealers) applied to concrete bridge decks, piers, abutments, columns, barriers, or aprons form a tight barrier to water and chlorides. The membrane penetrates up to 3/8 inch into the concrete to give strong adhesion. Membranes have good resistance to abrasion from weathering and traffic. Methyl methacrylate, silane, and silicone are three common water repellent coatings.

16.3.3 Surface Preparation

Concrete, as with any other surface, must be properly cleaned prior to coating. The surface may also require roughening to improve coating adhesion, as the forms used to mold concrete leave a surface that is too smooth for good coating adhesion. In addition, the oils applied to wooden forms to facilitate removal may impede coating adhesion.

Blast Cleaning

Blast cleaning with dry abrasives, high pressure water (up to 55,000 psi), or a water/abrasive mix is used to remove dirt, old paint, grease, and deteriorated concrete. It is also the best method to roughen the surface.

Open nozzle blast cleaning uses compressed air free of oil and moisture to propel the abrasive at speeds up to 400 miles per hour. Centrifugal wheel blast cleaning uses a rotating wheel to propel abrasive. The most common abrasive is sand, although many others, such as steel shot and grit, silica, aluminum oxide, and silicon carbide, are also available.

Unlike dry abrasive blast cleaning, high pressure water can penetrate deep into concrete. The concrete must be allowed to dry thoroughly before a coating is applied.

Acid Etching

Acid etching is an efficient method of cleaning concrete. Hydrochloric acid (also called muriatic acid) reacts with the alkaline concrete surface, allowing surface contaminants to easily wash away. It leaves a roughened surface profile for good coating adhesion. All acid must be removed prior to coating application.

16.3.4 Inspection of Concrete Bridge Coatings

While inspecting concrete coating, also examine the concrete substrate for cracking or spalling. This may be so severe as to expose steel reinforcing bars.

Areas to Inspect

While inspecting, pay close attention to the following areas:

- Areas open to direct weathering by wind, rain, hail, or seawater spray.
- Roadway splash zones along curbs, parapets, and expansion dams. These areas are subject to impact abrasion by debris from passing vehicles.
- Inaccessible or hard-to-reach areas where coatings may be missing or improperly applied.
- All concrete joints.
- Areas that retain moisture or salt. Horizontal surfaces of concrete beams and piers are common examples. Also inspect areas where drainage systems deposit salt and water, such as beneath catch basins, scuppers, downspouts, and bearing areas.

- Impact areas on bridge decks and parapets where snowplows or vehicle accidents damage coatings.

Coating Adhesion

Test the coating adhesion to concrete. A simple test is to probe under the coating with the point of a knife. This can also reveal spalling, in which a surface layer of concrete will peel away, exposing aggregate. Spalling and cracking may indicate rebar corrosion. A more quantitative coating adhesion assessment is performed by a tape test described in Section 16.2.4.

Coating Dry Film Thickness

Coating dry film thickness is measured with a Tooke Gage as described in Section 16.2.4.

Repainting

If a new layer of paint is to be applied to an existing layer, the type of paint already in place must be determined. Some paints adhere poorly to other types. Two methods to determine the type of existing paint are:

- Check historical records of previous painting
- Obtain paint samples from the bridge for laboratory analysis

A test patch of new paint may be applied over old paint. After the new paint thoroughly dries in accordance with the paint manufacturer's specification, inspect the test patch for appearance and adhesion.

16.3.5 Coating Failures

The following failures are characteristic of paint on concrete:

- Lack of adhesion/peeling can be caused by poor adhesion of the primer layer to the concrete, or by poor bonding between coating layers. Waterborne salts depositing under a water-impermeable coating (efflorescence) will also cause a coating to peel.
- Chalking is a powdery residue left on paint as ultraviolet light degrades the paint.
- Erosion is a gradual wearing away of a coating. It is caused by abrasion from wind-blown sand, soil and debris, rain, hail, or debris propelled by motor vehicles.
- Checking is composed of short, irregular breaks in the top layer of paint, exposing the undercoat.
- Cracking is similar to checking, but with cracking, the breaks extend completely through all layers of paint to the concrete substrate.
- Microorganism failure occurs as bacteria and fungi feed on paint containing biodegradable components. The damp nature of concrete makes it susceptible to this type of paint failure.
- Saponification results from a chemical reaction between concrete, which is alkaline, and oil-based paint. It destroys the paint, leaving a soft residue.
- Wrinkling is a rough, crinkled paint surface due to excessive paint thickness or excess temperature during painting. It is caused by the surface of the paint film at the air interface solidifying before solvents have had a chance to escape from the interior of the paint film.

16.3.6 Cathodic Protection

Corrosion of steel reinforcing bars in concrete occurs by an electrical process in a moist environment at the steel surface (see Figures 16-5 and 16-6). (For a discussion of the corrosion process, refer to Section 16.4.1.) During corrosion, a voltage difference (less than one volt) develops between rebars or between different areas on the same rebar. Electrons from the iron in the rebar are repelled by the negative anode area of the rebar and attracted to the positive cathode area. This electron flow constitutes an electrical current which is necessary for the corrosion process. Corrosion occurs only at the anode, where the electrons from the iron are given up.

By cathodic protection, this electrical current is reversed, slowing or stopping corrosion. By the impressed current method, an electrical DC rectifier supplies electrical current from local electrical power lines to a separate anode embedded in the concrete. The anode is usually a wire mesh embedded just under the concrete surface. Another type of anode consists of an electrically conductive coating applied to the concrete surface. The wires from the rectifier are embedded in the coating at regular intervals.

When the impressed current enters the mesh or coating anode, the voltage on the rebars is reversed, turning the entire rebar network into a giant cathode. Since natural corrosion occurs only at the anode, the rebars are protected.

The natural corrosion process is allowed to proceed by electrons leaving the iron atoms in the anode. With impressed current cathodic protection, however, the electrons are supplied from an external source, the DC rectifier. Thus, the artificial anode mesh or coating is also spared from corrosion.

During the bridge inspection, check that all visible electrical connections and wiring from the rectifier to the concrete structure are intact.

Figure 16-5 Corroding Concrete Reinforcing Bar

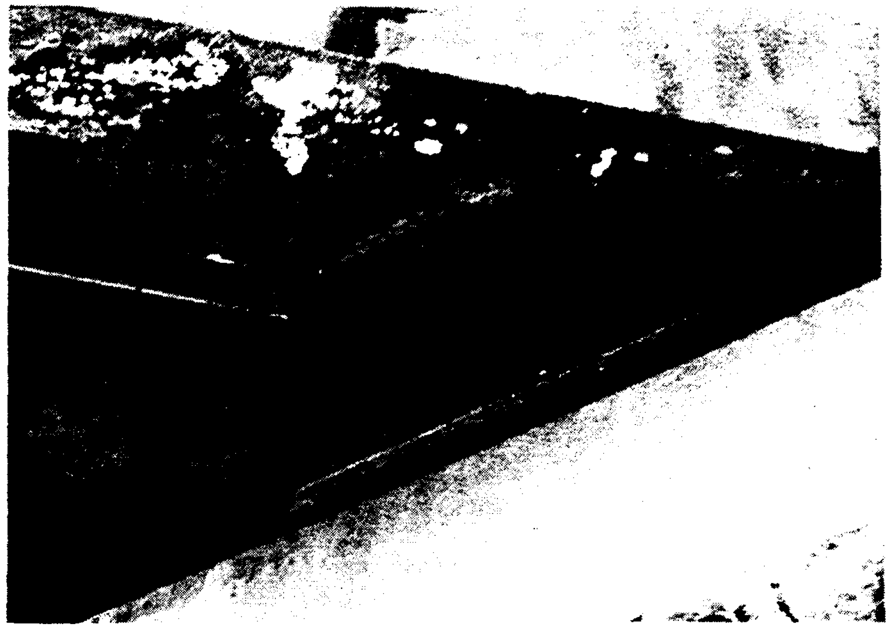


Figure 16-6 Exposed Reinforcing Bars on Bottom Surface of Concrete Pier Cap Beneath Expansion Dam (Note Also Corrosion and Paint Failure on Steel Girder and Cross Frame)

16.4 Protective Systems for Steel Bridges

16.4.1 Corrosion of Steel

Painting is the primary means to protect structural steel from rust and corrosion. To understand how paint prevents corrosion and how to inspect paint coatings, it is first necessary to understand the corrosion process.

Corrosion can be defined as a wearing away of metal by a chemical or electrochemical oxidizing process. Corrosion in metals is a form of oxidation caused by a flow of electricity from one part of the surface of one piece of metal to another part of the same piece. The result, for example, is the conversion of metallic iron to iron oxide.

A conductive solution (water) or electrolyte must be present in order for current to flow. Corrosion occurs very slowly in distilled water, but much faster in salty water, as the presence of salt (notably sodium chloride) improves the ability of water to conduct electricity. In the absence of chlorides, steel (iron) corrodes slowly in the presence of water. Water is both the medium in which corrosion normally occurs and is a participant in the corrosion reaction. In addition, oxygen accelerates the corrosion process. Corrosion is halted or proceeds at a reduced rate as access to water and oxygen is limited or eliminated. Water and oxygen are therefore essential factors, and the amount of corrosion can be controlled by absence of one or the other. For example, corrosion of steel does not occur in moisture-free air and is negligible when the relative humidity of the air is below 30% at normal or lower temperatures. The presence of chlorides in the water will accelerate corrosion by increasing the conductivity of the water and because chlorides enter into the corrosion reaction.

To have corrosion take place in steel, then, one must have:

- An electrolyte
- An area or region on a metallic surface with a negative charge in relation to a second area
- The second area with a positive charge in opposition to the first

Atmospheric exposure of steel assures that a plentiful supply of oxygen is present. In some cases, even in the presence of oxygen, corrosion can be limited by the formation of corrosion product films, which coat the surface and prevent water and oxygen from reaching the uncorroded steel. On steel surfaces, however, the presence of contaminants such as chlorides accelerates the corrosion rate by disrupting the protective oxide film.

Galvanic Action

The term "galvanic action" is generally restricted to the changes in normal corrosion behavior that result from the current generated when one metal is in contact with a different one, and the two metals are in a corrosive solution. In such a situation, one metal may become an anode when it is in contact with a dissimilar metal. In such a "galvanic couple," the corrosion of one of the metals (e.g., zinc) will be accelerated, and the corrosion of the other (e.g., steel) will be reduced or possibly even stopped. Galvanized coatings on highway guardrails and zinc-rich paint on structural steel are examples of galvanic protection using such a sacrificial (zinc) anode.

16.4.2 Types and Characteristics of Steel Coatings

Paint

Paint is by far the most common coating used to protect steel bridges. Paint is composed of three basic compounds: pigments, vehicle (also called binder), and solvents (also called thinners). The pigments contribute such properties as inhibition of corrosion of the metal surface (e.g., zinc, zinc oxide, red lead, and zinc chromate), reinforcement of the dry paint film, stabilization against deterioration by sunlight, color, and hardness. Pigments are generally powders before mixed into paint. The vehicle also remains in the dry-cured paint layer. It binds the pigment particles together and provides adhesion to the steel substrate and to other paint layers. Paint can be classified as inorganic or organic, depending on the vehicle. Inorganic paint uses a watersoluble silicate binder which reacts with water during paint curing. Most types of paint contain one of a variety of available organic binders. The organic binders cure (harden) by one or more of the following mechanisms:

- Evaporation of solvents
- Reaction with oxygen in the air
- Polymerization through the action of heat or a catalyst
- Combination of reactive components in the binder

Solvents are included in paint to transport the pigment-binder combination to the substrate, to lower paint viscosity for easier application, and to wet the substrate. Since the solvent is volatile, it eventually evaporates from the dry paint film.

Paint used on steel bridges acts as a physical barrier to moisture, oxygen, and chlorides, all of which promote corrosion. While water and oxygen are important to corrosion, chlorides from deicing road salts or seawater spray produce the greatest acceleration of corrosion.

Paint Layers

Paint on steel is applied in (usually) up to three layers (coats):

- Primer coat
- Intermediate coat
- Topcoat

The primer coat is in direct contact with the steel substrate. It is formulated to have good bonding and wetting properties and may or may not contain passivating (corrosion-inhibiting) pigments.

The intermediate coat must strongly adhere to the primer. It provides increased thickness of the total coating system, abrasion and impact resistance, and a barrier to chemical attack.

The topcoat (also called the finish coat) is typically a tough, resilient layer, providing a seal to environmental attack, water, impact, and abrasion. It is also formulated for an aesthetic appearance.

Types of Paint

A wide variety of paints are applied to steel bridges. All of them except some zinc-rich primers use an organic binder.

Oil/Alkyd Paints

Oil/alkyd paints use an oil such as linseed oil and an alkyd resin as the binding agent. Alkyd resin is synthetically produced by reacting certain acids and alcohols. Alkyd paints are low cost, with good durability, flexibility, and gloss retention. They are also tough, with moderate heat and solvent resistance. They should not be used in water immersion service or in alkaline environments.

Alkyd paints often contain lead pigments which are known to cause numerous health problems. The removal and disposal of lead-based paints is a regulated activity in all states.

Vinyl Paints

Vinyl paints are based on various vinyl polymer binding agents dissolved in a strong solvent. These paints cure by solvent evaporation. Vinyls have excellent chemical, water, salt, acid, and alkali resistance, good gloss retention, and are applicable at low temperatures. Conversely, their disadvantages include poor heat and solvent resistance, and poor adhesion. vinyls are usually not used with other types of paint in a paint system (vinyl coatings can be formulated to serve as primer, intermediate, and topcoat in paint systems).

Epoxies

Epoxies utilize an epoxy polymer binder which forms a tough, resilient film upon drying and curing. Drying is by solvent evaporation, while curing entails a chemical reaction between the coating components. Epoxy coatings have excellent atmospheric exposure characteristics, as well as resistance to chemicals and water. They are often used as the intermediate coat in a three-layer paint system. There are also two- and three-layer systems which use only epoxies. One disadvantage of epoxies is that they chalk when exposed to sunlight. This chalking must be removed prior to topcoating with another layer of epoxy or another material. If not removed, the chalking will compromise subsequent adhesion.

Epoxy Mastics

Epoxy mastics are heavy, high solid content epoxy paints, often formulated with flaking aluminum pigment. The mastics are useful in applications where a heavy paint layer is required in one application. They can be formulated with wetting and penetrating agents which permit application on minimally prepared steel surfaces.

Urethanes

Urethanes are commonly used as the topcoat layer. They provide excellent sunlight resistance, hardness, flexibility (i.e., resistance to cracking), gloss retention, and resistance to water, harmful chemicals, and abrasion. All-urethane systems are also available which utilize urethane paints as primer, intermediate, and topcoat.

Zinc-Rich Primers

Zinc-rich primers contain finely divided zinc powder (75% to 95%) and either an organic or inorganic binder. They protect the steel substrate by galvanic action, wherein the metallic zinc corrodes in preference to the steel. The materials have excellent adhesion and resist rust undercutting when applied over a properly prepared surface. The zinc-rich primers must be well mixed prior to application, or some coated areas will be deficient in zinc, lowering the substrate protection.

Latex Paint

Latex paint consists of a resin emulsion. The term covers a wide range of materials, each formulated for a different application. Latex on steel has excellent flexibility (allowing it to expand and contract with the steel as the temperature changes) and color retention, with good adhesion, hardness, and resistance to chemicals.

Protection of Suspension Cables

Suspension cables of steel suspension bridges are particularly difficult to protect from corrosion. One method is to wrap the cables with a neoprene elastomeric cable wrap system or with a glass-fabric-reinforced plastic shell. Another method is to pour or inject paints into the spaces between the cable strands. Commonly, inhibitive pigments, such as zinc oxide, in an oil medium, are used. (Red lead pigment was commonly used in the past. Exercise care, when inspecting cables, not to inhale or ingest old paint. Lead constitutes a significant health hazard.) The paint on the exterior surface of a suspension cable dries, but the paint on the interior, surrounding individual strands, stays in the liquid, uncured state for years. The exterior of the cable is often topcoated with a different paint, such as an aluminum pigmented oil-based paint.

16.4.3 Surface Preparation

The steel surface must be properly conditioned prior to paint application, and it must be cleaned of all foreign material, such as:

- Dirt and dust particles or spent abrasive from blast cleaning interfere with paint adhesion to the steel substrate and prevent application of a smooth, uniform film of paint. Debris embedded in the paint can also wick moisture and corrosive elements through the film to the substrate.

- Rust cannot be penetrated by most paints. Rust can become poorly adherent. In such cases, disbonding of the rust carries away the paint layers, permitting accelerated corrosion.
- Flash rust is a light layer of rust which forms on the cleaned steel soon after exposure to the air, particularly in moist or humid environments. This layer may not be thoroughly wetted and may impede adhesion.
- Salts trapped in the paint film can cause blistering and disbonding.
- Oil and grease prevent good paint adhesion and must be completely removed. Welding smoke and inspection markings leave an oily residue that must also be completely removed.
- Dead paint that is loose, cracking, or flaking will eventually lift from the surface, carrying any new paint with it.
- Mill scale is a crust (oxide) that forms on the surface of steel as it is hot rolled in the mill. It has a bluish, somewhat shiny appearance which may be difficult to see on partially blast cleaned steel. It must be completely removed when using most coating materials, as it may disbond upon expansion and contraction, carrying the paint with it.
- Weld spatter may also dislodge, leaving a bare exposed steel surface.

The surface must also be roughened to promote paint adhesion, as paint will not adhere well to a smooth surface. Sharp edges and corners should be rounded, since paint draws thin at sharp discontinuities due to surface tension.

Methods of Surface Preparation

There are several methods appropriate for preparing a steel surface prior to painting. The Steel Structures Painting Council (SSPC) publishes a set of standards and specifications describing the following methods:

- Solvent cleaning
- Hand tool cleaning
- Power tool cleaning
- Abrasive blast cleaning
- Water blast cleaning

Solvent cleaning removes oil and grease. It is usually used in conjunction with or prior to the mechanical preparation methods. Common solvents include petroleum and coal tar solvents, turpentine, mineral spirits, alkaline cleaners, and emulsion cleaners which contain oil soaps mixed with kerosene or mineral spirits.

Hand tool cleaning is used for removing loosely adhering paint, rust, or mill scale. It will not remove tightly adhering mill scale, or dirt and oils in crevices. Due to its slow speed, hand tool cleaning is used mostly for small area spot cleaning. Common hand tools include scrapers, wire brushes, chipping hammers, knives, chisels, and abrasive pads.

Power tool cleaning entails using power driven cleaning tools for cleaning plane and contoured steel surfaces. The devices remove loose paint, rust, and scale. Power tools do not leave the residue common with blast cleaning and are used on small areas and where abrasive and debris could damage sensitive surroundings.

Abrasive blast cleaning is the preferred surface preparation method for coatings which require a high degree of cleanliness and a uniformly roughened surface profile (see Figure 16-7). Blast cleaning is a high production method which can remove intact mill scale. A water collar is sometimes used with abrasive blast cleaning to reduce the amount of airborne abrasive rust, and paint particles.

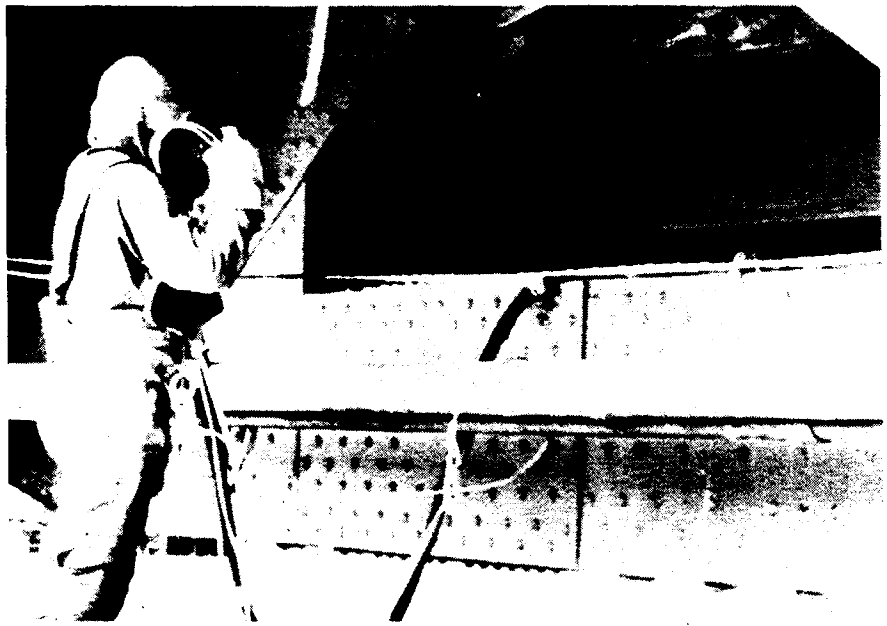


Figure 16-7 Open Nozzle Dry Abrasive Blast Cleaning

Water blast clearing (hydroblasting) may be high or low pressure, hot or cold, with or without detergent, depending upon the type of cleaning desired. Water does not etch a steel surface and may not remove tight paint, rust, or mill scale. Abrasives may be injected into the water stream to remove tightly adhering material for faster clearing or to produce a roughened surface profile. Sand is the most common abrasive. The process can remove all old paint, rust, and mill scale. It yields a degree of cleanliness equivalent to open nozzle abrasive blast cleaning. Due to flash rusting caused by the high pressure water, water blast cleaned areas must be either cleaned by dry abrasive blast cleaning or a corrosion inhibiting chemical must be added to the high pressure water to prevent flash rusting.

16.4.4 Inspection of Steel Bridge Coatings

During the coating inspection, knowing where to inspect is just as important as knowing how to inspect.

Areas to Inspect

Rust typically starts in a few characteristic places, then spreads to larger areas.

Examine any sharp edges and square corners of structural members (see Figure 16-8). Paint is generally thinner at sharp edges and corners than at rounded edges and corners or flat surfaces. Rusting starts at sharp edges, then undercuts intact paint as it spreads away from the edge. Inside square corners often receive an extra thick layer of paint due to double or triple passes made over them. Extra thick layers are prone to cracking, exposing the steel. It is difficult to completely remove dirt and spent blast cleaning abrasive from inside corners. Painting over this foreign material results in early peeling and the consequent corrosion.

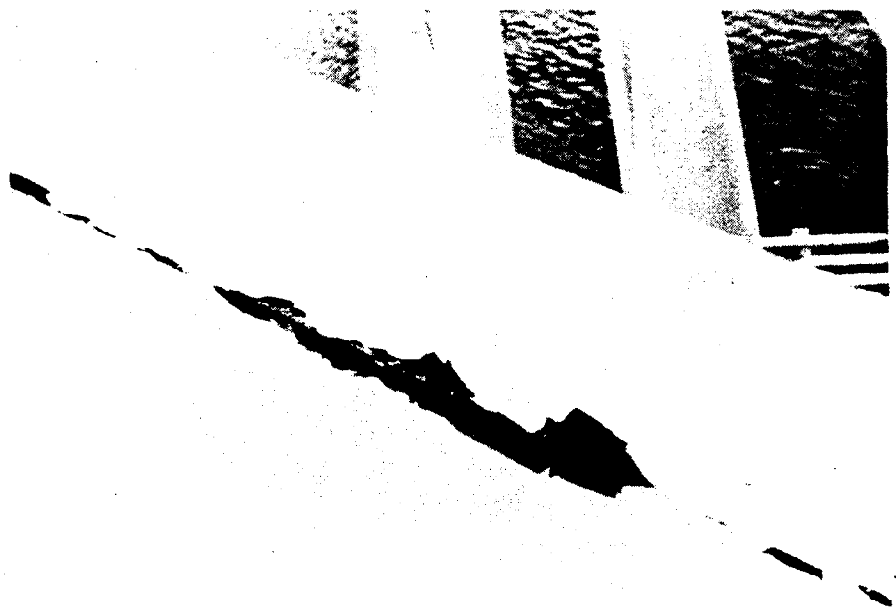


Figure 16-8 Edge Failure on Painted Steel Beam

Examine all areas that retain moisture and salt. Check under scuppers and beneath downspouts. Check horizontal surfaces under the edge of bridge decks and under expansion dams, where roadway deicing salt runoff collects (see Figure 16-9). Examine the inside bottom flange of girders.

Inspect at inaccessible or hard-to-reach areas that may be missed during painting. A flashlight and inspection mirror are invaluable here. Examine the inside surfaces of lattice girders and beams. Examine the top surface of girder upper flanges under the bridge deck, if possible.

Inspect around bolts, rivets, and pins (see Figure 16-10). Rust detected around the heads may indicate corrosion along the entire length of the bolt, rivet, or pin, causing reduced structural integrity.

Examine roadway splash zones, where debris and corrosive deicing salt-laden water are directly deposited on painted members by passing traffic (see Figure 16-11). On through-truss bridges, this includes some bracing members above the roadway.

Examine areas directly open to wind and rain, seawater spray, hall, and other damaging weather conditions.

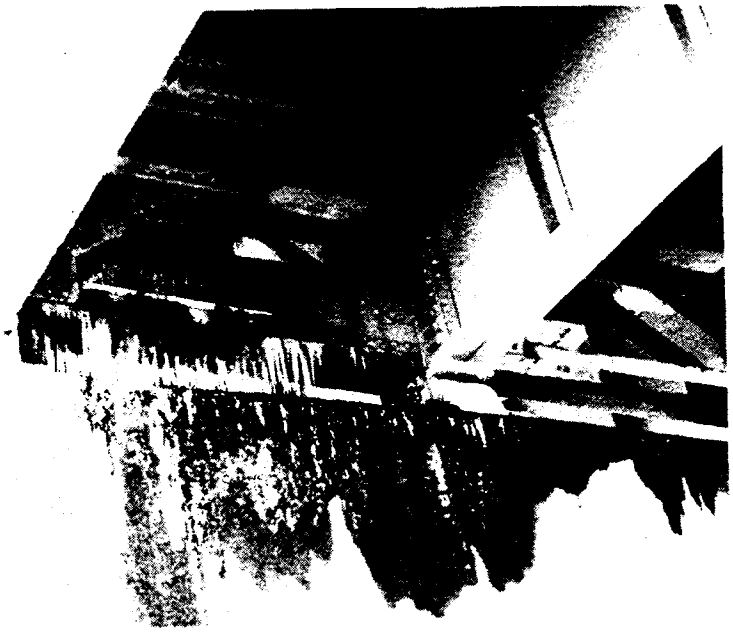


Figure 16-9 Water and Salt Runoff Under Expansion Dam Deck Opening

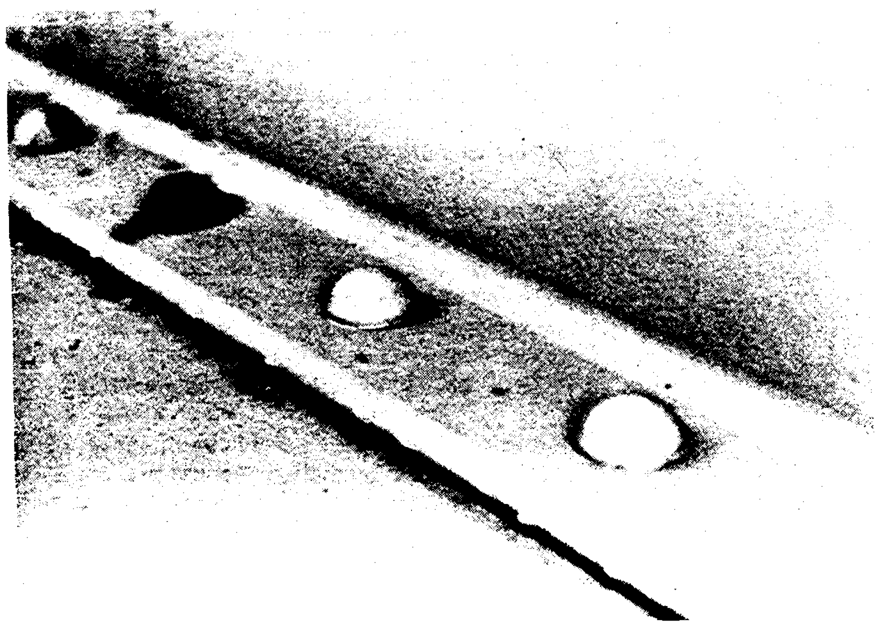


Figure 16-10 Corroding Rivet Head

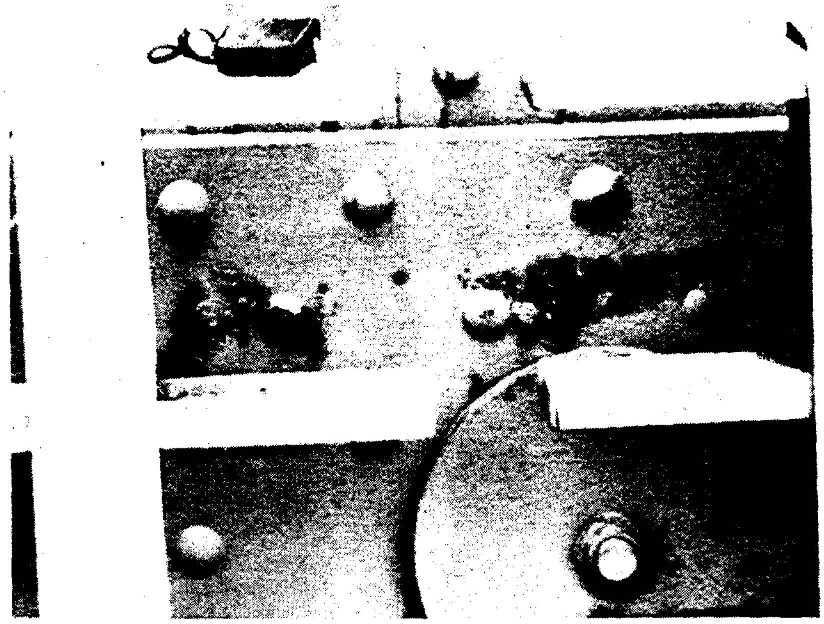


Figure 16-11 Roadway Splash Zone Damage (Note Aluminum Bridge Railing in Foreground)

Degree of Corrosion

The degree of coating corrosion must be assessed during the inspection. Coating corrosion is measured differently than structural corrosion. There are a variety of proprietary procedures which use a set of photographic standards to evaluate and categorize the degree and extent of coating corrosion on composite spans, cross frames, exterior fascias, and bearings. A simple method entails evaluation of painted surfaces in accordance with SSPC-Vis 2. Vis 2 is a pictorial standard for evaluating the degree of rusting on painted steel surfaces.

Mill Scale

Incomplete removal of mill scale can provide a starting point for corrosion. When mill scale cracks, it allows moisture and oxygen to reach the steel substrate. Because of its electrochemical properties, mill scale accelerates corrosion of the substrate. Use a knife to remove a small patch of paint in random spots. Inspect the exposed surface for mill scale, either intact or rusted. Probe with a knife or other sharp object at weld spatter to check for rusting. Re-coat areas where paint is removed.

Invisible microscopic chloride deposits from deicing salt or seawater spray may permeate a corroding steel surface. Painting over a partially cleaned chloride-contaminated surface simply seals in the contaminant. Salt deposits draw moisture through the paint by osmosis, and corrosion will continue.

Paint Adhesion

Paint can undergo adhesion failure between paint layers or between the primer and steel. Some bridge painting contracts specify a minimum acceptable paint adhesion strength for new paint. Over time, however, adhesion strength may degrade as the paint weathers and is affected by sunlight, or as rusting occurs under the paint.

The simplest test of adhesion is to probe under paint with the point of a knife. A more quantitative evaluation is performed by a tape test, as described in Section 16.2.4.

Paint Dry Film Thickness

There are a variety of instruments to measure the dry film thickness of paint applied to steel. Their accuracy ranges from about 10% to about 15%, and they fall into three classes:

- Magnetic pull-off
- Fixed probe
- Destructive test

The magnetic pull-off dry film thickness gages use the attractive force between a magnet and the steel substrate to determine the paint thickness. The thicker the paint, the lesser the magnetic force. These instruments must be calibrated prior to and during use with plastic shims of known thickness, or with ferrous plates coated with a non-ferrous layer. Such shims are produced by the National Bureau of Standards (NBS).

The fixed probe gages also use a magnet. Measurement of paint thickness is done by an electrical measurement of the interaction of the probe's magnetic field with the steel rather than by the force to move the magnet. They are normally calibrated with plastic shims. Neither the magnetic pull-off nor fixed probe gages can be used closer than one inch to edges, as this will distort the reading. SSPC-PA2 "Measurement of Dry Paint Thickness With Magnetic Gages" provides a detailed description of how to calibrate and take measurements using magnetic gages.

A destructive method for measuring dry film thickness uses the Tooke Gage described in Section 16.2.4. An advantage of this method is that it can be used at any location, including close to edges. While the magnetic gages measure the combined thickness of all paint layers, the Tooke Gage measures each layer individually. Limitations of the destructive test are that only coatings up to 50 mils thick can be measured and different layers of the same color cannot be distinguished.

Repainting

If the coating is to be repainted, the type of in-place paint must be known, since different type paints may not adhere well to each other. The methods described in Section 16.2.4 can be used to determine the type of in-service paint.

16.4.5 Paint Failures

The following failures are characteristic of paint on steel:

- Chalking, erosion, checking, cracking, and wrinkling, as discussed in Section 16.3.5 (see Figure 16-12).
- Blisters are caused by painting over oil, grease, water, salt, or by solvent retention. Corrosion can occur under blisters without being visible.
- Undercutting is the rusting, blistering, or peeling of paint over corroding steel (see Figure 16-13). It commonly occurs along scratches that expose the steel or along sharp edges. The corrosion undermines intact paint, causing it to blister and peel.

- Pinpoint rusting can occur at pinholes, which are tiny, deep holes in the paint exposing the steel (see Figure 16-14). It can also be caused by thin paint coverage. In this case, the "peaks" of the roughened steel surface protrude above the paint and corrode.
- Microorganism failure is caused by bacteria or fungi attacking biodegradable coatings. Oil/alkyds are the most often affected.
- Alligatoring can be considered a widely spaced checking failure, caused by internal stresses set up within the surface of a coating during drying (see Figure 16-15). The stresses cause the surface of the coating to shrink more rapidly to a much greater extent than the body of the coating. This causes large surface checks that do not reach the steel substrate.
- Mudcracking can be considered a widely spaced cracking failure, where the breaks in the coating extend to the steel substrate, allowing rapid corrosion (see Figure 16-16). Mudcracking is often a phenomenon of inorganic zinc-rich primers which are applied very thick or to too hot of a surface. Rapid curing causes the shrinkage which yields the mudcracks.
- Bleeding occurs when soluble colored pigment from an undercoat penetrates the topcoat, causing discoloration (see Figure 16-17).

Figure 16-12 Paint Wrinkling

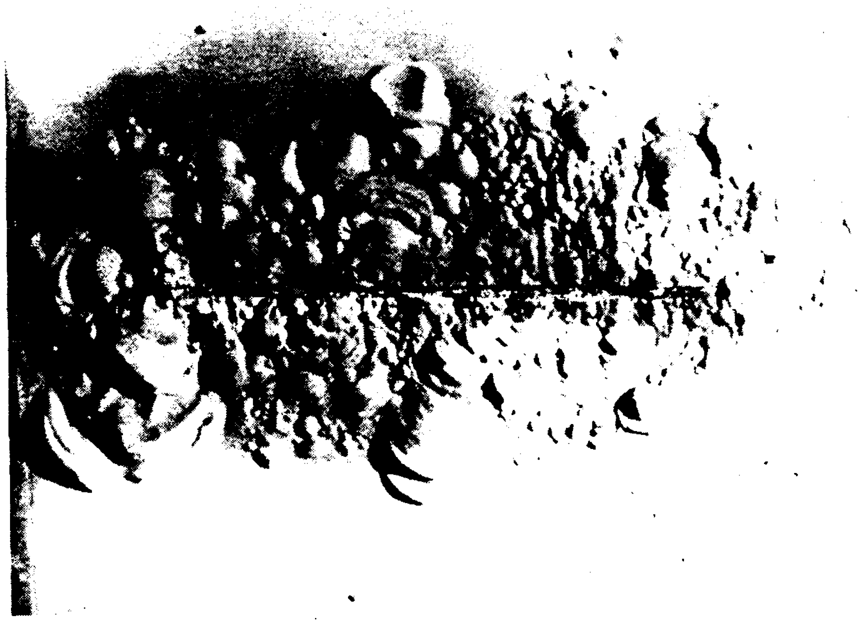


Figure 16-13 Rust Undercutting at Scratched Area

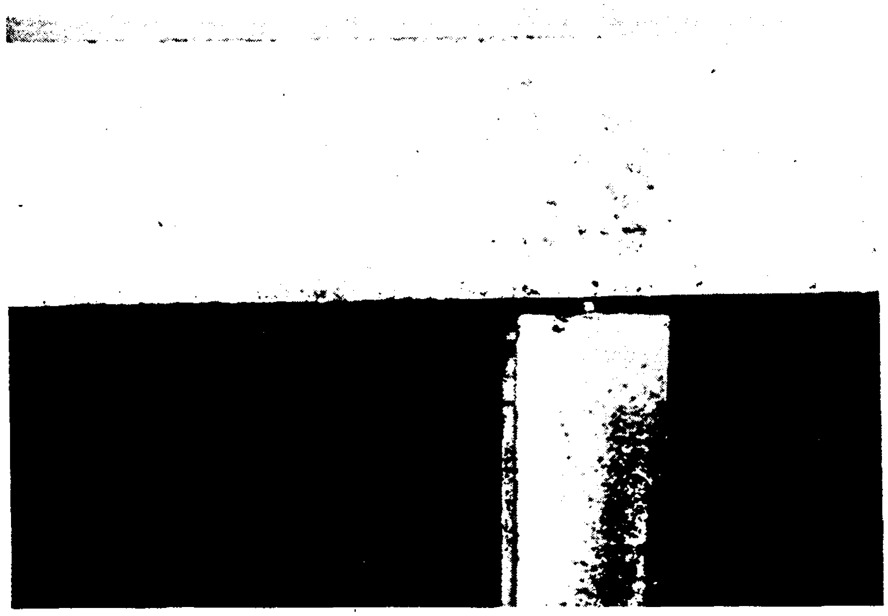


Figure 16-14 Pinpoint Rusting

Figure 16-15 Paint Peeling from Steel Bridge Members

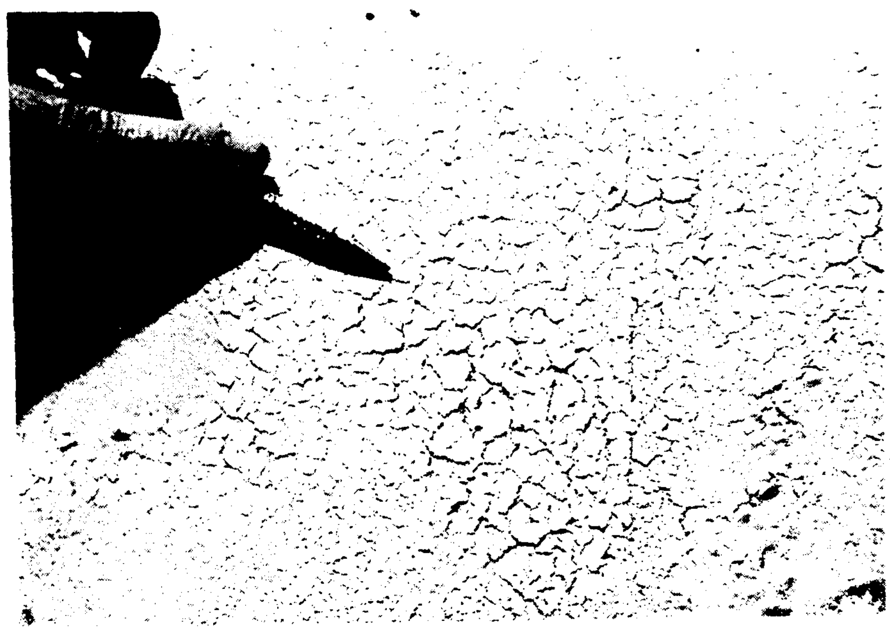


Figure 16-16 Cracking Paint

Figure 16-17 Aged Oil/Alkyd Coating and Disbonding (Note Mill Scale on Steel Surface Beneath Orange Primer)

16.4.6 Weathering Steel

When exposed to the atmosphere, weathering steel develops a protective oxide film which seals the surface of the member from further corrosion. This oxide film is actually an intended layer of surface rust which protects the member from further corrosion and loss of material thickness.

Background

Weathering steel was first used in bridges in 1964 in Michigan. Since then, over 2,000 bridges have been constructed of weathering steel in the United States. The early successes of weathering steel in bridges led to the use of this steel in locations where the steel could not attain a protective oxide layer and where corrosion progressed beyond the intended layer of surface rust. Therefore, it is important for the inspector to distinguish between the protective layer of rust and advanced corrosion that can lead to section loss.

Protective Process

The frequency of surface wetting and drying cycles determines the oxide film's texture and protective nature. The wetting cycle includes the accumulation of moisture from rainfall, dew, humidity, and fog, in addition to the spray of water from traffic. The drying cycle involves the drying actions of the sun and wind. Alternate cycles of wetting and drying are essential to the formation of the protective oxide coating. The protective film will not form if weathering steels remain wet for long periods of time.

Uses of Weathering Steel

Weathering steels may be unsuitable in the following environments:

- Areas with frequent high rainfall, high humidity, or persistent fog
- Marine coastal areas where the salt-laden air may deposit salt on the steel, which leads to moisture retention and corrosion
- Industrial areas where chemical fumes may drift directly onto the steel and cause corrosion

The location and geometrics of a bridge also influence the performance of weathering steel. Locations where weathering steel may be unsuitable include:

- Tunnel-like situations which permit concentrated salt-laden road sprays, caused by high-speed traffic passing under the bridge, to accumulate on the superstructure
- Low level water crossings where insufficient clearance over bodies of water exists so that spray and condensation of water vapor result in prolonged periods of wetness of the steel

Inspection Locations

Weathering steel should be inspected in the following locations:

- Where the steel remains damp for long periods of time due to condensation, leaky joints, or traffic spray
- Where debris is likely to accumulate
- Where the steel is exposed to salts and atmospheric pollutants

Color

The color of the surface of weathering steel is an indicator of the protective oxide film (see Figure 16-18). The color changes with age until the steel oxide film reaches its protective stage. Table 16-1 presents a correlation between the color of the weathering steel and its condition.

Figure 16-18 Color of Oxide Film is Critical in the Inspection of Weathering Steel; Dark Black Color is an Indication of Non-Protective Oxide

Color	Condition
Yellow orange	Early stages of exposure or active corrosion
Light brown	Early stages of exposure
Chocolate brown to purple brown	Boldly exposed under good conditions
Black	Non-protective oxide

Table 16-1 Correlation Between Weathering Steel Color and Condition (Source: 29)

An area of steel which is a different color than the surrounding steel indicates a potential problem. The discolored area should be investigated to determine the cause of the discoloration. Color photographs are an ideal way to record the color of the weathering steel over time.

Texture

The texture of the oxide film also indicates the degree of protection of the film. An inspection of the surface by tapping with a hammer and vigorously brushing the surface with a wire brush determines the adhesion of the oxide film to the steel substrate. Surfaces which have granules, flakes, or laminar sheets are examples of non-adhesion. Table 16-2 presents a correlation between the texture of the weathering steel and its condition.

Texture	Condition
Tightly adhered, capable of withstanding hammering or vigorous wire brushing	Protective oxide
Dusty	Early stages of exposure; should change after few years
Granular	Possible indication of problem depending on length of exposure and location of structure
Small flakes, 1/4 inch in diameter	Initial indication of non-protective oxide
Large flakes, 1/2 inch in diameter or greater	Non-protective oxide
Laminar sheets or nodules	Non-protective oxide, severe corrosion

Table 16-2 Correlation Between Weathering Steel Texture and Condition (Source: 29)

Inspection Procedures

Weathering steel with any of the following conditions should be inspected:

- Laminar texture of steel surface, such as slab rust or thin and fragile sheets of rust
- Granular and flaky rust texture of steel surface
- A very coarse texture
- Large granular (1/8 inch in diameter) texture
- Flakes (1/2 inch in diameter)
- Surface rubs off by hand or wire brush revealing a black substrate
- Surface is typically covered with deep pits

If such conditions are discovered, the following steps should be taken to determine the condition of the oxide film:

- Scrape the surface of the steel to the bare metal
- Check to determine the extent of pitting
- Measure the metal section loss with calipers or an ultrasonic thickness gauge

It is important to set a benchmark at the point where the metal thickness measurement is taken so that any metal loss may be monitored with future measurements. The benchmarks are important since steel rolled sections and steel plates often vary within acceptable tolerances in thickness from the nominal thickness values.

Data obtained in an inspection should include visual observations of the steel (e.g., color, texture, and flaking), physical measurements with a thickness gauge, and observation of environmental conditions. (29)

17

Underwater Inspection

17

Underwater Inspection

17.1 Introduction

The need for underwater inspections is great. Approximately 86 percent of the bridges in the National Bridge Inventory (NBI) are built over waterways, and most bridge failures occur because of underwater problems. Underwater members must be inspected to the extent necessary to determine with certainty that their condition has not compromised the structural safety of the bridge.

Several bridge collapses during the 1980's, traceable to underwater deficiencies, have led to revisions in the National Bridge Inspection Standards (NBIS) (see Figure 17-1). As a result, bridge owners have been mandated to develop a master list of bridges requiring underwater inspections. In addition, the frequency of inspection is not to exceed five years.

Figure 17-1 Schoharie Creek Bridge Failure

In general, the term "underwater inspection" is taken to mean a hands-on inspection requiring underwater breathing apparatus and related diving equipment. The expense of such inspections necessitates careful consideration of candidate bridges.

17.1.1 Bridge Selection Criteria

Bridges that cross waterways often have foundation elements located in water to provide the most economical total design. Where these elements are continuously submerged, underwater inspection and management techniques must be used to establish their condition so that failures can be avoided.

In many cases, a bridge located over water must be evaluated by a multi-disciplinary team including structural, hydraulic, and geotechnical engineers. Underwater inspection is therefore only one step in the investigation of a bridge.

Selection Criteria

Various factors influence the bridge selection criteria. As a minimum, all structures must receive routine underwater inspections at intervals not to exceed five years. This is the maximum interval permitted between underwater inspections for bridges which are both in excellent condition underwater and which are located in passive, nonthreatening environments. More frequent routine and in-depth inspections may be desirable for many structures and necessary for critical structures. The bridge owner must determine the inspection interval that is appropriate for each individual bridge. Factors to consider in establishing the inspection frequency and levels of inspection include:

- Age
- Type of construction materials
- Configuration of the substructure
- Adjacent waterway features such as dams, dikes, or marinas
- Susceptibility of streambed materials to scour
- Maintenance history
- Saltwater environment
- Waterway pollution
- Damage due to waterborne traffic, debris, or ice

Selected Bridges

Those bridges which require underwater inspection must be noted on individual inspection and inventory records as well as be compiled in a master list. For each bridge requiring underwater inspection, the following information should be included as a minimum:

- Type and location of the bridge
- Type and frequency of required inspection
- Location of members to be inspected
- Inspection procedures to be used
- Dates of previous inspections
- Special equipment requirements
- Findings of the last inspection
- Follow-up actions taken on findings of the last inspection
- Type of foundation
- Bottom of foundation elevation or pile tip elevation

17.2 Methods of Underwater Inspection

There are three general methods used to perform underwater inspections:

- Wading inspection
- Scuba diving
- Hardhat diving

17.2.1 Wading Inspection

Wading inspection is the basic method of underwater inspection used on structures over wadable streams. The substructure units and the waterway are evaluated using a probing rod, sounding rod or line, waders, and possibly a boat. Wading inspections can often be performed by regular bridge inspection teams with waders or a boat (see Figure 17-2).

Figure 17-2 Wading Inspection

17.2.2 Scuba Diving

The acronym "scuba" stands for self-contained underwater breathing apparatus. This method is well suited for many inspections. The scuba diver is independent from the surface dive team, as the air tank is strapped to the diver's back.

17.2.3 Hardhat Diving

Hardhat diving uses a body suit, a hard helmet covering the head, and a surface supplied air system. (Although some scuba divers may use a "hardhat", in this Manual "hardhat" implies a surface supplied air system.) Hardhat diving is well suited for waterway inspections with adverse conditions, such as high stream flow velocity (8 knots or 9 mph maximum), polluted water, and long duration requirements. It requires more equipment than scuba diving. Both scuba and hardhat diving inspections can be made at depths in excess of 100 feet; however, most underwater bridge inspections will be made at depths of less than 30 feet (see Figure 17-3).

Figure 17-3 Hardhat Diver Entering the Water

17.2.4 Method Selection Criteria

In determining whether a bridge can be inspected by wading or whether it requires the use of diving equipment, water depth should not be the sole criteria. Many factors combine to influence the proper underwater inspection method:

- Water depth
- Water visibility
- Current velocity
- Streambed conditions (softness, mud, "quick" conditions, and slippery rocks)
- Debris
- Substructure configuration

17.3 Diving Inspection Intensity Levels

Originating in the United States Navy and offshore diving industry, the designation of standard levels of inspection has gained acceptance. Three diving inspection intensity levels have evolved as follows:

- Level I: Visual, tactile inspection
- Level II: Detailed inspection with partial cleaning
- Level III: Highly detailed inspection with nondestructive testing

17.3.1 Level I

Level I consists of a "swim-by" overview at arm's length with minimal cleaning to remove marine growth. Although the Level I inspection is referred to as a "swim-by" inspection, it must be detailed enough to detect obvious major damage or deterioration. A Level I inspection is normally conducted over the total (100%) exterior surface of each underwater element, involving a visual and tactile inspection with limited probing of the substructure and adjacent streambed. The results of the Level I inspection provide a general overview of the substructure condition and verification of the as-built drawings. The Level I inspection can also indicate the need for Level II or Level III inspections and aid in determining the extent and selecting the location of more detailed inspections.

17.3.2 Level II

Level II inspection is a detailed inspection which requires that portions of the structure be cleaned of marine growth. It is intended to detect and identify damaged and deteriorated areas which may be hidden by surface growth. A Level II inspection is typically performed on at least 10% of all underwater elements. In some cases, cleaning is time consuming and should be restricted to critical areas of the structure. The thoroughness of cleaning should be governed by what is necessary to determine the condition of the underlying material. Removal of all growth is generally not needed. Generally, the critical areas are near the low waterline, near the mud line, and midway between the low waterline and the mud line. On pile structures, 10-inch high bands should be cleaned at designated locations:

- Rectangular piles - the cleaning should include at least three sides
- Octagonal piles - at least six sides
- Round piles - at least three-fourths of the perimeter
- H-piles - at least the outside faces of the flanges and one side of the web

On large faced elements, such as piers and abutments, 1 foot by 1 foot areas should be cleaned at three levels on each face of the element. Deficient areas should be measured, and the extent and severity of the damage documented.

17.3.3 Level III

A Level III inspection is a highly detailed inspection of a critical structure or structural element, or a member where extensive repair or possible replacement is contemplated. The purpose of this type of inspection is to detect hidden or interior damage and loss in cross-sectional area. This level nondestructive of inspection includes extensive cleaning, detailed measurements, and selected nondestructive and partially destructive testing techniques such as ultrasonics, sample coring or boring, physical material sampling, and in-situ hardness testing. The use of testing techniques is generally limited to key structural areas, areas which are suspect, or areas which may be representative of the underwater structure.

17.4 Types of Inspection

A comprehensive review must be made of all bridges contained in an agency's inventory to determine which bridges require underwater inspection. Many combinations of waterway conditions and bridge substructures exist. For any given bridge, the combination of environmental conditions and structure configuration can significantly affect the requirements of the inspection. It is generally accepted that there are five different types of inspections:

- Inventory
- Routine
- Damage
- In-depth
- Interim

Underwater inspections are typically either routine or in-depth inspections.

17.4.1 Inventory Inspections

An inventory inspection is the first inspection of a bridge as it becomes a part of the bridge inventory. An inventory inspection may also apply when there has been a change in the configuration of the structure (e.g., widenings, lengthenings, and supplemental bents). The inventory inspection is a fully documented investigation, and it must be accompanied by an analytical determination of load capacity, which includes scour analyses if appropriate.

There are two purposes for an inventory inspection:

- Collection of Structure Inventory and Appraisal (SI&A) data
- Establish as-built conditions

The second important aspect of the inventory inspection is the determination of baseline structural conditions and the identification and listing of existing problems or locations in the structure that may have potential problems.

Aided by a prior detailed review of plans, it is during this inspection that any underwater members (or details) are noted for subsequent focus and special attention.

17.4.2 Routine Inspections

A routine inspection is a regularly scheduled, intermediate level inspection consisting of sufficient observations and measurements to determine the physical and functional condition of the bridge, to identify any change from "inventory" or previously recorded conditions, and to ensure that the structure continues to satisfy present service requirements.

The routine inspection must fully satisfy the requirements of the NBIS with respect to maximum inspection frequency, updating of SI&A data, and the qualifications of the inspection personnel.

Routine inspections of substructures in water must be conducted at least every five years. Structures having underwater members which are partially deteriorated or which are in unstable channels may require shorter inspection intervals.

The scope of work for a routine inspection should include:

- A Level I inspection should be made on 100% of the underwater portion of the structure to determine obvious problems.
- A Level II inspection should be made on at least 10% of underwater units selected as determined by the Level I inspection.
- A Level III inspection may need to be performed to gain additional data so that the structural conditions can be evaluated with certainty.

The duties of the dive team should include:

- Inspect the channel bottom and sides for scour.
- Cross sections of the channel bottom should be taken and compared with as-built plans or previously taken cross sections to detect lateral channel movement or deepening.
- Soundings should be made in a grid pattern about each pier and upstream and downstream of the bridge to detect areas of scour. Permanent reference-point markers should be placed on each abutment/pier. Data obtained from the soundings should be correlated with the original plans (if available) of the bridge foundations and tied to these markers for reference during future underwater inspections.
- Local scour should be determined with probes in the vicinity of piers and abutments. In streams carrying large amounts of sediment, reliable scour depth measurements may be difficult at low flow due to scour hole backfilling.

17.4.3 Damage Inspections

Certain conditions and events affecting a bridge may require more frequent, or unscheduled, inspections to assess structural damage resulting from environmental or man-inflicted causes.

The scope of inspection must be sufficient to determine the need for emergency load restrictions or closure of the bridge to traffic and to assess the level of effort necessary to repair the damage. The amount of effort expended on this type of inspection will vary significantly depending upon the extent of the damage. If major damage has occurred, inspectors must evaluate section loss, make measurements for misalignment of members, and check for any loss of foundation support.

Situations that may warrant a damage inspection include:

- Floods - bridge elements located in streams, rivers, and other waterways with known or suspected scour potential should be inspected after every major runoff event to the extent necessary to ensure bridge foundation integrity (see Figure 17-4).
- Vessel impact - bridges should be inspected underwater if there is visible damage above water; this should be done in order to determine the extent of damage and to establish the extent of liability of the vessel owner for damages.
- Ice floes - ice floes can damage substructure elements, and accumulations of ice on the elements can cause scouring currents or increase the depth of scour.
- Prop wash from vessels - prop wash (i.e., turbulence caused by the propellers of marine vessels) can cause scouring currents and may propel coarse-grained bottom materials against substructure elements in a manner similar to that of blast cleaning operations.
- Buildup of debris at piers or abutments - this material buildup effectively widens the unit and may cause scouring currents or increase the depth of scour (see Figure 17-5).

- Evidence of deterioration or movement - many underwater deficiencies only become apparent above water when the distress extends above the waterline or is manifested by lateral movement or settlement; bridges should also by inspected underwater following significant earthquakes (see Figure 17-6).

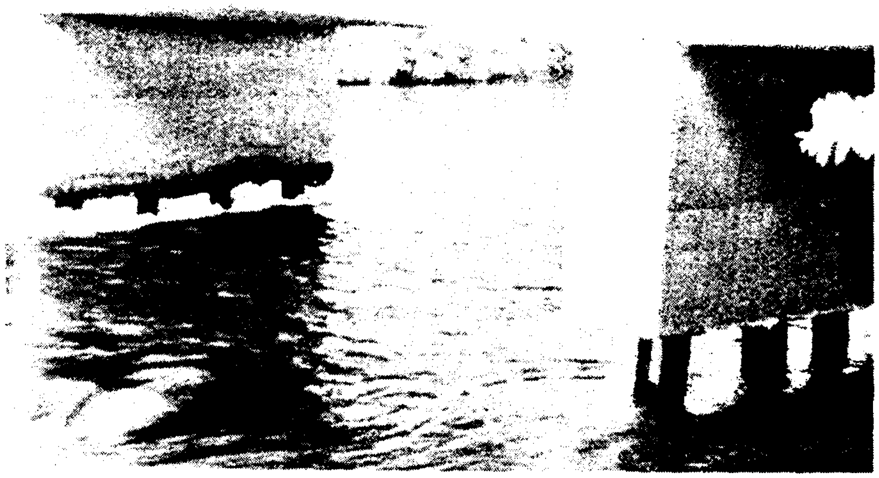


Figure 17-4 Flood Conditions

Figure 17-5 Buildup of Debris

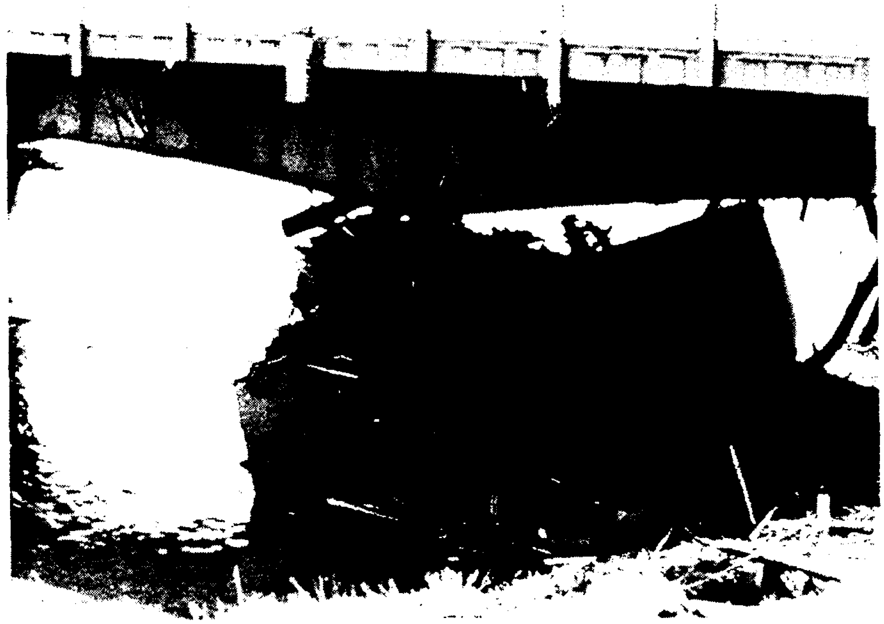


Figure 17-6 Movement of a Substructure Unit

17.4.4 In-Depth Inspections

An in-depth inspection is a close-up, hands-on inspection of one or more members below the water level to detect any deficiencies not readily apparent using routine inspection procedures. When appropriate or necessary to fully ascertain the existence of or the extent of any deficiencies, nondestructive tests may need to be performed.

The inspection may include a load rating to assess the residual capacity of the member or members, depending on the extent of the deterioration or damage.

One or more of the following conditions may dictate the need for an in-depth inspection:

- Inconclusive results from a routine inspection
- Critical structures whose loss would have significant impact on life or property
- Unique structures whose structural performance is uncertain
- Prior evidence of distress
- Consideration of reuse of an existing substructure to support a new superstructure or planned major rehabilitation of the superstructure
- Adverse environmental conditions such as brackish and polluted water

The in-depth inspection typically includes Level II inspection over extensive areas and Level III inspection of limited areas. Nondestructive testing is normally performed, and the inspection may include partially destructive testing methods, such as extracting samples for laboratory analysis and testing, boring, and probing.

All findings should be recorded using notes and sketches. Underwater photographs and video recordings can also be used where visibility permits.

The distinction between routine and in-depth inspections is not always clearly defined. For some bridges, such as steel pile supported structures in an actively corrosive environment, it may be necessary to include Level III, nondestructive testing inspection techniques as part of routine inspections.

17.4.5 Interim Inspections

An interim inspection is an inspection scheduled at the discretion of the individual in responsible charge of bridge inspection activities. An interim inspection is used to monitor a particular known or suspected deficiency (e.g., foundation settlement or scour).

17.5 Qualifications of Diver-Inspectors

The National Bridge Inspection Standards (NBIS) do not specify minimum requirements necessary for a diver to be considered fully trained and experienced in the inspection and evaluation of substructure and streambed conditions.

The underwater inspector must have knowledge and experience in bridge inspection. Obviously, it is also helpful to be an experienced and accomplished diver.

A diver not fully qualified as a bridge inspector or bridge inspection team leader must be used only with care and under close supervision. All underwater inspections should be conducted under the direct supervision of a qualified bridge inspection team leader.

17.5.1 Diver Training Certifications

At present, there is no single, nationally recognized dive certification agency. However, the following three types of formal diving training are commonly available.

Diver Training Programs

Diver training programs are oriented toward the recreational diver and include the following:

- YMCA
- PADI (Professional Association of Diving Instructors)
- NAUI (National Association of Underwater Instructors)

Commercial Diving School

Graduates of commercial diving schools are taught various types of diving methods, equipment maintenance, and how to perform mechanical tasks underwater. Some schools also provide specialty courses in nondestructive testing (NDT).

Military Training

Military divers complete extensive courses in various types of diving systems and normally receive extensive on-the-job training and experience in diving operations.

17.5.2 Dive Team Requirements

The Federal Highway Administration's main concern is whether the diver has knowledge and experience in normal bridge inspections. The States are in the best position to determine their individual needs.

One fact is certain, however, and this is that diving requires special training which the typical bridge inspector may not have. Conversely, most divers are not trained bridge inspectors. Consequently, most underwater inspections will require a joint effort between an inspector and a diver.

17.5.3 OSHA Safety Requirements

Safe conditions should always be the first and foremost consideration. The Occupational Safety and Health Administration (OSHA) regulates all commercial diving performed inland and on the coast (OSHA Part 1910: Commercial Diving Operations). This reference should be consulted for details on commercial diving procedures and safety.

All divers, regardless of their training, if receiving remuneration for their diving services, are considered commercial divers. The OSHA standard delineates minimum personnel requirements, general operations procedures, specific operations procedures, equipment procedures and requirements, and recordkeeping requirements.

17.6 Planning an Underwater Inspection

Planning for underwater bridge inspections is particularly important because of:

- Unknown factors which may be discovered during the diving
- The difficulty for the bridge owner to verify the thoroughness of the inspection
- The cost of conducting underwater inspections

These factors are most influential for first-time (inventory) underwater inspections which set a benchmark for future inspections. It is, therefore, important to distinguish between the first-time and follow-up inspections.

The effectiveness of an underwater inspection depends on the agency's ability to properly consider all factors:

- Method of underwater inspection
- Diving inspection intensity level
- Type of inspection
- Qualifications of diver-inspectors

With these factors considered, an agency may opt for a lower level of inspection. Depending on conditions and the type of damage found, a higher level may then be necessary to determine the actual bridge condition. It is also possible that different levels may be required at various locations on the same bridge.

17.7 Substructure Units and Elements

The underwater portions of bridge structures can be classified into four broad categories: bents, piers, abutments, and protection systems. Proper identification is important since various elements may require different inspection procedures, levels of inspection, or inspection tools.

17.7.1 Bents

The majority of substructure units requiring underwater inspection are piers and bents. We can divide bents into two groups:

- Pile bents
- Column bents

Pile Bents

Pile bents carry the superstructure loads through a pile cap directly to the underlying soil or rock. The piles (and pile cap) can be constructed of timber, steel, or concrete. Pile bents are generally distinguished from piers by the presence of some battered piles and also bracing which provides stability for the individual piles.

Important items to be noted by the inspector are collision damage, corrosion, and section loss. Scour of the river bottom material at the bottom of the piles can result in instability of the piles. The underwater inspector must compare present scour and resultant pile length with that observed in previous inspections.

Column Bents

Column bents have two or more columns supporting the superstructure and may in turn be supported by piling below the mud line. The column bents are typically constructed of concrete, but the piling may be timber, concrete, or steel.

17.7.2 Piers

Piers carry superstructure loads from the pier cap to the footing, which may be a spread footing or may be supported on piles. Piers can be constructed of steel, timber, concrete, or masonry and are usually distinguished by two to four large columns or a single large shaft. As with pile bents, collision damage, deterioration, and scour are important items to look for in an underwater inspection. It is also important for the inspector to note if the pier shaft or columns are plumb. There are three common types of piers the inspector is likely to encounter:

- Column pier with solid web wall
- Cantilever or hammerhead pier
- Solid shaft pier

17.7.3 Abutments

Abutments carry the superstructure loads to the underlying soil or rock and also retain the earth at the end of the structure. In most cases, the abutments are dry during low water periods and do not require a diving inspection. However, occasionally the abutments remain continually submerged and must be inspected underwater. Abutments can be constructed from concrete, masonry, or timber and may be supported by spread footings, piles, caissons, or pedestals.

Scour is probably the most critical item to be aware of when performing an underwater abutment inspection. Extreme local scour (undermining) could result in a forward tilting or rotation of the abutment, especially on those abutments without pile foundations.

17.7.4 Protection Systems

Dolphins and fenders are often placed around substructure units to protect them from impact damage. Since these systems are usually at least partially underwater, a diving inspection should be conducted in concert with the substructure unit inspection. Additional protection systems and scour countermeasures include spur dikes, streambed armoring, rip rap, wing dams, and check dams.

17.8 Scour Investigations

Divers may be able to note scour degradation under certain conditions. The most important assessment is how much of the bent or pier is exposed when compared to plans and typical designs.

Local scour is sometimes detectable by divers since this type of scour is characterized by holes near bents, piers, or abutments. Divers should routinely check for such scour holes. A typical approach is to take depth measurements around the substructure, both directly adjacent and at concentric intervals. It should also be noted that divers operate in low current situations. Sediment often refills scour holes during these periods, making detection of even local scour difficult. However, since this refilled sediment is usually soft, a diver using a probing rod can often detect the soft areas indicating scour refilling.

Depth measurements will not directly reveal the more general scour of significant sections of the streambed. However, the diver may find evidence of such scour from examination of the structure if parts of the substructure are exposed, or by comparing successive cross sections.

The diver's role is primarily to point out a potential scour problem. Almost invariably, an additional interdisciplinary engineering investigation will be needed. The diver's primary role in scour investigation is to measure scour by one of two methods:

- Sounding/sensing devices
- Diver investigations

17.8.1 Sounding Devices

Although sounding/sensing devices can be used independently of diving, they are commonly part of an underwater inspection. With the exception of poles and lead lines, sounding/sensing devices depend on some type of signaling system. While these systems are quite effective, they can be misinterpreted. An on-site diver can investigate questionable readings and more fully determine the bottom conditions.

Black and White Fathometer

The most commonly used device is the black and white fathometer. A transducer floats just below the waterline and bounces sound waves off the bottom. Depths are continuously recorded on a strip chart.

Advantages of the black and white fathometer include the following:

- Inexpensive
- Effective

Disadvantages include the following:

- False readings can occasionally occur due to heavy drift or heavy turbulence
- The strip chart moves at a constant rate and does not record a horizontal scale; unless the boat can be kept at a constant speed, the scale becomes distorted
- Fathometers may also fail to detect refilled scour holes during calm water

Dual Frequency and Color Fathometer

Dual frequency and color fathometers can be used to detect refill since more than one frequency is utilized. With color fathometers, materials of different densities are displayed as different colors. The primary drawback is that a hard copy cannot be obtained except with videotape recordings.

Fathometer/Theodolite

The horizontal scale problem can be solved by using equipment which combines a fathometer with a total station theodolite. The theodolite is set up on shore, it tracks and records the coordinates of the transducer, and it automatically records depths at specified increments using a microprocessor. The data can be processed and plotted as a topographic map.

Ground-Penetrating Radar

Ground-penetrating radar and tuned transducer (low frequency sonar) equipment are also used in scour surveys. These are good in shallow water but not very effective in salty, brackish water.

Fixed Instrumentation

An alternative to the sounding and scour sensing devices used during inspections is to permanently install fixed instrumentation directly on the bridge substructure. With fixed instrumentation, local scour is continuously monitored and recorded as it occurs, unaffected by washing back of silts and sands, and making information readily available to the bridge owner by setting off a beacon-type alarm on the bridge deck (or relayed back to an office). The instrument consists of a steel rod inside of a conduit attached to the substructure unit. The rod acts as a probe, resting on the vulnerable soil supporting the substructure. As local scour occurs the soil is washed away and the rod drops a measured distance.

17.8.2 Diver Investigations

Diver investigations include:

- Laying out a grid pattern and taking depth measurements
- Sampling soils to determine backfilling of scour holes
- Probing to check for refilling
- Detecting undermining and scour holes
- Detecting small diameter but deep scour holes around piles
- Protective system evaluation (e.g., rip rap)

17.9 Underwater Inspection for Material Defects

The materials typically used in bridge substructures are concrete, timber, steel, and masonry. An estimated 75% of all underwater elements are concrete. The balance consists of timber, steel, and masonry, in descending order of use.

17.9.1 Concrete and Masonry

Plain, reinforced, and prestressed concrete are used in underwater elements. Since the majority of substructures are basically compression units, concrete is a nearly ideal material choice. Some concrete damage tends to be surface damage which does not jeopardize the integrity of the system. However, concrete deterioration that involves corrosion of the reinforcement can be very serious (see Figure 17-7).

Typical defects include:

- Cracking
- Spalls
- Exposed reinforcing
- Concrete laitance - a weak surface layer consisting only of cement paste and fine aggregates
- Sulfate attack
- Honeycombing
- Rust spots
- Grout loss
- Scaling

Figure 17-7 Spalled Concrete Piles at Low Water Level

17.9.2 Timber Piles

Piles and protection systems often utilize timber. Timber pile bents are typical for short span bridges in many parts of the country, particularly for older bridges. The primary cause of timber deterioration is biological organisms, such as fungi, insects, bacteria, and marine borers. The ingredients for an attack include suitable food, water, air, and a favorable temperature. The waterline of pile structures offers all of these ingredients during at least part of the year. Since water, oxygen, and temperature generally cannot be controlled in a marine environment, the primary means to prevent a biological attack is to deny the food source through treatment to poison the wood as a food source. Timber piles are particularly vulnerable if the treatment leaches out (which happens with age) or if the core is penetrated. It is, therefore, important to carefully inspect in the vicinity of connectors, holes, or other surface blemishes (see Figure 17-8).

Piles used in older bridges quite often were not treated if the piles were to be buried below the mud line (eliminating the source of food and oxygen). However, in some cases, streambed scour may have exposed these piles. Special care should be taken in differentiating between treated and untreated piles to ensure a thorough inspection of any exposed, untreated piles. With each inspection, the diameter or circumference should be noted for each timber pile. As a minimum, these measurements should be made at the waterline and mud line. Comparisons should be made with the original pile size.

Another primary caution for inspecting underwater timber piles is that the damage is frequently internal. Whether from fungal decay or borers, timber piles may appear sound on the outside shell but be completely hollow inside. While some sources recommend hammer soundings to detect internal damage, this method is unreliable in the underwater environment. One way to inspect for such damage is to take core samples. All bore holes should be plugged. Ultrasonic techniques for timber piling are also available.

Figure 17-8 Decayed Timber Pile

17.9.3 Steel

Underwater steel structures are highly sensitive to corrosion, particularly in the low to high water zone. Whenever possible, steel should be measured to determine if section loss has occurred. Ultrasonic devices are particularly useful to determine steel thicknesses.

17.9.4 Previous Repairs

The inspector must also be alert to note deterioration of previous member repairs or rehabilitations. The first step in the inspection of previous repairs is to review all existing bridge substructure plans prior to the actual inspection. Repair areas should be noted as important areas of inspection. Typical previous repairs might be:

- Steel cover plates
- Concrete fill repairs
- Epoxy crack repairs
- Concrete encasement or jacketing
- Limited replacement of members
- Masonry stone replacement
- Underpinning and rip rap to repair scour

17.9.5 Hands-on Inspection of Material Underwater

When visibility permits, the diver should visually observe all exposed surfaces of the substructure. Scraping over the surface with a sharp-tipped probe, such as a knife or ice pick, is particularly useful for detecting small cracks. With limited visibility, the diver should "feel" for damage. Because orientation and location are often difficult to maintain, the diver should be systematic in the inspection. Regular patterns should be established from well-defined reference points.

Typical inspection patterns include:

- Circular or semicircular horizontally around piers or abutments beginning at the base, moving upward a specified increment, and repeating until complete
- Probing zones of undermining of piers by moving uniform increments from start to finish and recording the undermined penetration
- Down one side and up the other for piles (or spirally downward)
- For scour surveys, record depths at regular increments adjacent to substructure (e.g., at each pile or 10 foot increments around piers), and then at each measured point extend radially from the substructure a uniform distance and repeat depth measurements

The major advantages of diver-to-surface communications are that the diver can be guided from the surface with available drawings and that immediate recording of observations can be made topside along with the clarification of any discrepancies with plans.

17.9.6 Measuring Damage

Any damage encountered should be measured in detail. As a minimum for a Level II or III inspection include:

- Location of the damage zone both horizontally and vertically from a fixed reference point

- A good vertical reference point is the waterline, provided that the waterline is measured with respect to a fixed reference point on the bridge prior to the dive
- Locate the beginning and ends of cracks and intermediate points as needed to define the pattern
- Measure the maximum crack width and penetration depth
- Measure the length, width, and penetration of spalls or voids
- Measure the thicknesses of all four flange tips on steel H-piles at distressed areas, and specify the vertical location
- Locate buckles, bulges, or holes in steel members
- For undermining of foundations, take enough measurements to define the zone no longer providing soil bearing
- If plans are not available, measure the basic dimensions of damaged members (it is also usually prudent to spot check dimensions of damaged members even if plans are available)
- Measure the diameter of timber piles
- Note the degree of scaling on concrete
- Check for displacements of major elements and whether they are plumb
- Note damage at connections

17.9.7 Recordkeeping and Documentation

Because of the effort in conducting underwater inspections, combined with the time between inspections, it is particularly important to carefully document the findings. On-site recording of all conditions is essential:

- Sketches - it is recommended that sketches be used as much as possible; providing enough detail is critical since it is difficult to go back to check items once the diving is completed
- Logs - in addition to sketches, a written log is often kept describing the inspection
- Tape recordings - when significant damage is encountered, a tape recording of the diver's observations can also prove helpful
- Underwater photographs
- Underwater videotapes

The results should also be included in a report. Drawings and text should describe all aspects of the inspection and any damage found. The report should also include recommendations on condition assessment, repairs, and time interval for the next inspection.

17.10 Underwater Inspection Equipment

17.10.1 Diving Equipment

For scuba diving, air supply equipment is provided by the pressure tank carried by the diver. Personal equipment includes:

- Exposure suit (wet or dry)
- Face mask or helmet
- Breathing apparatus
- Weight belt
- Swim fins

- Knife
- Wristwatch
- Buoyancy compensator (a flotation device capable of maintaining a diver faceup at the surface)
- Depth gauge
- Pressure gauge

Typical hardhat diving equipment includes a compressor which collects and pumps air into a volume tank for storage. The compressed air is regulated to the diver through a hose which passes through an air filter. The hose is part of a tether which includes a safety line, communication line, and pneumofathometer hose. The pneumofathometer provides depth measurements to the surface. A reserve air tank may also be carried by the diver for emergencies.

Equipment malfunction leading to loss of air supply must be a constant concern to the dive team. Unless the depth is shallow enough to allow the diver to reach the surface independently upon loss of air supply, a reserve air supply should always be carried. Other threats, such as the contamination of the air supply, are also a concern. For example, carbon monoxide poisoning can occur if the intake of the air compressor for surface supplied air is located near the exhaust of other motorized equipment.

17.10.2 Surface Communication

There is no pressing need to have voice communications in all situations, particularly for shallow dives where the diver can readily return to report any findings. However, on deep dives there are several advantages provided to the underwater inspection by the use of direct two-way communication:

- It allows the diver to immediately describe observations and location for simultaneous recording by a note taker on the surface.

- The diver can ask questions to the surface personnel which may clarify what is being observed.
- The note taker can follow drawings, verify their validity, note damage on the drawings at the proper location, and track the progress of the diver.
- Areas of concern can be more clearly and efficiently defined.
- Surface communication also allows an engineer at the surface to discuss observations with a non-engineer diver, to direct attention to specific zones, and to have follow-up inspection with specific measurements according to the type of damage found.

17.10.3 Access Equipment

While inspection of short-span bridges can often be accessed from shore, many bridges require a boat for access. Typically, an 18 foot or larger vessel can safely handle the equipment and crew. Occasionally, access is made from the bridge itself.

17.10.4 Tools

A number of inspection tools are available. The dive team should have access to the appropriate tools and equipment as warranted by the type of inspection being conducted. Of particular importance is a depth gauge for recording vertical measurements of key elements of the substructure.

Hand Tools

While most hand tools can be used underwater, the most useful include rulers, calipers, scrapers, probes (ice picks and screwdrivers), flashlight, hammers, wire brushes, incremental borers, and pry bars.

Power Tools

Typical power tools include drills, hammers, grinders, saws, and chippers. While pneumatic tools are sometimes used, hydraulic tools tend to be used for heavy or extensive work.

Cleaning Tools

Light cleaning can be accomplished with scrapers and wire brushes. Heavier cleaning requires automated equipment such as grinders. One of the most effective means of cleaning is with the use of water blasters. Particular care must be taken with such equipment to ensure that structural damage does not result from over-zealous blasting.

17.10.5 Nondestructive Testing Equipment

Ultrasonic measuring devices measure the thickness of steel by passing a sound wave through the member. The transducer is placed on one side only, and the thickness is displayed on an LED readout. Totally submersible or surface display units are available. They are very effective for measuring thickness.

A V-meter is an ultrasonic device which requires two transducers and measures the time required for the sound wave to pass through the concrete. Similar devices have also been developed for timber.

A waterproof Schmidt hammer can be used underwater to measure concrete compression strength in-place.

An R-meter is used to locate and measure the depth of cover and the size of reinforcing bars in concrete by inducing a magnetic field.

17.10.6 Coring Equipment

Coring is a partially destructive evaluation method whose use is usually limited to critical areas. Cores can be taken in either concrete or timber.

Concrete coring requires pneumatic or hydraulic equipment. Deep cores (3 feet or more) can be taken to provide an interior assessment of massive substructures. Two-inch diameter cores are common, but coring tools are available in other sizes. Cores not only provide knowledge about interior concrete consistency but can be tested to determine compression strength.

Timber coring is much simpler and less costly to perform than concrete coring. While power tools are sometimes used, the most effective procedure is still to hand core with an increment borer. This approach preserves the core for laboratory as well as field evaluation. Examination of the core should include its compressibility, evidence of borers or other infestation, and indications of void areas. The hole should always be plugged with a treated hardwood dowel to prevent infestation.

17.10.7 Underwater Photography and Video Equipment

Cameras come with a variety of lens and flash units. In some cases, visibility is limited and the camera must be placed close to the subject. Wide angle lenses are therefore most often used. Suspended particles often dilute the light reaching the subject and can reflect light back into the lens. When visibility is very low, clear water boxes can be used. The boxes are constructed of clear plastic and can be filled with clean water. By placing the box against the subject area, the dirty water is displaced and the camera shot can be taken through the clear water.

Video equipment is available either as self-contained, submersible units or as submersible cameras having cable connection to the surface monitor and controls. The latter type allows a surface operator to direct shooting while the diver concentrates on aligning the camera only. The operator can view the monitor, control the lighting and focusing, and communicate with the diver to obtain an optimum image. Since a sound track is linked to the communication equipment, a running commentary can also be obtained.

An extension of the video camera is a remotely operated vehicle (ROV), where the diver is eliminated and the camera is mounted on a surface controlled propulsion system. Its effectiveness diminishes substantially in stream velocities greater than 1.5 knots and is limited by cloudy water, inability to determine the exact orientation and position of the camera, and control sensitivity.

17.11 Special Considerations for Underwater Inspections

Once a diver enters the water, their environment changes completely. Visibility decreases and is often reduced to near zero due to muddy water and depth. In many cases, artificial lighting is required. There are times when inspections by feel are done; however, this method is used simply to determine whether a particular element is still intact. It offers little in the way of condition evaluation.

The diver not only has reduced perceptual capabilities but is less mobile as well. Maneuverability is essential for underwater bridge inspections. With either scuba or hardhat equipment, the diver can adjust their underwater weight to near buoyancy and use swim fins for propulsion.

17.11.1 Dealing with Current

Most waterways have low flow periods when current will not hinder an inspection. Diving inspections should be planned with this consideration in mind. Divers can work in current below 1.5 knots with relatively little hindrance.

As current increases, special precautions are required. The simplest is to use bottom anchors to tether the diver. In swifter current, shielding devices and special anchor systems may be required.

17.11.2 Dealing with Drift and Debris

The drift and debris that occasionally collects at bridge substructures can be quite extensive. This type of buildup typically consists of logs and limbs from trees which are usually matted or woven either against or within the substructure elements. Often this debris is located on the lower parts of the substructure and cannot be detected from the surface. The buildup can be so thick as to prevent access to major portions of the underwater substructure.

Hidden Costs

Since they are often hidden, drift and debris problems present the bridge owner with an unknown cost factor. The removal of the drift and debris must be provided for if an inspection of the underwater elements is to proceed. While in come cases it can be removed by the inspection divers, heavy equipment, such as a hoist or underwater cutting devices, are often required.

Past History

Generally, such buildup occurs in repetitive patterns. If previous underwater inspections have been conducted, its presence can be estimated based on past history. Also, certain rivers and regions tend to have a history of drift problems, while others do not. Knowledge of this record can help predict the likelihood of drift. A separate drift removal team, working ahead of the dive inspection team, could possibly be utilized.

Safety

Divers must also have a safety concern about the buildup of debris near a bridge. Occasionally, debris can be quite extensive and can lead to entanglements or sudden shifts which might entrap the diver.

17.11.3 Cleaning

Bridges on many inland waterways are relatively clean and free of marine growth. In such cases, the inspection can be conducted with little extra effort from the diver other than perhaps light scraping.

In coastal waterways, the marine growth can completely obscure the substructure element and may reach several inches or more in thickness.

Cleaning Locations and Procedures

The best approach is to restrict cleaning to small zones which are:

- Structurally critical areas
- Areas known to frequently deteriorate for that specific structural configuration
- Areas randomly selected to statistically lower the probability of overlooking damage

Typically, 6 to 12 inch bands or squares are recommended depending on the size and shape of the element. Highest priority should be placed on locations near the low waterline and at connecting elements. If feasible, locations should also be included at the mud line and midway between the mud line and low waterline. On small diameter elements, cleaning can be limited to bands approximately three-fourths around the circumference. For large elements, squares around the perimeter should be chosen at effective intervals.

While minor cleaning can be done with hand tools, it is often more efficient to use hydraulic grinders or high pressure water blasting equipment.

17.11.4 Physical Limitations

This sometimes cold, dark, hostile environment can result in a reduced physical working capacity. The diver is also totally dependent on external life support systems, which adds psychological stress. Things that can be done intuitively above water must be conscientiously planned and executed step-by-step underwater. For example, maintaining orientation and location during an underwater inspection requires continual attention. Distractions are plentiful and range from living organisms, such as fish, snakes, and crustaceans, to environmental conditions, such as cold, high current, and debris.

17.11.5 Decompression Sickness

Since the majority of bridge inspections are in relatively shallow water and of short duration, decompression problems rarely occur. However, multiple dives have a cumulative effect and the no-decompression time limit decreases rapidly at depths greater than 50 feet. Therefore, divers should routinely track their time and depth as a safety precaution.

17.11.6 Marine Traffic

Another hazard is vessel traffic near the dive area. There should always be someone topside with the responsibility of watching boat traffic. In addition, flags should be displayed indicating that a diver is down. The international code flag "A" (white stripe on blue) signifies that a diver is down and to stay clear of the area. This flag is required by OSHA. However, it is also prudent to display the sport diver flag (white stripe on red), since it is more likely that recreational boaters will recognize this flag.

18

Inspection and Evaluation of Fracture Critical Bridge Members

18.7 Inspection Locations and Procedures

18

Inspection and Evaluation of Fracture Critical Bridge Members

18.1 Introduction

Over the past 30 years, several hundred steel bridges have developed cracks, mostly due to fatigue failures. Although these localized failures have been extensive, only two U.S. bridges have actually collapsed as a result of cracking.

The first was the Silver Bridge over the Ohio River at Point Pleasant, West Virginia. This structure was an eyebar chain suspension bridge with a 700-foot main span that collapsed without warning on December 15, 1967 (see Figure 1-1).

The second collapse occurred on June 28, 1983, when a suspended two-girder span carrying I-95 across the Mianus River in Greenwich, Connecticut failed.

Fatigue

The fatigue failure of a material is due to the formation of cracks resulting from the repeated application of loads. Failure develops at stresses well below the material's yield point.

Fracture Critical Member

A fracture critical member (FCM) is a member in tension, or with a tension element, whose failure would probably cause a portion of or the entire bridge to collapse.

Failure Mechanics

Fatigue is the primary cause of failure in fracture critical members. Describing the process by which a member fails when subjected to fatigue is called failure mechanics.

18.1.1 Inspection of Fracture Critical Members

When inspecting steel bridges, the inspector must be able to identify a FCM by sight or based on previous reports and drawings. The National Bridge Inspection Standards (NBIS) require that all FCM's on a bridge be identified by an engineer and the inspection procedures listed prior to an inspection. For more detailed information on fatigue and FCM's, refer to:

- Federal Highway Administration's *Inspection of Fracture Critical Bridge Members*

- Pennsylvania Department of Transportation's *Manual for Inspecting Bridges for Fatigue Damage Conditions*

18.2 Redundancy

Redundancy means that should a member or element fail, the load previously carried by the failed member will be redistributed to other members or elements. These other members have the capacity to temporarily carry additional load, and collapse of the structure may be avoided. On nonredundant structures, the redistribution of load causes additional members to also fail, resulting in a partial or total collapse of the structure.

There are three basic types of redundancy in bridge design:

- Load path redundancy
- Structural redundancy
- Internal redundancy

Recognition or identification of a bridge's degree of redundancy is crucial to the determination of fracture criticality.

18.2.1 Load Path Redundancy

Bridge designs that are load path redundant have three or more main load-carrying members or load paths. If one member were to fail, load would be redistributed to the other members, and bridge failure would not occur. An example of load path redundancy is a multi-beam bridge (see Figure 18-1).

Figure 18-1 Multi-Beam Bridge

18.2.2 Structural Redundancy

Bridge designs which provide continuity of load path from span to span are referred to as structurally redundant. Some continuous span two-girder bridge designs are structurally redundant. In the event of a member failure, loading from that span can be redistributed to the adjacent spans, and bridge failure may not occur.

Structural redundancy can be determined through computer programs which model element failure. Some truss bridges have structural redundancy, but this can only be determined through analysis.

18.2.3 Internal Redundancy

Internal redundancy exists when a bridge member contains several elements which are mechanically fastened together so that multiple load paths are formed. Failure of one member element would not cause total failure of the member. An example of an internally redundant member is a riveted plate girder (see Figures 6-17 and 6-18).

Internal redundancy of a member can be decreased or eliminated by repairs which involve welding. The welds provide paths for cracks to travel from one element to another.

Internal redundancy is also referred to as member redundancy.

18.2.4 Nonredundant Configurations

Bridge designs that are nonredundant have two or less main load-carrying members or load paths. Bridge members that are nonredundant have two or less elements. Nonredundant bridge configurations almost always contain fracture critical members.

In the interest of conservatism, the inspector should neglect structural and internal redundancy and classify all two-girder bridges as nonredundant (see Figure 18-2).

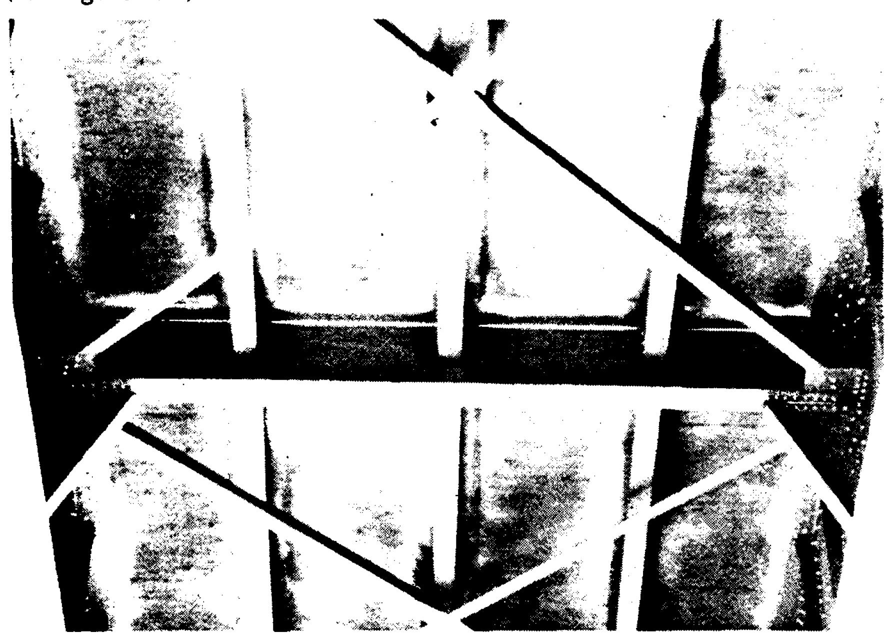


Figure 18-2 Two-Girder Bridge

18.3 Failure Mechanics

The fatigue failure process of a member consists of three phases:

- Crack initiation
- Crack propagation
- Fracture

Crack Initiation

A crack first initiates from points of stress concentrations in structural details. Stress concentrations can result from flaws, geometric details, or out-of-plane distortions. The most critical conditions for crack initiation at structural details are those combining:

- High stress concentrations due to flaws
- High stress concentrations due to geometric details
- High stress concentrations due to out-of-plane distortions

Crack Propagation

Once a fatigue crack has initiated, applied cyclic stresses propagate the crack across the section of the member until it reaches a critical size, at which time the member fractures.

Fracture

Fracture of a member is the separation of the member into two parts. The fracture of a critical member causes the span, or a portion of it, to collapse.

18.3.1 Fatigue Life

The number of cycles required to initiate a fatigue crack is the fatigue-crack-initiation life. The number of cycles required to propagate a fatigue crack to a critical size is called the fatigue-crack-propagation life. The total fatigue life is the sum of the initiation and propagation lives.

Bridge engineers use estimations of total fatigue life in evaluating the performance of bridges.

18.3.2 Types of Fractures

It is common to classify fractures into two failure modes: brittle fracture and ductile fracture.

Brittle Fracture

Brittle fracture occurs with no warning (i.e., without prior plastic deformation and at average stresses below those of general yielding).

Ductile Fracture

Ductile fracture is generally preceded by local plastic deformation of the net uncracked section. This plastic deformation results in distortion of the member, providing some visual warning of the impending failure.

18.4 Factors Affecting Fatigue Crack Initiation

Recall that the most critical conditions for fatigue crack initiation are those which involve stress concentrations. Stress concentrations have resulted from out-of-plane distortion of elements of bridge members, and cracks have occurred due to such distortion. Good detailing can reduce the number and severity of these stress concentrations, but the need to connect girders, stringers, floorbeams, diaphragms, bracing, truss members, hangers, and other members makes it impossible to completely avoid them. Bridge structures, particularly those that are welded, cannot be fabricated without details which cause some level of stress concentrations.

18.4.1 Weldments

Conditions of stress concentration are often found at weldments, which are known to be prone to crack initiation. Weldments, or welds, are the connections of metal parts formed by heating the surfaces to a plastic (or fluid) state and allowing the parts to flow together and join with or without the addition of filler metal. The term base metal refers to the metal parts which are to be joined. Filler metal, or weld metal, is the additional molten metal generally used in the formation of welds.

The four common types of welds found on bridges are groove welds, fillet welds, plug welds, and tack welds.

Groove Welds

Groove welds, which are also known as butt welds, are used when the members to be connected are lined up in the same plane (see Figure 18-3).

Full penetration groove welds extend through the entire thickness of the piece being joined, while partial penetration groove welds do not.

Weld reinforcement is the added filler metal that causes the throat dimension to be greater than the thickness of the base metal. This reinforcement is sometimes ground flush with the base metal to qualify the joint for a greater fatigue strength category.

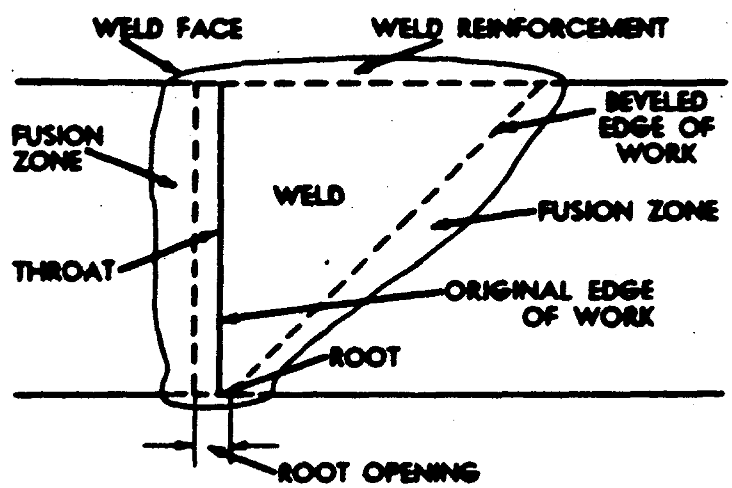


Figure 18-3 Groove Weld Nomenclature

Fillet Welds

Fillet welds connect members that overlap each other. Fillet welds are the most common type of weld since large tolerances in fabrication are allowable when members are allowed to lap over each other instead of fit together as in groove welds (see Figure 18-4).

Plug Welds

Plug and slot welds pass through holes in one member to another filling the holes and joining the members together. Plug welds may also be used to fill misplaced holes (see Figure 18-5).

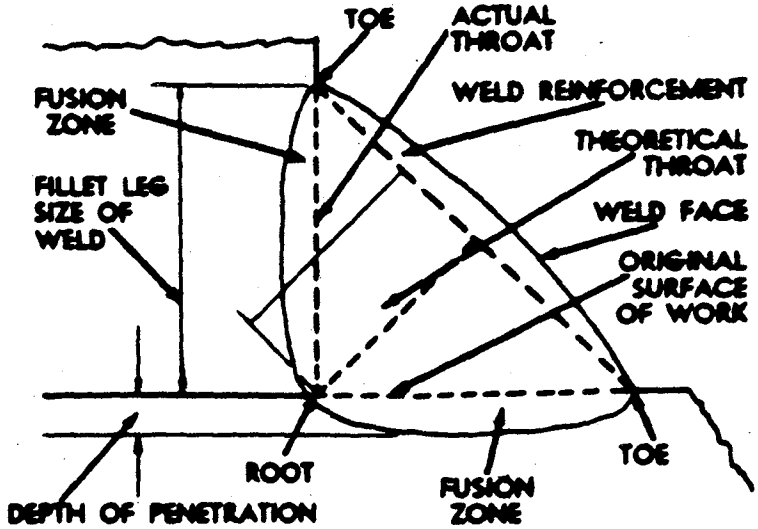


Figure 18-4 Fillet Weld Nomenclature

Figure 18-5 Girder Fracture Initiated at Plug Welded Bolt Hole

Tack Welds

Tack welds are small welds commonly used to hold pieces in position during fabrication or construction (see Figure 6-26).

Plug and tack welds are smaller than fillet and groove welds but they can be the source of serious problems to bridges.

The type of joint being used is also used to described the weld:

- Butt
- Lap
- Tee
- Edge
- Corner

18.4.2 Flaws

Bridge structures, particularly those that are welded, can contain flaws whose size and distribution depend upon the:

- Quality of material
- Fabrication methods
- Erection techniques
- In-service conditions

Flaws vary in size from very small undetectable nonmetallic inclusions to large inherent weld cracks.

Material Flaws

Material flaws may exist in different forms:

- External flaws (e.g., surface laps)
- Internal flaws (e.g., nonmetallic inclusions and lamellar tears)

Fabrication Flaws

Fabrication can introduce a variety of flaws. Among them are weld flaws consisting of:

- Incomplete fusion
- Slag inclusions
- Porosities
- Blow holes
- Undercuts
- Start and stop positions
- Craters
- Arc strikes
- Back-up bars and tack welds left in place
- Hot and cold cracks

Plug welds are sometimes found in bridge members. In most cases, they were made to fill mislocated bolt holes. It is very likely that such welds will contain incomplete fusion, slag inclusions, and porosity. There have been many instances where a crack and fracture has occurred because of a plug weld.

Repairing a weld flaw does not always eliminate the problem, since the repair weld may also be flawed. A common procedure to eliminate flaws caused by plug welds is to drill out the weld to a hole larger than was originally filled with the weld material. Other flaws that can occur in fabricating bridges are:

- Damage around the edges of drilled and punched holes
- Gouges and notches from flame cutting
- Gouges and notches from grinding operations
- Sharp corners at coped or blocked details

Erection Flaws

Careless handling during transportation and erection may leave the following flaws along the edges of members:

- Nicks
- Notches
- Indentations
- Chain marks

In-Service Flaws

Once the structure is placed in service, some members may be prone to collision damage by errant vehicles which may nick, tear, and excessively strain the steel. Improper heat straightening may damage the steel. Deep corrosion pits can develop in structures which are improperly detailed for corrosion control, poorly maintained, or constructed of bare steel.

18.5 Factors Affecting Fatigue Crack Propagation

The cracking and failures that develop as a result of cyclic loading usually provide little evidence of plastic deformation. Hence, they are often difficult to see before serious distress develops in the member. Fatigue cracks generally require large magnitudes of cyclic stresses, corresponding to a high frequency of occurrence or to a long exposure time. Structural details have various amounts of resistance to fatigue cracks caused by these large magnitudes of cyclic stresses. The three major parameters affecting fatigue crack propagation life are:

- Stress range
- Number of cycles
- Type of detail

18.5.1 Stress Range

The stress range is defined as the algebraic difference between the maximum stress and the minimum stress calculated at the detail under consideration. In other words, it is the value of the cyclic stress caused by a truck crossing the bridge. The weight of the bridge produces a constant stress instead of a cyclic stress. Therefore, it does not affect the crack propagation life. Only stress ranges in tension or stress reversal can drive fatigue cracks to failure. Stress ranges in compression may cause cracks to grow to some extent at weldments where there are high residual tensile stresses. However, these "compression" cracks eventually arrest, and they do not induce fracture of the member.

18.5.2 Number of Cycles

The number of stress cycles is, in most bridges, the number of trucks that cross the bridge in either direction during its service life. In some bridges, stress cycles are induced by wind loading.

18.5.3
Type of Detail

The term "type of detail" refers to the stress condition in a member or connection. Examples of types of details include:

- Flange cover plates
- Transverse stiffeners
- Flange groove welds
- Bolted joints
- Longitudinal stiffeners
- Connection plates (vertical or horizontal) attached to webs or flanges

Various details will have different fatigue strengths associated with them. It is common practice among bridge engineers to group steel bridge structural details into a number of categories. By doing this, the bridge engineer can design against risk levels of fatigue failure of the various details (i.e., details of higher fatigue strength categories are allowed higher stress ranges than the lower category details).

For purposes of designing bridges for fatigue caused by in-plane bending stress, the details are grouped into categories labeled A to F. The classification of details by category does not apply to details that crack due to out-of-plane distortion. Each letter represents a rating given to a detail which indicates its level of fatigue strength. The details assigned to the same category have about equally severe stress concentrations and comparable fatigue lives. The alphabetical classification by the severity of the stress concentration is a useful method of identifying fatigue strength.

When used in inspection, these fatigue categories serve as a reminder of which details are prone to fatigue cracking. The categories are defined as follows.

Category A

Category A refers to "base metal" or plain material with rolled or cleaned surfaces away from welded, riveted, or bolted connections. This condition has the longest fatigue life. It is not common practice to examine these base metal regions for fatigue cracks unless the regions are susceptible to distortion, because cracks usually develop at nearby connection details with lower fatigue strength categories.

Category B

Category B includes the following welds, structural details, and high strength bolted joints:

- Longitudinal continuous welds in built-up plates and shapes

- Transverse full penetration groove welds with weld reinforcement ground smooth and weld soundness established by nondestructive testing (NDT)

- Groove welded attachments with a transition radius not less than 24 inches

- High strength bolted connections

Category B'

Category B' is a new (1987) subcategory including details similar to those of Category B, but more sensitive to fatigue:

- Longitudinal continuous welds in built-up plates and shapes not detailed in Category B
- Transverse full penetration groove welds with reinforcement ground smooth to provide straight transition in width or thickness, slopes of transition not steeper than 1 to 2.5, and base metal being A514 or A517

Category C

Category C includes transverse stiffeners, very short attachments, and transverse groove welds with reinforcement not removed:

- Base metal at welds connecting transverse stiffeners or vertical gusset plates to connection and gusset plates of girder webs or flanges
- Transverse full penetration groove welds, weld reinforcement not removed, but with weld soundness established by NDT
- Groove or fillet welded horizontal gusset or attachment, the length of which (in the direction of the main member) is less than 2 inches
- Groove welded attachments 6 to 24 inches in length with transition radius
- Intersecting plates connected by fillet welds with the discontinuous plate not more than 1/2 inch thick
- Shear connectors

Category D

Category D includes welded short attachments, welded connections with sharp transition curves, and riveted joints:

- Welded attachments with a groove or fillet weld in the direction of the main member between 2 inches and 4 inches long but less than 12 times the plate thickness
- Groove welded attachments with transition radius between 2 and 6 inches
- Groove welded attachments with unequal plate thickness, weld perpendicular to attachment, weld reinforcement removed, and a transition radius of at least 2 inches
- Fillet weld 2 inches or larger and welds ground smooth
- Riveted connections, net section

Categories E and E'

Categories E and E' include details that have the lowest fatigue strength in comparison to those in other categories. Generally, for welded details in this group with the same configurations, Category E' applies if the flange plate thickness exceeds 8/10 of an inch or if the attachment plate thickness is 1 inch or more:

- Ends of partial length cover plates on girder or beam flanges
- Welded attachment, with groove or fillet weld in the direction of the main members, more than 4 inches or 12 times the plate thickness; this is a common detail on bridge girders (e.g., the gusset plate which connects lateral bracing to the girders)
- Welded attachment with curved transition
- Welded attachment with loads transverse to welds
- Intermittent fillet welds

Category F

Category F includes the shear stress on the throat of a fillet weld.

Inspection of Details

The thoroughness of a fracture critical member inspection should be in the order of their susceptibility to fatigue crack propagation. Therefore, the order should be from the highest susceptibility (F) to the lowest (A).

Of all the details, those of Categories E, E', and F are the most susceptible to fatigue crack growth. These details must be examined at every inspection. If Category E, E', or F details are found on a FCM, they should be carefully inspected and their presence clearly documented in the inspection report.

It should be noted that the direction of live load stress at a detail is a major factor of fatigue strength.

18.5.4 Transition Between Brittle and Ductile Fracture

The transition between a brittle and ductile type of fracture is greatly affected by:

- Ambient temperature
- Loading rate - rapid loading of a steel member, as would occur from a truck collision or an explosion, can create sufficient energy to cause a member to fail in brittle fracture; truck loading will normally stress the member at an intermediate loading rate which will not create a high energy level; variations in the speed at which the truck crosses the bridge do not significantly alter the rate of loading
- Degree of constraint - thick welded plates or complex joints can produce a high degree of constraint that will limit the steel's ability to deform plastically; thinner plates are less prone to fracture, given the same conditions, than are thicker plates

The likelihood of a brittle fracture is greatly enhanced by the adverse combination of three factors:

- Cold temperature
- Rapid loading
- High constraint

Conversely, some plastic deformation leads to a ductile fracture when the conditions are:

- Warm ambient temperature
- Normal truck loading rates
- Low constraint

The transition is a matter of degree. In either case, when it occurs, the fracture of a critical member is sudden and catastrophic.

18.5.5 Fracture Toughness

The fracture toughness is a measure of the material's resistance to crack extension. Fracture toughness can be defined as the ability to carry load and to absorb energy in the presence of a crack. Like the previously discussed brittle-to-ductile failure transition, the fracture toughness for a given steel type varies with:

- Temperature
- Loading rate
- Degree of constraint

In general, a steel plate with low toughness may experience a brittle failure when:

- The temperature is low
- The structure is rapidly loaded
- The member is thick

Conversely, for a steel plate with higher toughness, the fracture becomes increasingly ductile when:

- The temperature is higher
- The loading rate is slower
- The member is thinner

Trucks crossing a bridge stress the steel at rates intermediate between those of slow and rapid loading. Therefore, with actual bridges in service, the toughness of the steel is primarily a function of steel type, temperature, and constraint. In general, thick welded members made of steel with low toughness are more likely to fracture on cold days.

18.6 Fatigue Crack Categories

18.6.1 Out-of-Plane Distortion

The largest category of fatigue cracking is a result of out-of-plane distortion across a small concentration gap, usually a segment of a girder web (see Figure 4-26). In general, the cracks form in planes parallel to the stresses from loading and are not detrimental to the performance of the structure, providing they are discovered and retrofitted before becoming perpendicular to the primary stresses from loads.

The problem of distortion-induced fatigue cracking has developed in many types of bridges, including:

- Trusses
- Suspension bridges
- Two-girder bridges
- Multi-beam and multi-girder bridges
- Tied arch bridges
- Box girder bridges

When distortion-induced cracking develops in a bridge, there are usually large numbers of cracks that form before corrective action is taken, because the cyclic stresses are often very high. As a result, many cracks form simultaneously in the structural system.

18.6.2 Details and Defects

Low fatigue strength details and initial defects make up the next largest category of cracked members.

Low Fatigue Strength Details

Low fatigue strength details, such as cover-plated beams and welded web and flange gusset plates, should be carefully inspected on bridges that have experienced large numbers of stress cycles (see Figure 18-6).

Initial Defects

Initial defects, in many cases, are cracks resulting from poor quality welds. Many of these cracks occurred because the groove-welded element was considered a "secondary" attachment with no established weld quality criteria (e.g., splices in longitudinal web stiffeners) (see Figure 18-7). Lack-of-fusion discontinuities in welds can lead to crack initiation. Intersecting welds can provide a path for the crack to travel from secondary members to main members.

18.6.3 Copes, Flange Terminations, and Restraints

Another category of fatigue cracks is those related to connection restraint, such as at the end connections of stringers and floorbeams (see Figure 18-8).

Figure 18-6 Fatigue Crack at Cover Plate Detail

Figure 18-7 Poor Longitudinal Stiffener Weld

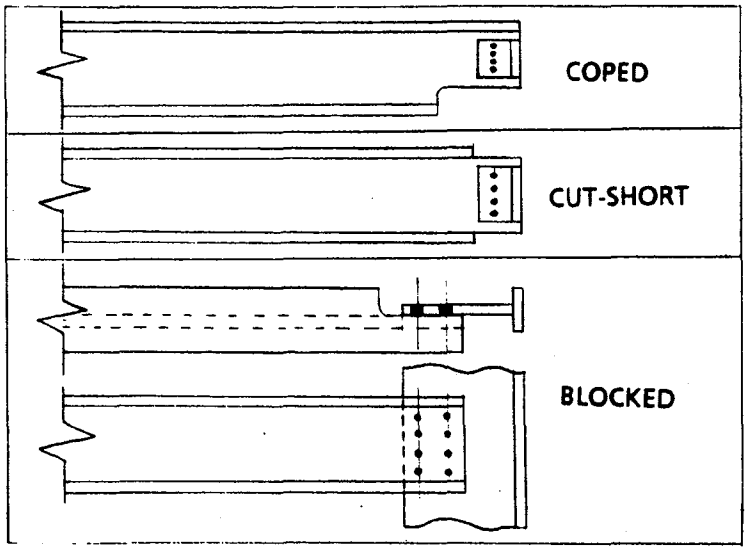


Figure 18-8 Cut Short, Coped, and Blocked Beam Flanges

Copes

The use of coped members, such as stringers, floorbeams, and diaphragms, is common in bridge floor systems. Copes are often flame cut, resulting in residual tensile stresses, along the cut edges, approaching the yield point.

Flange Terminations

It is also common to terminate the flange before the end connection. When one or both flanges are removed, the web plate has a lower cross section as compared to the entire member. This can increase the bending stress in the web plate by 200 or 300 percent.

End Restraints

A related type of cracking develops in the end connection angles. End rotation deforms the connection angle out-of-plane. This results in cracking of the angle often at the fillet or the bolt/rivet line. In some cases, the rivet or bolt heads will crack off when the angle is relatively thick.

18.7 Inspection Locations and Procedures

There are many factors which influence the fracture criticality of a bridge with FCM's, including:

- The degree of redundancy
- The live load member stress
- The propensity of the material to crack or fracture
- The condition of specific FCM's
- The existence of fatigue prone design details
- The previous number and size of loads
- The predicted number and size of loads

While FCM's should be given special attention, care should be taken to assure that the remainder of the bridge or member is not ignored and that it is also inspected thoroughly. Bridge plans and shop drawings for bridges designed after about 1980 should have FCM's clearly identified.

18.7.1 Fracture Critical Bridge Types

The following is a list of previously identified fracture critical steel bridge superstructures which are susceptible to failure due to fatigue cracking. The bridges are listed in order, with the most susceptible first:

- Suspended spans with two girders
- Bar-chain suspension bridge with two eyebars per panel
- Welded tied arches with box shaped tie girder
- Simple span truss with two eyebars or single member between panel points
- Simple span single welded box girders with details such as termination of longitudinal stiffeners or gusset plate
- Simple span two-girder bridges with welded partial length cover plates on the bottom flange
- Continuous span two-girder system with cantilever and suspension link arrangement and welded partial length cover plates
- Simple span two-girder system with lateral bracing connected to horizontal gusset plates which are attached to webs
- Single welded I-girder or box girder pier cap with bridge girders and stringers attached by welding

18.7.2 Inspection Locations

Fatigue cracks can develop in steel bridges as a result of repeated loading. Generally, the stress fluctuation, frequency, and type of detail are the most important factors. Recognizing and understanding the behavior of connections and details is crucial if the inspector is to properly inspect FCM's. This is because connections and details are often the locations of highest stress concentrations.

Welded Details

Welded details tend to be less forgiving of small weld discontinuities than riveted details because welds are more sensitive to repeated stresses. Once cracking starts to develop, it can destroy the member as a result of the continuous path provided by the welded connections. Cracking has developed more frequently in welded bridges because of flaws that escape detection, the use of details less fatigue resistant than assumed in the design, and secondary and displacement induced stresses.

Fatigue cracks can also develop at welded details in the compression regions of steel bridge members. However, when a crack propagates out of the weld tensile-residual-stress zone and into the adjacent compression region, the crack growth usually stops. Because of this, the inspection of welded details in regions of nominal compressive stress is of lower priority than in tension regions.

Effective and efficient inspection for fatigue cracks in welded bridges should be performed at several locations.

For out-of-plane distortion, inspect the following locations:

- Girder webs at floorbeam and diaphragm connections (see Figure 18-9)
- Ends of diaphragm connection plates in girder bridges (see Figure 18-10)
- Box girder webs at diaphragms
- Lateral bracing gusset plates on girder webs at floorbeam connections

- Floorbeam and cantilever bracket connections to girders
- Pin connected hanger plates and welded pin plates

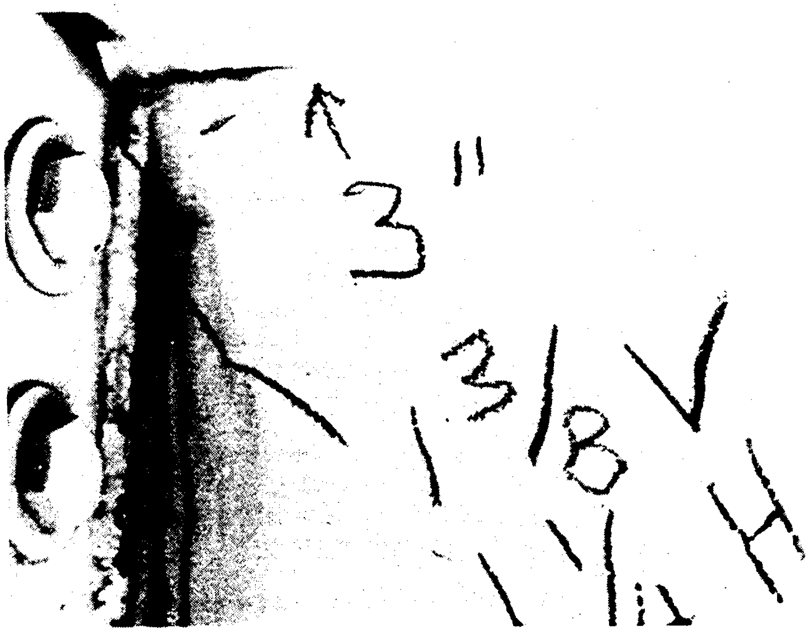


Figure 18-9 Cracks at Top of Floorbeam Connection to Girder

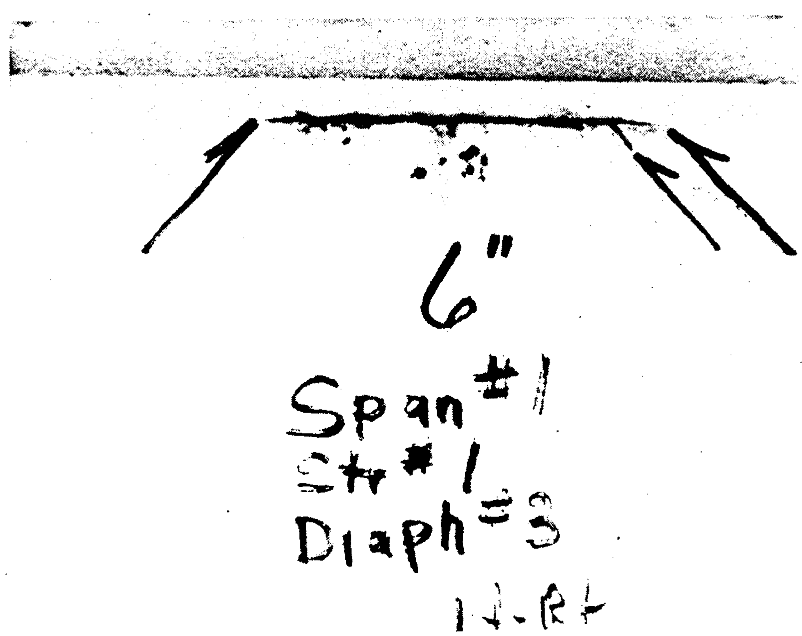


Figure 18-10 Cracked Girder Web Near Top Flange on the Opposite Side From a Diaphragm Connection

For main members, inspect the following locations:

- Ends of welded cover plates
- Groove welds in flange plates
- Butt welds in longitudinal stiffeners
- Web plates with cutouts and filler welds
- Intersecting groove welds
- Welded repairs and reinforcement
- Back-up bar splices

For connections and attachments, inspect the following locations:

- Cut short flanges
- Coped beam ends
- Blocked flange plates
- Welded rigid connections of cross girders at bents
- Welded flange attachments
- Intersecting welds at gusset plates and diaphragms

Except for excessive corrosion and secondary and displacement induced stresses, fatigue cracking generally does not develop in riveted and bolted bridge details. Crack growth is also inhibited by multiple element members (i.e., internal redundancy).

Riveted and Bolted Details

Most riveted bridges were constructed prior to the 1960's when bolted connections became common. Because of their age and the number of stress cycles already endured, the close inspection of riveted members and connections in bridges with high truck traffic volume is necessary. In general, the locations where fatigue cracks develop in riveted bridges are similar to those in welded bridges:

- Cracking and prying of rivets/bolts at end connections
- End connection angle failure (see Figure 18-11)
- Girder webs at floorbeam connections
- Floorbeam connections to girders
- Diaphragm connections to girders
- Cantilever bracket connections to girders
- Truss hangers
- Eyebars
- Tack welds

18.7.3 Inspection Procedures

Most cracks in steel bridges have been first detected by visual inspection. Thereafter, other nondestructive inspection methods, such as dye penetrant, magnetic particle, ultrasonics, eddy current, or radiography, have been used. More exact visual observations can also be employed using a magnifying unit after cleaning the paint from the suspect area.

Removal of paint can be done using a wire brush, grinding, or sand blasting, depending on the size of the suspected crack. The use of degreasing spray before and after removal of the paint may help in revealing the crack.

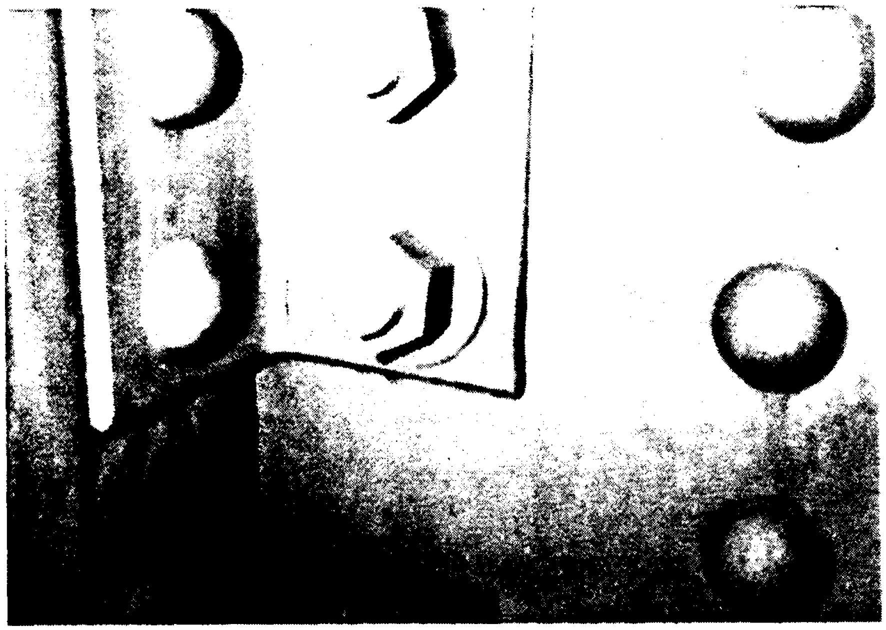


Figure 18-11 Cracked Stringer Connection Angle

The usual and most reliable sign of fatigue cracks is the oxide or rust stains that develop after the paint film has cracked. Experience has shown that cracks have generally propagated to a depth between one-fourth and one-half the plate thickness before the paint film is broken, permitting the oxide to form.

Smaller cracks are not likely to be detected visually unless the paint, mill scale, and dirt are removed by carefully cleaning the suspect area. If the confirmation of a possible crack is to be conducted by another person, it is advisable not to disturb the suspected crack area so that the re-examination of the actual conditions can be made.

Once the presence of a fatigue crack has been verified, the inspector should examine all other similar locations and details.

Cracks Perpendicular to Primary Stress

Cracks perpendicular to primary stress are very serious because all stresses applied to the member will work towards propagating the crack. The inspector should report them immediately so that repairs can be performed.

Cracks Parallel to Primary Stress

Cracks parallel to primary members are less serious than other cracks because they are parallel to the main direction of stress, reducing their ability to propagate. These cracks are still serious because they can turn perpendicular to the direction of stress at any time.

Corrosion

Corrosion is probably the most common form of defect found on steel bridges. More section loss results from corrosion than from any other cause. However, few bridge failures can be attributed solely to corrosion. Shallow surface corrosion is generally not serious but is quite common when the paint system has failed. Measurable section loss is significant as it may reduce the structural capacity of the member.

Nicks or gouges will often need to be evaluated by the bridge engineer responsible for the rating of the structure because they cause stress concentrations and may result in fatigue cracking. If large, they should be evaluated in a manner similar to section loss occurring due to corrosion.

Defective welds are quite serious but usually will not be detected unless special testing is performed. Defective welds can eventually crack.

18.7.4 Recordkeeping and Documentation

The consequences of deficiencies on bridges with FCM's can be very serious. The ability to verify a defect at the bridge site or to correctly evaluate it in the office will depend on the proper recording and documenting of conditions encountered in the field. Since many defects become obvious only as time passes, complete, clear, and concise recordkeeping provides a valuable reference for comparison in the future.

When a deficiency is encountered in a FCM, all relevant information should be recorded carefully and thoroughly, including:

- The date the deficiency was detected, confirmed, and re-examined
- The type of deficiency, such as cracks, notches, nicks, or gouges, defects in welds, excessive corrosion, or apparent distortion, mislocation, or misalignment of the member
- The general location of the deficiency, such as "at Panel Point L5 of the downstream truss" or "at the lower end of connection plate of Floorbeam No. 4 to the north girder of the eastbound bridge"
- Detailed sketches of the location, shape, and size of the deficiency; extra care should be given to determine the location of the ends of cracks
- The dimensions and details of the member containing the deficiency
- Any noticeable conditions at cracks when vehicles traverse the bridge, such as opening and closing of the crack or visible distortion of the local area
- Any changes in shape or condition of adjacent elements or members
- The presence of corrosion or the accumulation of dirt and debris at the general location of the deficiency
- Weather conditions when the deficiency was discovered or inspected

18.7.5 Recommendations for Fracture Critical Members

When deficiencies are encountered in FCM's, the repair of the condition generally demands a high priority. The defects listed for repair should be listed in order of priority. For example, a crack in a flange is more significant than surface corrosion of the web. There are two general classifications for repairs of FCM's:

- Urgent repairs - repairs that are required immediately in order to maintain the life of the structure or to keep the bridge open; these repairs are for bridge-threatening defects

- Programmed repairs - may be worked into the normal maintenance schedule; these repairs are for nonthreatening deficiencies and activities such as cleaning and painting of structural steel

18.7.6 Steel Pins

Steel pins are generally considered FCM's when used in a fracture critical bridge type. Since access to these pin members is usually difficult, advanced inspection techniques are often required. Ultrasonic testing is a common advanced inspection method used to inspect steel pins.

Any defects, or indications, in the pin are documented on sketches using a reference system similar to that of a clock face. For example, 12:00 is straight up, 3:00 is directly to the right, 6:00 is straight down, and 9:00 is directly to the left. The penetration distances are also presented for these indications, documenting their location along the length of the pin (see Figure 18-12).

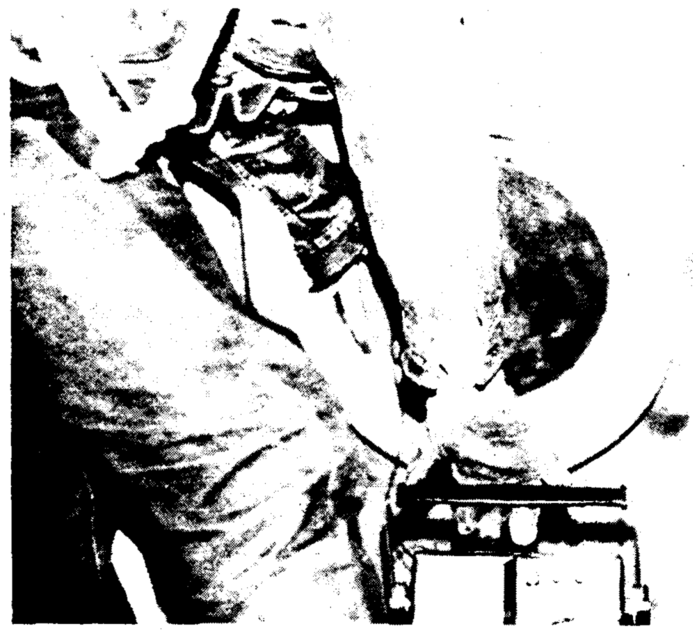


Figure 18-12 Ultrasonic Testing of a Steel Pin

When indications are encountered using ultrasonic testing, it is suggested that the results be confirmed by repeating the procedure from the other end of the pin. The same indications should be encountered from both ends of the pin.

18.7.7 Fatigue and Concrete Bridges

Neither reinforced concrete nor prestressed concrete members are fracture critical in the sense that they develop fractures from overstress of a single element of steel which leads to collapse. Internal redundancy is always present because of the presence of numerous reinforcing bars in reinforced concrete and numerous strands in prestressed concrete. The fracture of one strand or bar, while of serious concern, will not usually result in fracture of the concrete member.

Compared to steel bridges, concrete bridges are much less likely to suffer from fatigue damage. Several factors are involved:

- Low vibration - any vibration caused by passing trucks is damped-out due to the mass and stiffness of the member

- Tensile strength - since the tensile strength of concrete is ignored by bridge designers, cracking of the concrete in the tension zone does not affect the internal mechanism of stress transmission

Only the tension reinforcement is susceptible to fatigue. Because reinforcing is hidden from the inspector's view by the concrete cover, fatigue distress is more difficult to detect in concrete bridges, as compared to steel bridges. Inspectors can only examine the behavior of concrete surface cracks, and there is no difference in the appearance between a fatigue crack in concrete and a crack caused by flexure or shrinkage.

A false sense of security for concrete bridges because of their internal redundancy should be avoided. This is particularly true in view of the increasing complexity and variety of concrete bridge construction such as exhibited in segmental concrete box girders (refer to Section 21.4).

A thorough inspection of nonredundant concrete members in tension should be conducted routinely since problems in the reinforcing bars or strands may progress for some time before visible cracking occurs. Moisture and corrosive contaminants penetrate concrete members causing section loss to the embedded steel. This loss cannot be readily measured or monitored as on a steel bridge. The inspector should look for and document early signs of this problem and monitor the condition during subsequent inspections.

19

Culvert Inspection

19

Culvert Inspection

19.1 Introduction

Like bridges, culverts should be inspected regularly. Safety problems, culvert conditions, and repair and maintenance needs must be identified. This will preserve the investment in the structure and minimize property damage due to improper hydraulic functioning.

This chapter is based on the Federal Highway Administration (FHWA) *Culvert Inspection Manual,* published in July 1986 as a supplement to the *Bridge Inspector's Training Manual 70*. The *Culvert Inspection Manual* should be referred to for more detailed information. The FHWA *Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges* (*Coding Guide*) should also be used as a reference.

19.1.1 What is a Culvert?

A culvert is a drainage opening beneath a roadway embankment (see Figure 19-1). The opening is designed for full flow. A culvert has no definite distinction between substructure and superstructure, and it has no "deck." While culverts were once defined as bridges with a span of less than 20 feet, this definition is no longer used.

Many structures which meet the definition of a bridge for purposes of inspection programs have been designed hydraulically and structurally as culverts or a series of closely spaced culverts. The structural and hydraulic design of culverts is substantially different from that of bridges, as are construction methods, maintenance requirements, and inspection procedures.

Hydraulic Features

Openings of culverts are usually designed to operate at peak flows with a submerged inlet to improve hydraulic efficiency. Bridges that constrict flow and reduce hydraulic efficiency are sometimes designed to permit water to flow over the bridge or approach roadways during peak flows. However, bridges are generally not designed to take advantage of inlet submergence that is often used for culverts.

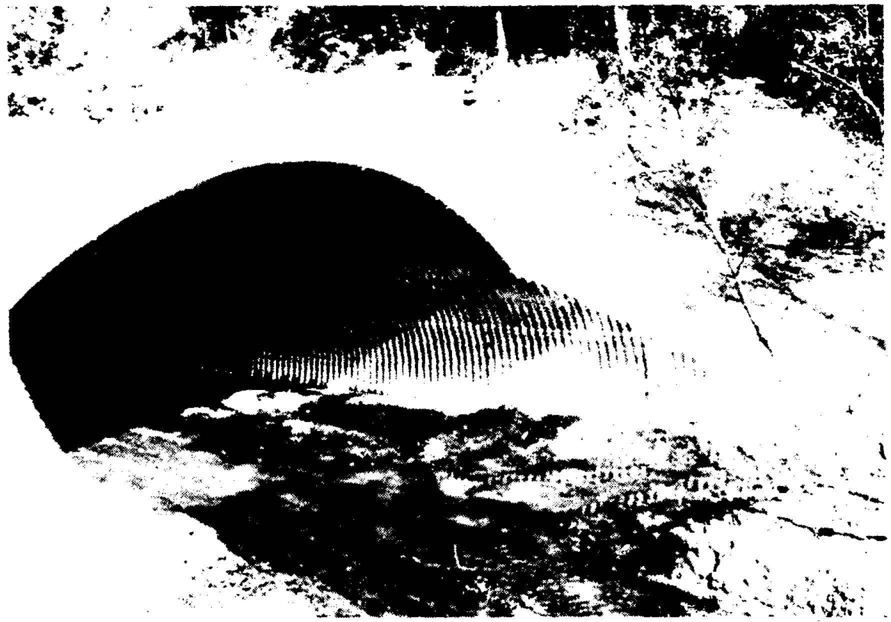


Figure 19-1 Steel Arch Culvert

Structural Features

Culverts are usually covered by embankment material. They are designed to support the dead load of the soil over the culvert, as well as live loads of traffic. Either live loads or dead loads may be the most significant load, depending on the type of culvert and thickness of cover. Live loads on culverts are generally not as significant as the dead load unless the cover is shallow (i.e., 0 to 3 feet).

In most culvert designs, the soil or embankment material surrounding the culvert plays an important structural role. Lateral soil pressures enhance the culvert's ability to support vertical loads. The stability of the surrounding soil is important to the structural performance of most culverts.

In some culvert designs such as large multi-plate corrugated metal arches ("superspans"), proper interaction between the soil and structure is critical.

Maintenance Features

Because culverts usually constrict flow, there is an increased potential for waterway blockage by debris and sediment, especially for culverts subject to seasonal flow. Scour caused by high outlet velocity and turbulence at the inlet end is a concern. As a result of these factors, routine maintenance for culverts primarily involves the removal of obstructions and the repair of erosion and scour.

19.1.2 Why Inspect Culverts?

Safety is the most important reason that culverts should be inspected. To ensure that a culvert is functioning safely, the inspector should evaluate structural integrity, hydraulic performance, and roadside compatibility.

Structural Integrity

The failure of major culverts can present a life threatening safety hazard. The identification of potential structural and material problems requires a careful evaluation of indirect evidence of structural distress as well as actual deterioration and distress in the culvert material.

Hydraulic Performance

When a culvert's hydraulic performance is inadequate, potential safety hazards may result. The flooding of adjacent properties from unexpected headwater depth may occur. The roadway embankment or culvert may be damaged because of erosion. Downstream areas may be flooded by failure of the embankment.

Roadside Compatibility

Some culverts, like older bridges, present roadside hazards. Headwalls and wingwalls higher than the road or embankment surface may constitute a fixed obstacle hazard if not protected by guardrails. Abrupt dropoffs over the end of a culvert or steep embankments are roll-over hazards to vehicles which accidentally leave the roadway.

Maintenance Needs

Lack of maintenance is a prime cause of improper functioning in culverts and other drainage structures. Regular periodic inspections allow minor problems to be found and corrected before they become serious.

19.2 Culvert Structures

A wide variety of culvert structures are currently in use as stream crossings, underpasses, and other highway applications. The inspector should be familiar with the various types of culverts which may be encountered during inspections and should have some understanding of how culverts function hydraulically and structurally.

19.2.1 Culvert Shapes

A wide variety of standard shapes and sizes are available for most culvert materials (see Figures 19-2 and 19-3). Since equivalent openings can be provided by a number of standard shapes, the selection of shape may not be critical in terms of hydraulic performance. In some cases, a low profile shape may be needed. Other factors, such as the potential for clogging by debris, the need for a natural stream bottom, or structural and hydraulic requirements, may influence the selection of culvert shape. Each of the common culvert shapes is discussed in the following paragraphs.

Circular Shapes

The circular shape is the most common shape manufactured for pipe culverts. It is hydraulically and structurally efficient under most conditions. Possible hydraulic drawbacks are that circular pipe generally causes some reduction in stream width during low flows. It may also be more prone to clogging than some other shapes .

Pipe Arch and Elliptical Shapes

Pipe arch and elliptical shapes are often used instead of circular pipe when the distance from channel invert to pavement surface is limited or when a wider section is desirable for low flow levels. These shapes may also be prone to clogging as the depth of flow increases.

Arch Shapes

Arch culverts offer less of an obstruction to the waterway than pipe arches and can be used to provide a natural stream bottom where the stream bottom is naturally erosion resistant. Foundation conditions must be adequate to support the footings. Riprap (a foundation of stones) is frequently used for scour protection.

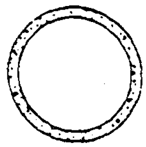
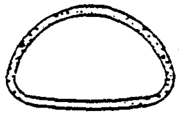
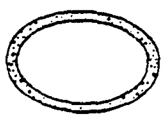
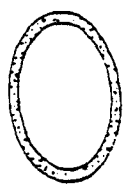
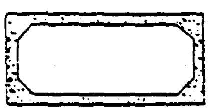
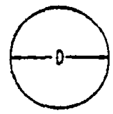
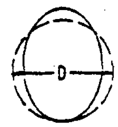
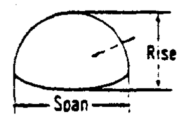
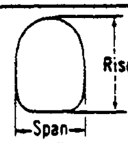
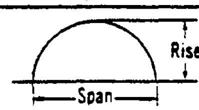
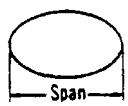
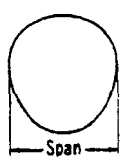
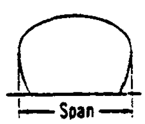
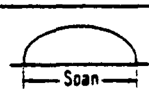
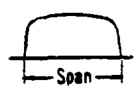
SHAPE	RANGE OF SIZES	COMMON USES
CIRCULAR 	12 to 180 inches reinforced 4 to 36 inches non-reinforced	Culverts, storm drains, and sewers.
PIPE ARCH 	15 to 132 inches equivalent diameter	Culverts, storm drains, and sewers. Used where head is limited.
HORIZONTAL ELLIPSE 	Span x Rise 18 to 144 inches equivalent diameter	Culverts, storm drains, and sewers. Used where head is limited.
VERTICAL ELLIPSE 	Span x Rise 36 to 144 inches equivalent diameter	Culverts, storm drains, and sewers. Used where lateral clearance is limited.
RECTANGULAR (box sections) 	Span 3ft to 12ft	Culverts, storm drains, and sewers. Used for wide openings with limited head.
ARCH 	Span 24 ft to 41 ft	Culvert and storm drains. For low, wide waterway enclosures.

Figure 19-2 Standard Concrete Pipe Shapes

Shape		Range of Sizes	Common Uses
Round		6 in – 26 ft	Culverts, subdrains, sewers, service tunnels, etc. All plates same radius. For medium and high fills (or trenches).
Vertically-elongated (ellipse) 5% is common		4–21 ft nominal; before elongating	Culverts, sewers, service tunnels, recovery tunnels. Plates of varying radii; shop fabrication. For appearance and where backfill compaction is only moderate.
Pipe-arch		Span x Rise 18 in. x 11 in. to 20 ft 7 in. x 13 ft 2 in.	Where headroom is limited. Has hydraulic advantages at low flows. Corner plate radius, 18 inches or 31 inches for structural plate.
Underpass*		Span x Rise 5 ft 8 in. x 5 ft 9 in. to 20 ft 4 in. x 17 ft 9 in.	For pedestrians, livestock or vehicles (structural plate).
Arch		Span x Rise 6 ft x 1 ft 9½ in. to 25 ft x 12 ft 6 in.	For low clearance large waterway opening, and aesthetics (structural plate).
Horizontal Ellipse		Span 20–40 ft	Culverts, grade separations, storm sewers, tunnels.
Pear		Span 25–30 ft	Grade separations, culverts, storm sewers, tunnels.
High Profile Arch		Span 20–45 ft	Culverts, grade separations, storm sewers, tunnels. Ammo ammunition magazines, earth covered storage.
Low Profile Arch		Span 20–50 ft	Low-Wide waterway enclosures, culverts, storm sewers.
Box Culverts		Span 10–21 ft	Low-wide waterway enclosures, culverts, storm sewers.
Specials		Various	For lining old structures or other special purposes. Special fabrication.

*For equal area or clearance, the round shape is generally more economical and simpler to assemble.

Figure 19-3 Standard Corrugated Steel Culvert Shapes (Source: *Handbook of Steel Drainage and Highway Construction Products*, American Iron and Steel Institute)

Box Shapes

Rectangular cross-section culverts are easily adaptable to a wide range of site conditions including sites which require low profile structures.

Multiple Barrel Shapes

Multiple barrels are used to obtain adequate hydraulic capacity under low embankments or for wide waterways. In some locations they may be prone to clogging as the area between the barrels tends to catch debris and sediment.

19.2.2 Culvert Materials

Aluminum, steel, concrete and stone masonry are the most commonly found materials for existing culverts. There are several other materials which may be encountered during culvert inspections, including timber, cast iron, stainless steel, terra cotta, asbestos, cement, and plastic.

Timber Culverts

Timber culverts are generally box culverts and are constructed from individual timbers similar to railroad ties.

Masonry Culverts

In some areas masonry arches and masonry box culverts are still found. With good foundations these culverts have long service lives. Stone and brick are durable, low maintenance materials.

CIP Concrete Culverts

Reinforced concrete culverts that are cast-in-place (CIP) are typically either rectangular (box) or arch-shaped. The rectangular shape is more common and is usually constructed with multiple cells (barrels) to accommodate longer spans (see Figure 19-4). One advantage of cast-in-place construction is that the culvert can be designed to meet the specific requirements of a site.

Precast Concrete Culverts

Precast concrete culverts are manufactured in six standard shapes:

- Circular
- Arch
- Horizontal elliptical
- Vertical elliptical
- Pipe arch
- Box section

With the exception of box culverts, concrete culvert pipe is manufactured in up to five standard strength classifications. Higher classification numbers indicate higher strength. Box culverts are designed for various depths of cover and live loads. All of the standard shapes are manufactured in a wide range of sizes. Circular and elliptical pipes are available with standard sizes as large as 12 feet in diameter, with larger sizes available for special designs. Standard box sections are also available with spans as large as 12 feet. Some box sections may have spans of up to 20 feet if a special design is used. Precast concrete arches on cast-in-place footings are available with spans of up to 40 feet.

Metal Culverts

Metal culverts are typically either steel or aluminum and are constructed from factory-made corrugated metal pipe or field assembled from structural plates. Structural plate products are available as plate pipes, box culverts, or long span structures.

Figure 19-4 Cast-in-Place Concrete Multicell Box Culvert

Corrugated Pipe

Factory-made pipe is produced in two basic shapes: round and pipe arch. Both shapes are produced in several wall thicknesses, several corrugation sizes, and with annular (circumferential) or helical (spiral) corrugations. Pipes with helical corrugations have continuously welded seams or lock seams. Both round and arch steel pipe shapes are available in a wide range of standard sizes. Round pipe is available in standard sizes up to 12 feet in diameter. Standard sizes for pipe arch are available in sizes up to the equivalent of a 10-foot diameter round pipe. Round aluminum pipe is available in standard sizes up to 10 feet in nominal diameter. Aluminum arch pipe is available in sizes up to the equivalent of an 8-foot diameter round pipe.

Structural Plate Pipe

Structural plate steel pipes are field assembled from standard corrugated galvanized steel plates. Standard plates have corrugations with a 6-inch pitch and a depth of 2 inches. Plates are manufactured in a variety of thicknesses and are pre-curved for the size and shape of structure to be erected. Structural steel plate pipes are available in four basic shapes:

- Round
- Pipe arch
- Arch
- Underpass

The standard sizes available range in span from 5 feet to 26 feet.

Structural plate aluminum pipes are produced in five basic shapes:

- Round
- Pipe arch
- Arch

- Pedestrian/animal underpass
- Vehicle underpass

A wide range of standard sizes are available for each shape. Spans as large as 30 feet can be obtained for the arch shape.

Box Culverts

Corrugated steel box sections use standard corrugated galvanized steel plates with special reinforcing elements applied to the areas of maximum bending stress. Steel box culverts are available with spans that range from 9 feet 8 inches to 20 feet 9 inches.

The aluminum box culvert utilizes standard aluminum structural plates with aluminum rib reinforcing added in the areas of maximum bending stresses. Ribs are bolted to the exterior of the aluminum shell during installation. Aluminum box culverts are suitable for shallow depths of fill and are available with spans ranging from 8 feet 9 inches to 25 feet 5 inches.

Long Span Culverts

Long span steel culverts are assembled using conventional 6 by 2 inch corrugated galvanized steel plates and longitudinal and circumferential stiffening members. There are five standard shapes for long span steel structures:

- Horizontal elliptical
- Pipe arch
- Low profile arch
- High profile arch
- Pear shape

The span lengths of typical sections range from 19 feet 4 inches to 40 feet. Longer spans are available for some shapes as special designs. It should be noted that each long span installation represents, to a certain extent, a custom design. The inspector should therefore use design or as-built plans when checking dimensions of existing long span structures.

Long span aluminum structures are assembled using conventional 9 by 2 1/2 inch corrugated aluminum plates and aluminum rib stiffeners. Long span aluminum structures are essentially the same size and available in the same five basic shapes as steel long spans.

19.3 Culvert Inspection

A logical sequence for inspecting culverts helps ensure that a thorough and complete inspection will be conducted. In addition to the culvert components, the inspector should also look for highwater marks, changes in the drainage area, settlement of the roadway, and other indications of potential problems. In this regard, the inspection of culverts is similar to the inspection of bridges.

For typical installations, it is usually convenient to begin the field inspection with general observations of the overall condition of the structure and inspection of the approach roadway. The inspector should select one end of the culvert and inspect the embankment, waterway, headwalls, wingwalls, and culvert barrel. The inspector should then move to the other end of the culvert. The following sequence is applicable to all culvert inspections:

- Review available information
- Observe overall condition
- Inspect approach roadway and embankment
- Inspect waterway
- Inspect end treatments
- Inspect culvert barrel

19.3.1 Review Available Information

Previous inspection reports and as-built plans, when available, should be reviewed prior to, and possibly during, the field inspection. A review of previous reports will familiarize the inspector with the structure and make detection of changed conditions easier. A review will also indicate critical areas that need special attention and the possible need for special equipment.

19.3.2 Observe Overall Condition

General observations of the condition of the culvert should be made while approaching the culvert area. The purpose of these initial observations is to familiarize the inspector with the structure. They may also point out a need to modify the inspection sequence or indicate areas requiring special attention. The inspector should also be alert for changes in the drainage area that might affect runoff characteristics.

19.3.3 Inspect Approach Roadway and Embankment

Inspection of the approach roadway and embankment includes an evaluation of the functional adequacy. The functional assessment is recorded under Structure Inventory and Appraisal (SI&A) Items 68 Deck Geometry and 72 Approach Roadway Alignment. Collection and validation of inventory data needed for the standard SI&A sheet may also be performed as part of the approach roadway inspection.

Defects in the approach roadway and embankment may be indicators of possible structural or hydraulic problems in the culvert. The approach roadway and embankment should be inspected for the following conditions:

- Sag in roadway or guardrail
- Cracks in pavement
- Pavement patches or evidence that roadway has settled
- Erosion or failure of side slopes

The approach roadway and embankment should also be inspected for the following functional requirements:

- Signing
- Alignment
- Clearances
- Adequate shoulder profile
- Safety features

19.3.4 Inspect Waterway

The SI&A Sheet requires a condition rating for the stream channel (SI&A Item 61) and a functional rating of the Waterway Adequacy (SI&A Item 71).

Channel Conditions

The inspection of waterway components is a key part of culvert inspection. The condition of the stream channel should be visually inspected for the following:

- Horizontal alignment of the culvert with the stream channel - the inspector should be aware that this may change during high or low flows and that poor alignment may reduce the hydraulic capacity of the culvert
- Vertical alignment of the culvert - this may cause problems with sedimentation or scour
- Erosion and scour - these may be related to a steep profile, horizontal alignment, or to more frequent flows of higher magnitudes resulting from changes in the water shed
- Accumulations of debris and sediment - these may be caused by a number of factors including a culvert opening that is too small, installation of the culvert with its invert below the streambed, obstructions downstream, or development upstream

Waterway Adequacy

Evaluation of the waterway adequacy involves checking for indications of an inadequate opening. The stream channel and drainage area should be evaluated for the following:

- Changes in stream channel alignment which may reduce hydraulic capacity or cause scour
- Changes in ground cover or land use which may affect the amount of runoff the culvert must handle
- Changes in the amount and type of channel erosion; excessive bank erosion, stream channel aggradation/degradation, or head cutting may indicate increased runoff
- Changes in high water marks; highwater marks may indicate that culverts are inadequately sized, increasing the potential for flooding damage or roadway overtopping
- Changes in flow, from intermittent to continuous, which may indicate changes in the drainage area
- Channel obstructions such as deposits of debris, mud slides, beaver dams, fences, and utility pipes which may affect the hydraulic capacity of culverts

19.3.5 Inspect End Treatments

End treatments such as headwalls, wingwalls, slope protections, and energy dissipaters are used to protect the culvert barrel, retain the embankment, and improve hydraulic efficiency (see Figure 19-5). The SI&A Inspection Sheet does not specifically address end treatments in terms of inventory data or condition. The condition rating of end treatments is included in SI&A Item 62, Culvert Condition. The appraisal rating should be included in SI&A Item 67, Structural Evaluation.

Inspections of end treatments primarily involve visual inspection, although hand tools should be used such as a plumb bob to check for misalignment, a hammer to sound for defects, and a probing rod to check for scour and undermining. In general, headwalls should be inspected for movement or settlement, cracks, deterioration, and traffic hazards. All ends should be checked for undermining, scour, and evidence of piping (i.e., the removal of soil by water seeping along the outside of the pipe).

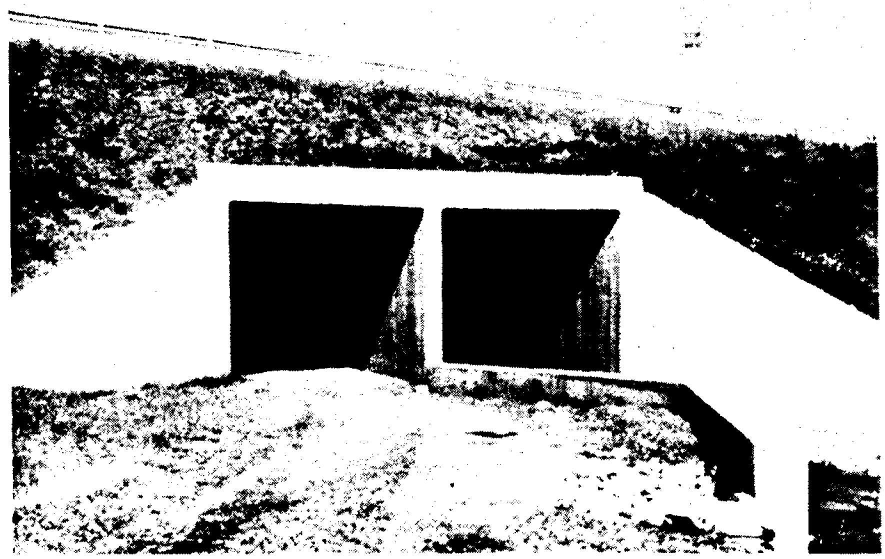


Figure 19-5 Headwall and Wingwall End Treatment

19.3.6 Inspect Culvert Barrel

When the size of the barrel and flow of water permits, the full length of the culvert should be inspected from the inside. Culverts with small diameters can be inspected by looking through the culvert from both ends. The condition of the culvert barrel is rated under SI&A Items 62 and 67, which cover all structural components of a culvert.

Locations in sectional pipe can be referenced by using pipe joints as stations to establish the stationing of specific cross-sections. Stations should start with number 1 at the outlet and increase going upstream to the inlet. The location of points on a circular cross section can be referenced like hours on a clock. The clock should be oriented looking upstream. On structural plate corrugated metal culverts, points can be referenced to bolted circumferential and longitudinal seams.

The types of defects to look for when inspecting the culvert barrel will depend upon the type of culvert being inspected. In general, corrugated metal culvert barrels should be inspected for cross-sectional shape and barrel defects such as joint defects, seam defects, plate buckling, lateral shifting, missing or loose bolts, corrosion, excessive abrasion, material defects, and localized construction damage. A critical area for the inspection of long span metal culverts is at the 2 o'clock and 10 o'clock locations. An inward bulge at these locations may indicate potential failure of the structure. Concrete culvert barrels should be inspected primarily for barrel defects such as misalignment, joint defects, cracking, spalling, and other material defects.

19.3.7 Factors Affecting Culvert Performance

Factors affecting culvert performance include:

- Construction techniques - specifically, how well soil compaction was performed
- Steam flow characteristics
- Structural integrity
- Hydraulic capacity
- Suitability of the foundation material
- Embankment stability
- Cross section of culvert - if insufficient for flow, upstream ponding could result, damaging the embankment
- Presence of excess vegetation and channel debris
- Environment - the possibility of abrasion or corrosion caused by substances in the water, the surrounding soil, or atmosphere

19.3.8 Types of Culvert Distress

The combination of high earth loads, long pipe-like structures, and high velocity water flow tends to cause the following types of distress:

- Shear or bending failure - high embankments impose very high loads on all sides of a culvert and can cause shear or bending failure
- Settlement - foundation settlement can be noticed as either a smooth sag or differential vertical displacement at construction or expansion joints; signs of settlement are also seen in tipping or movement of wingwalls and lateral movement of precast or cast-in-place box sections
- Scour - full flow design conditions result in accelerated scour and undermining at culvert ends, as well as at any irregularities, due to foundation problems within the culvert barrel
- Buckling - deformation of ribs, plates, joints, and bolts

19.3.9 Coding Guide

Item No. 62 of the SI&A *Coding Guide* and descriptions are used to evaluate the alignment, settlement, joints, structural condition, scour, and other items associated with culverts. The rating code is intended to be an overall condition evaluation of the culvert. Integral wingwalls to the first construction or expansion joint shall be included in the evaluation.

The deck, superstructure, and substructure condition rating items are not applicable and are coded "N".

19.3.10 Inspection Procedures

Timber Culverts

Timber culverts should be inspected as would any other timber member, including sounding and drilling to determine the extent of rot. The inspector should accurately describe the construction of the timber culvert.

Masonry Culverts

Masonry culverts should be inspected for signs of stone surface weathering, cracked, loose, crushed, displaced, or missing stones. The inspector should note the mortar or lack of it between the stones. Lack of mortar may result in loss of shape leading to bulging, tilting, or closing of the walls. Since many of these culverts do not have bottoms, the footings should be inspected carefully for undermining and scour. A probing rod should be used to check for voids and scoured areas that may have filled with sediment.

Concrete Culverts

The principal properties of concrete, the factors causing deterioration, and common signs of distress and deterioration in reinforced concrete are discussed in Chapter 4. There are, however, certain important considerations related to concrete used in culverts. Both cast-in-place and precast concrete culverts are somewhat protected by the soil backfill from rapid fluctuations in surface temperature and direct application of chloride (salts) used for deicing. As a result they are generally more resistant to surface deterioration than concrete bridge elements. Concrete culverts do not bend or deflect appreciably. Therefore inspectors should concentrate on defects in the alignment, joints, and walls of the structure.

Corrugated Metal Culverts

Corrugated aluminum and corrugated steel culverts are flexible structures and respond to and depend upon the soil backfill to provide structural stability and support to the culvert. The flexible corrugated metal is essentially a liner. This liner acts mainly in compression and can carry large ring compression thrust, but very little bending or moment force. (Rib reinforced box culverts are exceptions.) Inspection of the culvert determines whether the soil envelope provides adequate structural stability for the culvert and verifies that the liner is capable of carrying the compressive forces and protecting the soil backfill from water flowing through the culvert. Verification of the stability of the soil envelope is accomplished by checking culvert shape. Verification of the integrity of the liner is accomplished by checking for pipe and plate culvert barrel defects.

19.4 Recordkeeping and Documentation

The usefulness of the information collected in the field depends upon how well the inspection is accomplished and documented. The information must be recorded in a manner that provides a permanent record, is easy to understand, furnishes an accurate assessment of conditions at the time of inspection, makes information readily available for a variety of uses, and is easily verified and updated. Refer to Chapter 14 for a more detailed description of bridge inspection recordkeeping and documentation.

19.4.1 Inventory Data

Bridge culvert information, such as the identification number assigned to the structure, location, type of structure, number of spans, cells or barrels, length of span, road or facility served by the structure, and the stream or feature crossed by the structure, should be available since this data is required in accordance with the *Coding Guide*. This data may also be available on inventory cards or forms maintained by maintenance personnel.

19.4.2 Structure File

The contents of any particular file may vary depending upon the size and age of the structure, the functional classification of the road carried by the structure, and the informational needs of the agencies responsible for inspection and maintenance. A very small culvert may be documented in an inventory listing or with a file that contains little more than an inventory card plus dates and comments of previous inspections. For larger culverts it is recommended that the following types of information be assembled when possible.

Design Data

"As built" or design plans should be included in a structure file. If plans are not available, the following types of construction information should be determined:

- Date built
- Type of structure including size, shape, and material
- Wall thickness (or gauge)
- Class of pipe
- Joint types
- Size of corrugations, if applicable
- Type and thickness of pavement
- Design capacity
- Design service life
- Height of cover
- End treatments

Hydraulic Data

Standard drawings that indicate minimum and maximum allowable depth of cover, wall thickness, gauge, and end treatments are often as useful as plans. Hydraulic data should also be assembled where available, including:

- Slope of structure
- Elevation of inverts
- Stream channel and water surface during normal and high flows
- Design storm frequency
- Drainage area
- Design discharge
- Date of design policy
- Flow indications
- Limits of flood plain
- Type of energy dissipaters
- Cut of wall depth
- Channel alignment
- Channel protection

Repair History

Information on repairs, culvert extensions, and rehabilitation activities should be collected. The types and amount of repairs performed at a culvert site can be extremely important. Frequent roadway patching due to recurring settlement over a culvert may indicate serious problems that are not readily apparent through inspection of the culvert barrel itself.

Inspection History

Data from previous inspections can be particularly useful in identifying components that required special attention during an inspection. Information from earlier inspections can be compared with current conditions to estimate rates of deterioration and to help judge the seriousness of the problems detected and the anticipated remaining life of the structure.

19.4.3 Recording the Inspection

When inspecting culverts, information will usually be recorded by a variety of methods, including standard forms, standard prepared sketches, narrative descriptions, and photographs.

Inventory Data

A standard inventory card or form should be used to record basic information such as location and structure type.

Standard Forms

Standard inspection report forms are usually the most convenient method for recording specific items of information such as numerical data and brief descriptions or remarks. Properly designed forms can provide assistance in field data collection by providing a list of the items that must be evaluated or measured and can also organize data, making it more accessible for review.

Office Sketches

Standard prepared sketches are a convenient method for recording field measurements.

Field Sketches

Additional sketches may need to be prepared in the field to document deficiencies found during the inspection. An overall sketch should also be made to show the general layout of the stream, structure, and roadway indicating any skew, if present.

Photographs

Photographs are an excellent method for documenting problems found during an inspection.

Narrative Descriptions

Narrative descriptions supplement the information recorded on forms, photographs, and sketches. Descriptions of the condition of each component, such as the culvert barrel, headwalls, wingwalls, and stream channel, should be prepared by the inspector.

Summary

Generally a brief summary of the structure's condition should be included in the report. The summary should identify and describe any significant problems found during the inspection. The summary should also include comments about the types of defects found and their location on the structure.

Recommendations

The inspector should list any maintenance or repairs that are needed to maintain structural integrity, ensure public safety, and extend service life.

19.4.4 Updating Inventory Records

The usefulness of information collected during field inspections depends upon its availability for use. Records must be maintained systematically so that specific records can be easily located for updating or review.

20

Movable Bridges

20

Movable Bridges

20.1 Introduction

Movable bridges are constructed across designated "Navigable Waters of the United States," in accordance with "Permit Drawings" approved by the U.S. Coast Guard. When a movable bridge is fully open, it must provide the channel width and the underclearance shown on the Permit Drawings (see Figure 20-1). If the bridge cannot be opened to provide these clearances, the U.S. Coast Guard should be notified immediately and action taken to restore the clearances. If that is impossible, application must be made to revise the Permit Drawings.

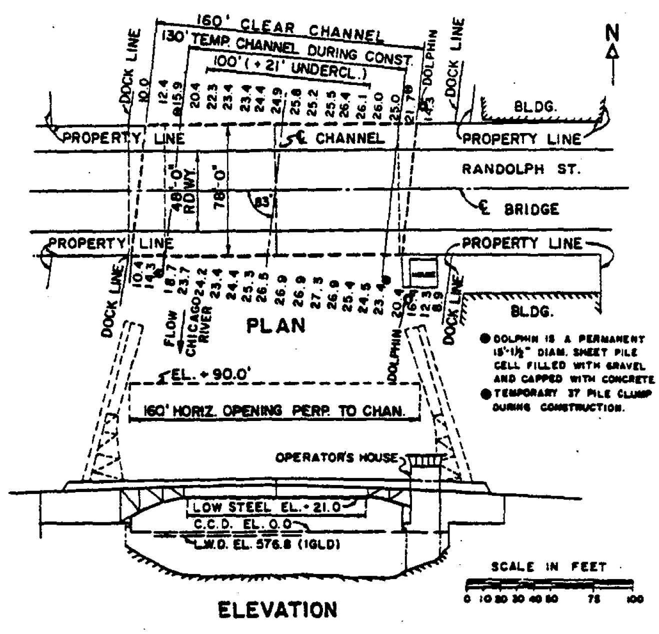


Figure 20-1 Typical "Permit Drawing" Showing Channel Width and Underclearance, Both Closed and Open, that Must Be Provided

If any work is to be done in the channel or on the movable span to reduce the clearances from those shown on the Permit Drawing, an additional permit, covering the scheduled time for the work, must be obtained from the U.S. Coast Guard District that has jurisdiction.

The U.S. Coast Guard publishes Local Notices to Mariners to keep waterway users informed of work in progress that may affect navigation. The permittee must keep the U.S. Coast Guard informed of all stages of construction.

An inspection of the bridge should verify that the bridge conforms to the Permit Drawing and that the operator is instructed to open the bridge to the fully open position every time the bridge is operated. Failure to do this would establish a precedent that a vessel is expected to proceed before the green navigation lights have turned "on." Any accident caused as a result of this practice could be ruled the fault of the bridge owner.

Early America's engineering literature did not establish where the first iron drawbridge was built. The first all-iron movable bridge in the midwest was completed in 1859 carrying Rush Street over the Chicago River (see Figure 20-2). The bridge was a rim bearing swing span and was probably operated by steam. It was destroyed November 3, 1863 when it was opened while a drove of cattle were on one end. It was rebuilt and finally destroyed by the great Chicago fire of 1871.

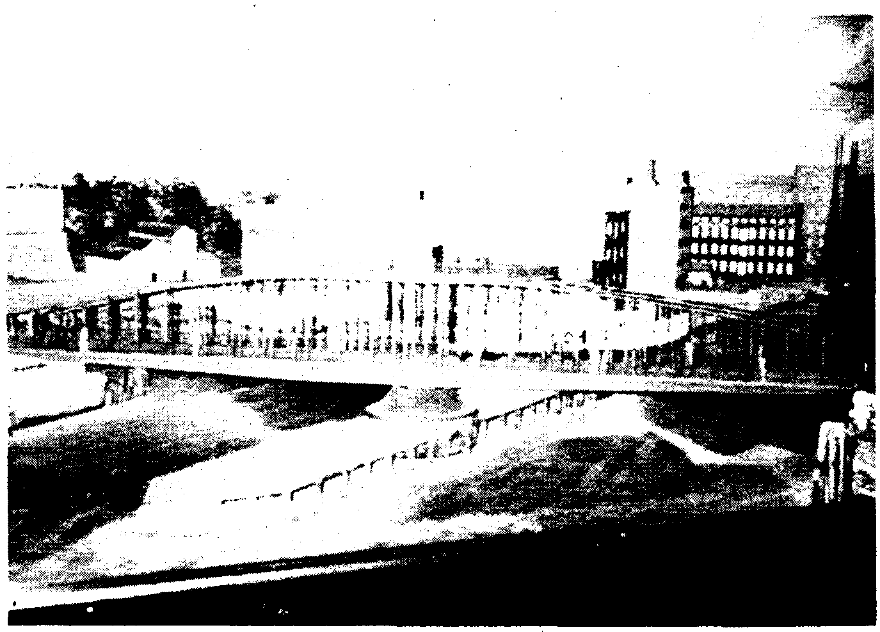


Figure 20-2 The First All-Iron Movable Bridge in the Midwest was Completed in 1859 (Photo on File at the Chicago Historical Society)

All categories of movable bridges are powered by electric-mechanical or hydraulic-mechanical drives with power driven pinions operating against racks, or by hydraulic cylinders. A small number are hand powered for normal operation, and a few use it for standby operation. Three categories of movable bridges comprise over 95 percent of the total number of movable bridges within the United States. These categories are:

- Swing bridges
- Bascule bridges
- Vertical lift bridges

20.1.1 Swing Bridges

Swing bridges consist of two-span trusses or continuous girders which rotate horizontally about the center (pivot) pier (see Figure 20-3). The spans are usually, but not necessarily, equal. When open, the swing spans are cantilevered from the pivot (center) pier and must be balanced longitudinally and transversely about the center. When closed, the spans are supported at the pivot pier and at two rest (outer) piers or abutments. In the closed condition, wedges are usually driven under the outer ends of the bridge to lift them, thereby providing a positive reaction sufficient to offset any possible negative reaction from live load and impact in the other span.

This design feature prevents uplift and hammering of the bridge ends under live load conditions. Swing spans are subdivided into two types:

- Center-bearing
- Rim-bearing

Center-Bearing

Center-bearing swing spans carry the entire load of the bridge on a central pivot (usually metal discs) (see Figure 20-4). Balance wheels are placed on a circular track around the outer edges of the pivot pier to prevent tipping (see Figure 20-5). When the span is closed, wedges similar to those at the rest piers are driven under each truss or girder at the center pier. This relieves the center bearing from carrying any live load. However, these wedges should not raise the span at the pivot pier, but should merely be driven tight.

Rim-Bearing

Rim-bearing swing spans transmit all loads, both dead and live, to the pivot pier through a circular girder or drum to beveled rollers. The rollers move on a circular track situated inside the periphery of the pier. The rollers are aligned and spaced on the track by concentric spacer rings. This type of swing span bridge also has a central pivot bearing which carries part of the load. This pivot bearing is connected to the rollers by radial roller shafts and keeps the span centered on the circular track.

On both types of swing bridges, the motive power is usually supplied by an electric motor(s), hydraulic motor(s), or hydraulic cylinder(s), although gasoline engines or manual power may also be used. The bridge is rotated horizontally by a circular rack and pinion arrangement, or cylinders.

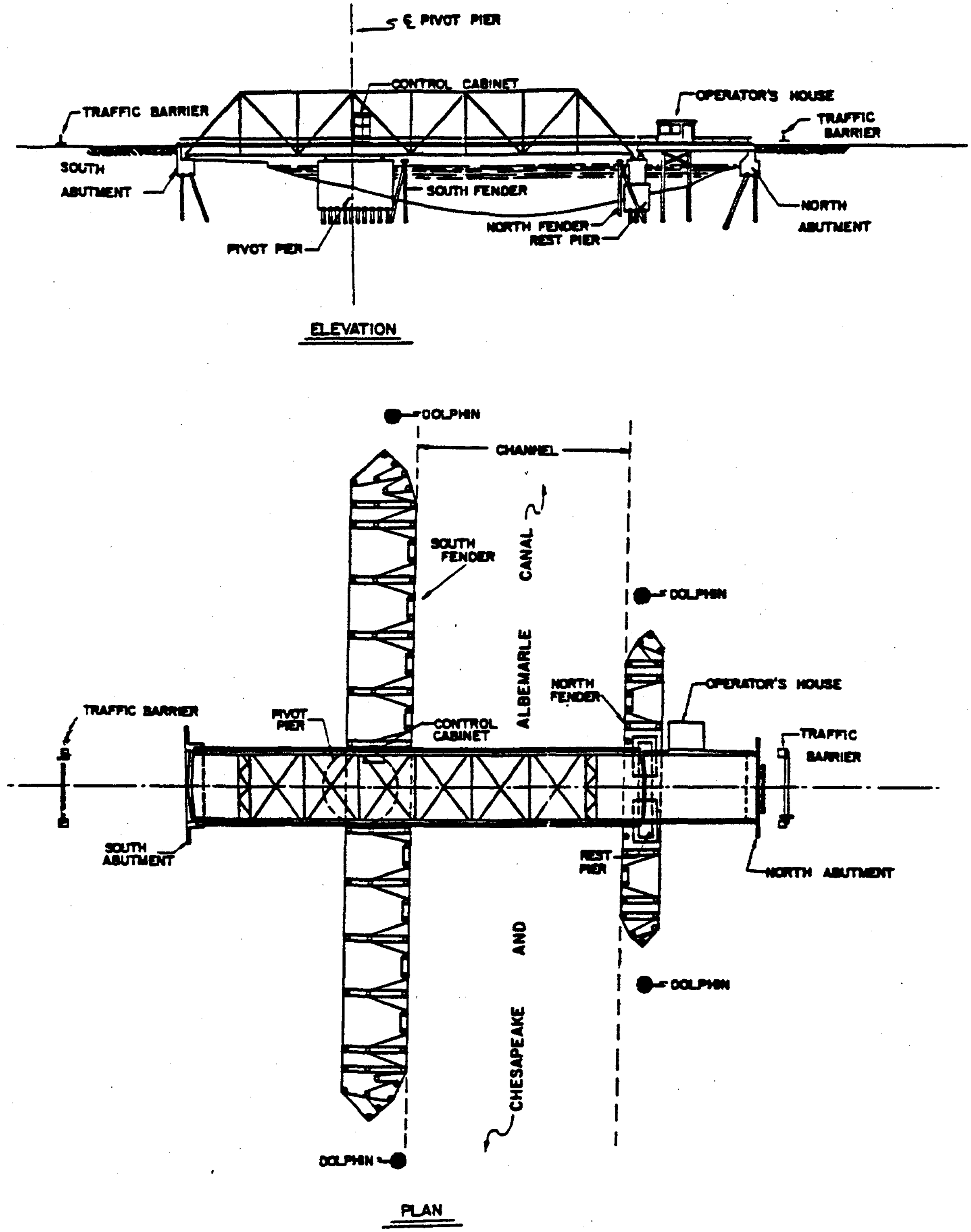


Figure 20-3 Swing Span with Unequal Span Lengths

Figure 20-4 Swing Span with Operator's House on Approach at Left and Control Cabinet on Swing Span at Right

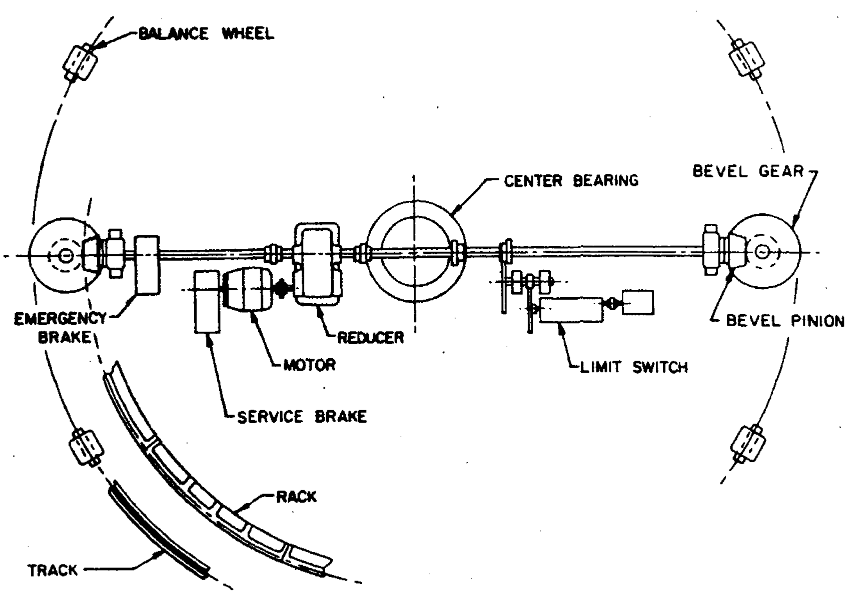


Figure 20-5 Layout of Center Bearing Type Swing Span with Machinery on the Span

20.1.2 Bascule Bridges

In bascule bridges, the leaf (movable portion of the span) lifts up by rotating vertically about a horizontal axis. The weight of the counterweight is adjusted by removing or adding balance blocks in pockets to position the center of gravity of the moving leaf at the center of rotation. Bascule bridges may be either single- or double-leafed. In the former case, the entire span lifts about one end. A double-leafed bascule has a center joint, and half of the span rotates about each end (see Figures 20-6 and 20-7). In older bridges, the counterweight was usually overhead. However, in most bridges, the counterweight is placed below deck and lowers into a pit as the bridge is opened. There are many types of bascule bridges, but the most common are the following three types:

- Rolling lift (Scherzer) bridge
- Simple trunnion (Chicago) bridge
- Multi-trunnion (Strauss) bridge

Rolling Lift (Scherzer) Bridge

The first rolling lift bridge, completed in January 1895 in Chicago, was designed by William Scherzer. The entire moving leaf, including the front arm with the roadway over the channel and the rear arm with the counterweight, rolls away from the channel while the moving leaf rotates open (see Figure 20-8). The leaf rolls back on circular castings whose centerline of roll is also the center of gravity of the moving leaf. On one variation of this type, the trusses on the two leaves acted as three-hinged arches when closed. There is a 310 feet span between the centerline of bearings. This bridge was built across the Tennessee River at Chattanooga in 1915, and it is believed to be the third longest double-leaf bascule in the world. It provides a 295 foot channel, which is the widest channel spanned by a bascule bridge.

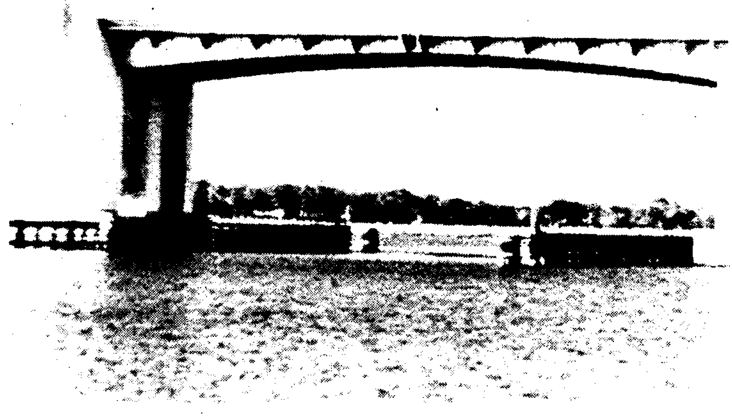


Figure 20-6 Double-Leaf Bascule Bridge; There is a "Center Break in Floor" at the Centerline of Bascule Span

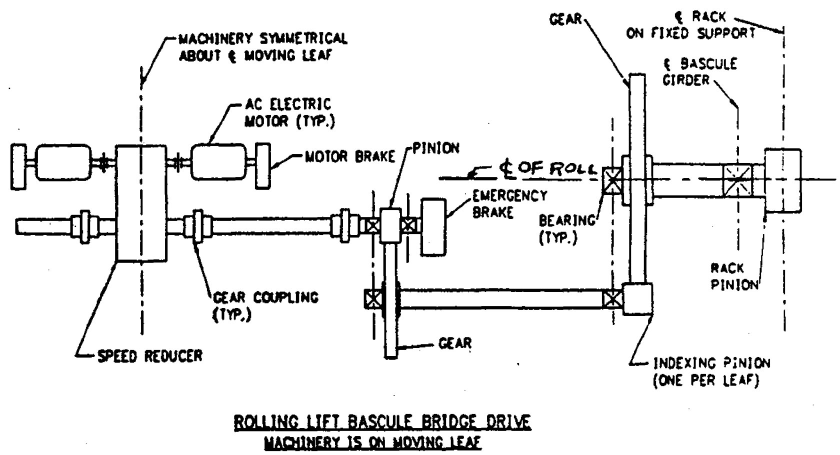


Figure 20-7 Rolling Lift Bridge Machinery (for One Quadrant) is Located on the Moving Leaf, which Rotates the Centerline Rack Pinion (Center of Roll) as it Rolls Open

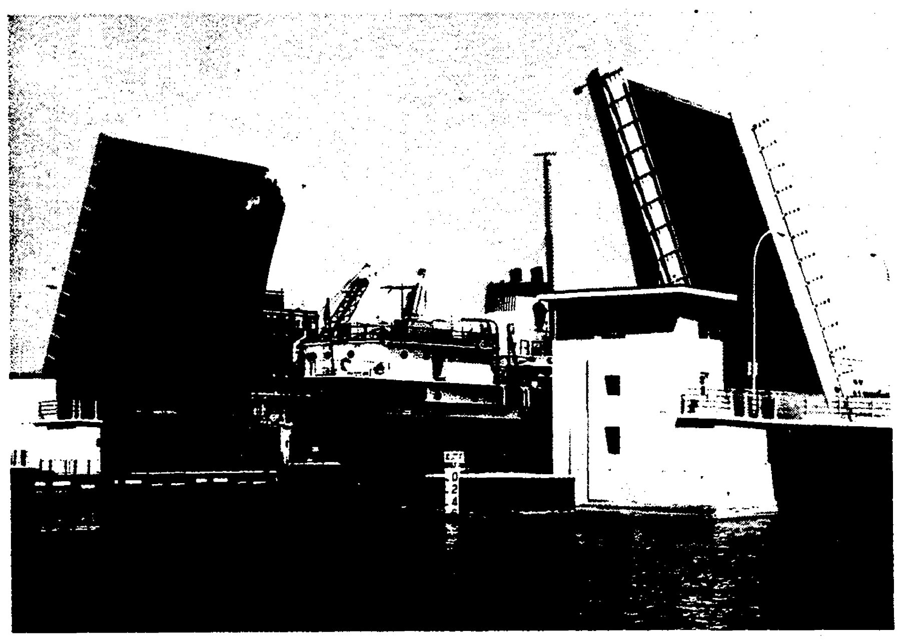


Figure 20-8 Double-Leaf Rolling Lift; the Leaves Roll Away from the Channel While the Moving Leaves Rotate Open

Simple Trunnion (Chicago) Bridge

The first Chicago type simple trunnion bascule bridge, completed during 1902 in Chicago, was designed by the Chicago Bridge Department staff of Engineers. This type of bascule bridge consists of a forward cantilever arm out over the channel and a rear counterweight arm. The leaf rotates about the trunnions. Each trunnion is supported on two bearings, which in turn, are supported on the fixed portion of the bridge such as a trunnion cross-girder, steel columns, or on the pier itself (see Figures 20-9 through 20-11). Forward bearing supports located in front of the trunnions are engaged when the leaf reaches the fully closed position. They are intended to support only live load reaction. Uplift supports are located behind the trunnions to take uplift until the forward supports are in contact (if misadjusted) and to take the live load uplift that exceeds the dead load reaction at the trunnions. If no forward live load supports are provided or if they are grossly misadjusted, the live load and the reaction at the uplift supports are added to the load on the trunnions. A double-leaf bascule bridge of this type in Lorain, Ohio has 333 feet between trunnions. It was built on a skewed crossing of a river, and it is believed to be the second longest double-leaf bascule in the world.

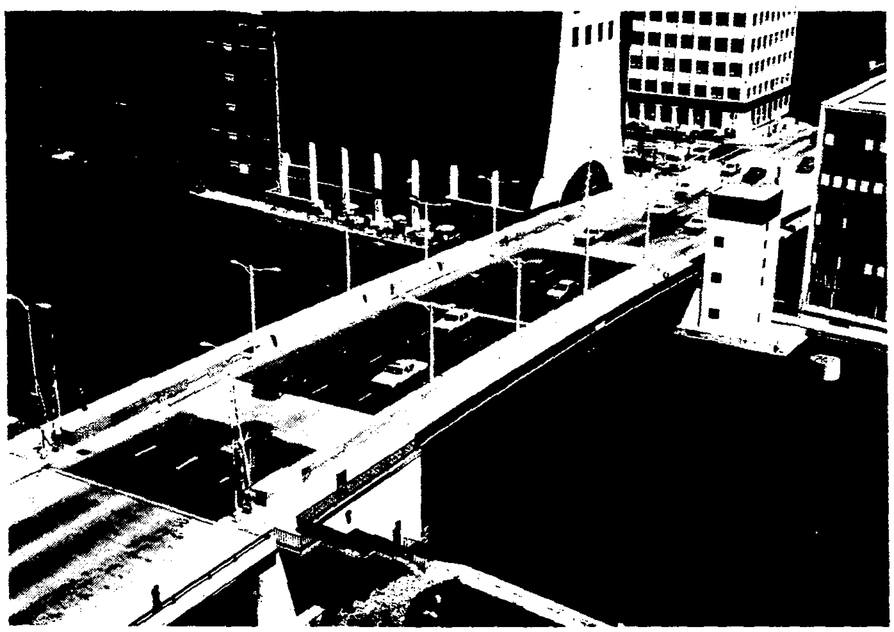


Figure 20-9 A Simple Trunnion (Chicago Type) Double-Leaf Bascule Bridge Over the Chicago River

Figure 20-10 Each Trunnion is Supported on Two Bearings, Which in Turn are Supported on a Fixed Cross-Girder

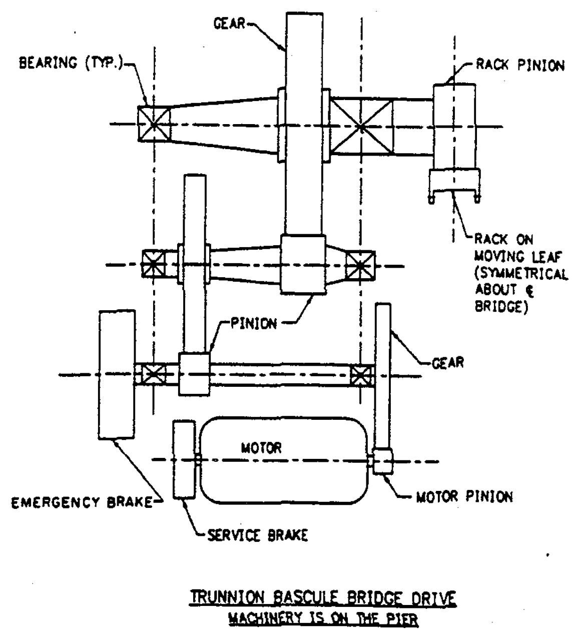


Figure 20-11 The Trunnion Bascule Bridge Machinery (One Quadrant Shown) is Located Outside of the Bascule Trusses on the Pier; the Leaf Rotates About the Centerline of the Trunnions

Multi-Trunnion (Strauss) Bridge

The first multi-trunnion (Strauss) bascule bridge was designed by J.B. Strauss and completed during 1905 in Cleveland, Ohio. There are many variations of multi-trunnion bascule bridges, but basically one trunnion supports the moving span, one trunnion supports the counterweight, and two link pins are used to form the four corners of a parallelogram-shaped frame that changes angles as the bridge is operated (see Figure 20-12). One variation of this parallelogram layout is the heel trunnion. A double-leaf bascule bridge of this type in Sault St. Marie, Michigan has 336 feet between the span trunnions. It was built across the approach to a lock in 1914, and it is believed to be the longest double-leaf bascule in the world.

20.1.3 Vertical Lift Bridges

Vertical lift movable bridges have a movable span with a fixed tower at each end. The span is supported by steel wire ropes at its four corners. The ropes pass over sheaves (pulleys) atop the towers and connect to counterweights on the other side. The counterweights descend as the span ascends. There are two basic types of vertical lift bridges:

- Power and drive system on lift span
- Power and drive system on towers

Power and Drive System on Lift Span

The first vertical lift bridge completed during 1894 in Chicago was designed by J.A.L. Waddell. This type locates the power on top of the lift truss span. The actual lifting is accomplished using "up-haul and down-haul ropes" where turning of drums wind the up-haul (lifting) ropes as they simultaneously unwind the down-haul ropes (see Figures 20-13 and 20-14). A variation of this type provides drive pinions at both ends of the lift span which engage racks on the towers.

Power and Drive System on Towers

The other basic type of vertical lift bridge locates the power on top of both towers, where drive pinions operate against circular racks on the sheaves. The lifting speed at both towers must be synchronized to keep the span horizontal as it is lifted (see Figures 20-15 through 20-18).

20.2 Special Elements - Identification

Particular attention should be given to the special elements found in swing bridges, bascule bridges, and vertical lift bridges during inspection. These elements are commonly found on all types of movable bridges.

20.2.1 Elements Common on All Types

Open Gearing

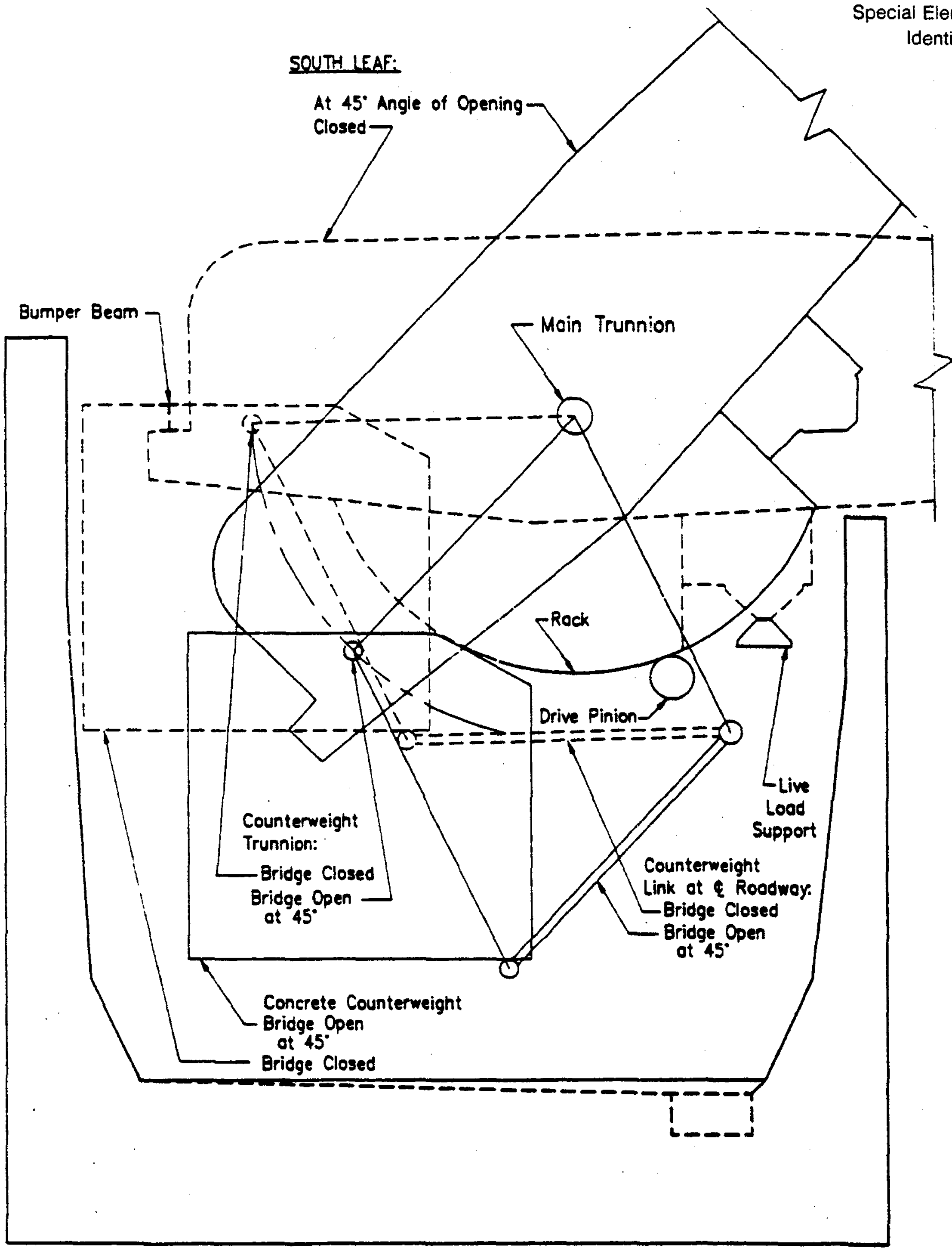
Open gearing is used to transmit power from one shaft to another and to alter the speed and torque output of the machinery. Beveled gears are also used to change direction.

Speed Reducers Including Differentials

Speed reducers including differentials serve the same function as open gearing. However, they may contain several gear sets, bearings, and shafts to provide a compact packaged unit which protects its own mechanical elements and lubrication system with an enclosed housing. Differential speed reducers also function to equalize torque and speed from one side of the mechanical operating system to the other.

Shafts and Couplings

Shafts transmit mechanical power from one part of the machinery system to another. Couplings transmit power between the ends of shafts in line with one another, and several types can be used to compensate for slight imperfections in alignment between the shafts.



SECTION THROUGH COUNTERWEIGHT PIT
SHOWING BASCULE LEAF AT 45° ANGLE OF OPENING

Figure 20-12 Multi-Trunnion, Strauss Type Bascule Bridge, in Which the Counterweight Link Keeps the Counterweight Hanging Vertically from the Counterweight Trunnions while the Moving Leaf Rotates About the Main Trunnions

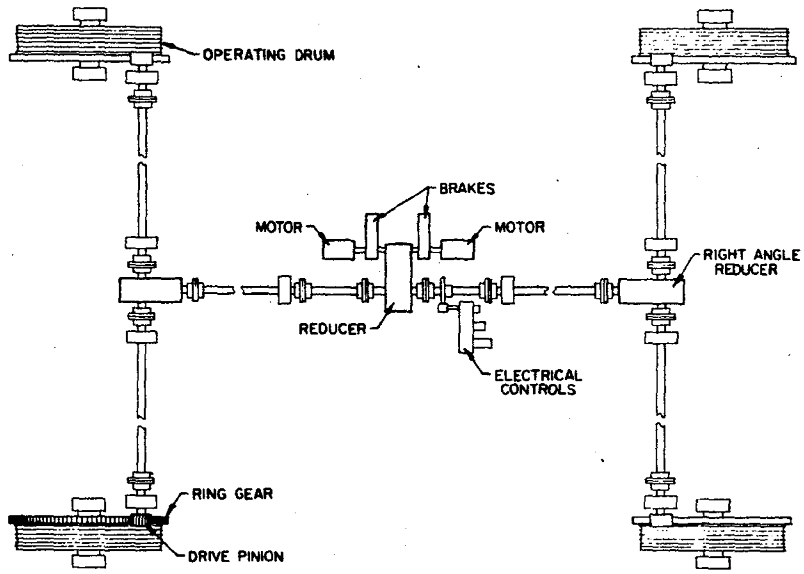


Figure 20-13 Vertical Lift Bridge Machinery is Located on Top of the Lift Truss Span, and the Operating Drums Rotate to Wind the Up-Haul (Lifting) Ropes as They Simultaneously Unwind the Down-Haul Ropes

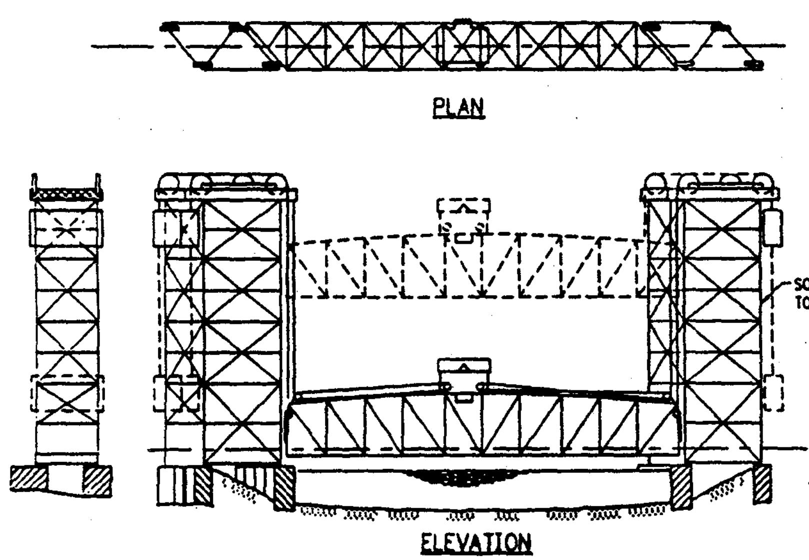


Figure 20-14 Vertical Lift Span with Power and Drive System on Lift Span; Due to Skew of Channel, Double Trunnions are Used To Place Counterweight on Back Towers

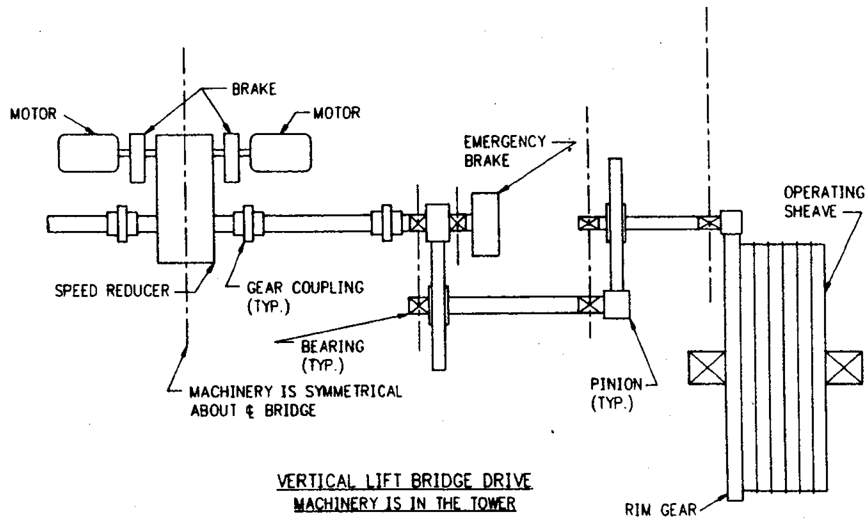


Figure 20-15 Vertical Lift Bridge Machinery is Located on the Towers, and the Rim Gears (and Operating Sheaves) are Rotated to Raise and Lower the Bridge

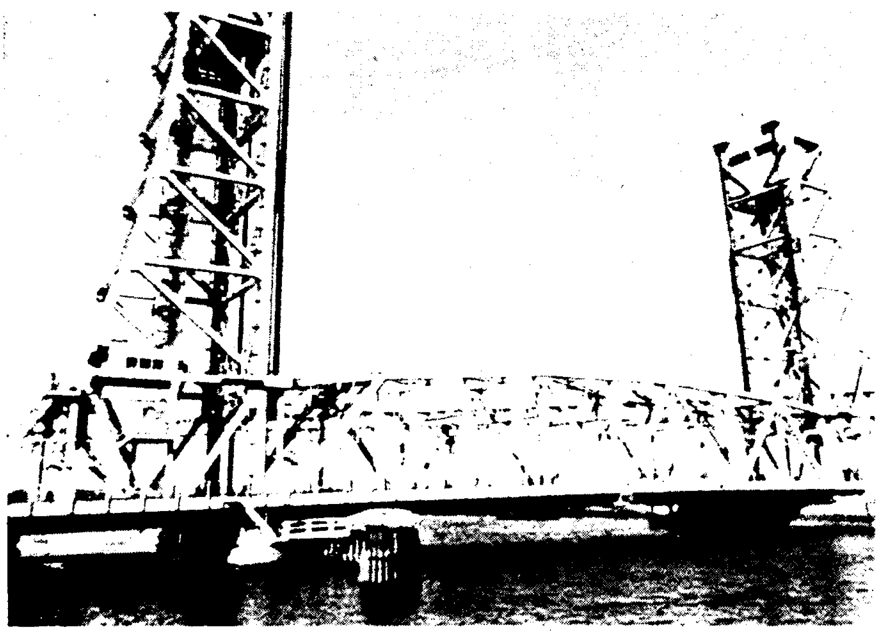


Figure 20-16 Vertical Lift Bridge with Power and Drive System on Towers

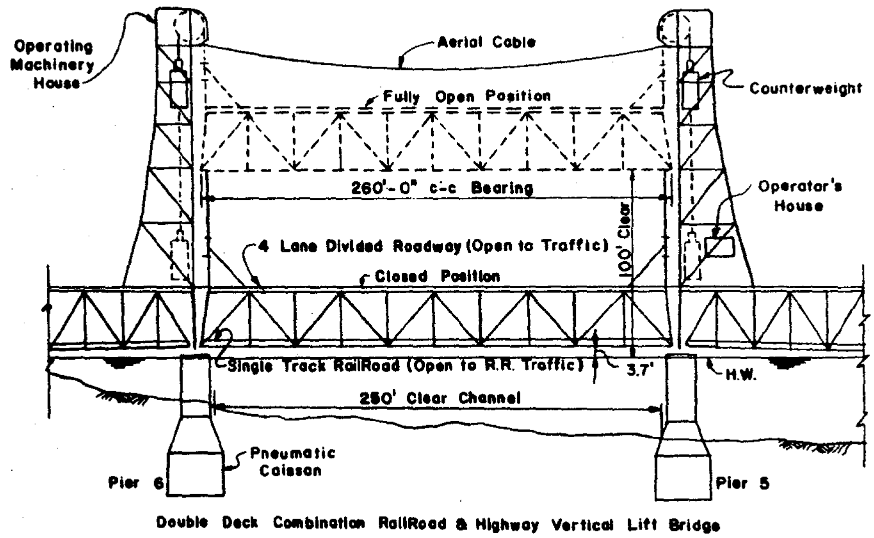


Figure 20-17 Outline of Double Deck Vertical Lift Bridge in Closed Position (Solid Lines) and Fully Open Position (Dotted Lines)

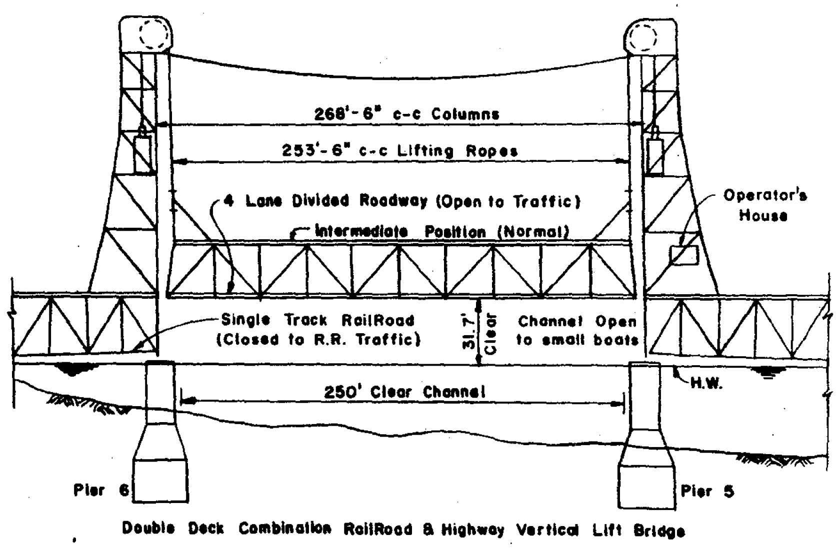


Figure 20-18 Outline of Double Deck Vertical Lift Bridge in Intermediate (Normal) Position to Provide Clearance for Small Boats Between Train Movements

Bearings

Bearings provide support and prevent misalignment of rotating shafts, trunnions, and pins.

Brakes

Brakes can be of either the shoe type or disc type, and can be released manually, electrically, or hydraulically. They are generally spring applied for fail safe operation. Motor brakes are located close to the drive to provide dynamic braking capacity, except that some types of drives can provide their own braking capability, thereby eliminating the need for separate motor brakes. Machinery brakes are located closer to the operating interface between movable and fixed parts of the bridge and are used to hold the span statically, in addition to serving as emergency brakes in many cases. Supplemental emergency brakes are sometimes also provided.

Drives

Drives can consist of electric motors, hydraulic equipment, or auxiliary drives.

For electric motors, either AC or DC power may be used. AC power is often used to power wound rotor motors with torque controllers on older bridges, while new bridges may utilize squirrel cage induction motors with adjustable frequency speed control. DC motors can also provide speed control.

For hydraulic equipment, prime movers may include either large actuating cylinders or hydraulic motors. Either type of drive must be supplied with pressure to provide force and fluid flow to provide speed to the operating system. These are provided by electrically operated hydraulic power units consisting of a reservoir and pump, with controls.

For auxiliary drives, emergency generators are provided to serve in the event of power failure. Auxiliary motors and hand operators, with their clutches and other mechanical power transmission components, are provided to serve in the event the main drive fails. In some cases, to prevent the need for larger auxiliary generators, the auxiliary motors are required for use any time the auxiliary generators are used, requiring increased time of operation.

Air Buffers and Shock Absorbers

Air buffers and shock absorbers are located between the span and the pier at points where impact may occur between the two. Air buffers utilize air compression to slow the moving leaf and cushion such impact through the use of a piston rod extension. Self-contained shock absorbers operate on the same principle, but use hydraulic oil enclosed within the unit.

Span Locks

Span lock bars at the end of the span are driven when the span is fully closed to prevent movement under live load. Span locks may also be provided at other locations on the span to hold the span in an open position against strong winds or to prevent movement from an intermediate position.

Counterweights

Adjustable quantities of counterweight blocks are provided in addition to the permanent counterweight which is part of the structure so that adjustments may be made from time to time due to changes in conditions. A movable span is designed to function in a balanced condition, and serious unbalanced conditions will cause overstress or even failure of the mechanical or structural elements.

Live Load Shoes and Strike Plates

Live load shoes and strike plates between the movable and fixed portions of the bridge are designed to bear most or all of the live load when the bridge is carrying traffic.

Traffic Barriers

Traffic barriers are heavy duty movable gates or posts which are designed to prevent a vehicle from plunging from the roadway into the draw or into the pit below the bridge. Their operation is important for public safety. They are used mainly in situations where a large opening exists between the approach span and the movable span when it is open.

20.2.2 Elements for Swing Bridges

Swing bridges are designed utilizing the following special elements.

Pivot Bearings

In center-bearing types (with balance wheels), the axially loaded thrust bearing is usually composed of spherical discs, attached to top and bottom bases, enclosed in an oil box to provide lubrication and prevent contamination. In rim-bearing types, the pivot bearing is also enclosed but will be radially loaded, maintaining the position of the pivot shaft or king pin.

Balance Wheels

On center-bearing types only, non-tapered balance wheels bear on the circular rail concentric to the pivot bearing only when the span is subjected to unbalanced loading conditions. At other times, when the span is not subjected to unbalanced loads, a gap should be found between each wheel and the rail.

Rim-Bearing Rollers

Usually tapered to allow for the differential rolling distance between the inside and outside circumferences of the rail circle, rim-bearing rollers should bear at all times.

Wedges

End wedges are used to raise the ends of the span and support live load under traffic. Center wedges are used to stabilize the center of the span and to prevent the center bearing from supporting live load. Wedges may be actuated by machinery and linkage which connects wedges to actuate together, or each wedge may have its own actuator.

End Latches

Located at the center of one or both rest piers, end latches generally consist of a guided tongue with roller mounted on the movable span which occupies a pocket mounted on the rest pier when the span is in the closed position. To open the span, the tongue is lifted until it clears the pocket at the time the wedges are withdrawn. As the span is swung open, the latch tongue is allowed to lower or fall into a position in which the roller may follow along a rail or track mounted on the pier. When closing, the tongue rolls along the rail or track and up a ramp which leads to the end latch pocket where the tongue is allowed to drop to center the span.

20.2.3 Elements for Bascule Bridges

Bascule bridges utilize the following elements peculiar to their design.

Rolling Lift Tread and Track Castings

Rolling lift tread and track castings are rolling surfaces which support the bascule leaves as they roll open or closed. Tread sockets and track teeth prevent transverse and lateral movement of the span due to unbalanced conditions, such as wind, during operation and especially when held in the open position.

Trunnions and Trunnion Bearings

Trunnions and trunnion bearings, which are large pivot pins or shafts and their bearings, entirely support the leaf as it rotates during operation as well as supporting dead load when the bridge is closed. Some designs, which do not provide separate live load supports, also require the trunnions to carry live load.

Hopkins Frame

A Hopkins frame machinery arrangement is provided on some trunnion bascule bridges. The main drive pinion locations are established in relationship to their circular racks by a pivot point on the pier and pinned links attached to the trunnions.

Tail (Rear) Locks

Located at the rear of the bascule girder on the pier, tail locks prevent inadvertent opening of the span under traffic or under a counterweight-heavy condition should the brakes fail or be released.

Center Locks

Center locks are provided to transfer shear load from one leaf to the other when the bridge is under traffic. Center locks may consist of a driven bar or jaw from one leaf engaging a socket on the other leaf, or may be a meshing fixed jaw and diaphragm arrangement with no moving parts. Without the center lock engaged, a double-leaf bascule functions as a cantilevered span, experiencing four times the bending moment, with proportional increases in stresses, at the pier.

Transverse Locks

In twin bascule bridges which are split longitudinally to allow flexibility during construction, repair, or rehabilitation, transverse locks between the inside girders are used to keep the pairs together during operation. These are usually operated manually as they are not normally used for long periods of time.

20.2.4 Elements for Vertical Lift Bridges

Vertical lift bridges may utilize the following elements peculiar to their design.

Wire Ropes and Sockets

Wire ropes and sockets include up-haul and down-haul operating ropes and counterweight ropes. Ropes consist of individual wires twisted into several strands which are wound about a steel core. Fittings secure the ends of the rope and allow adjustments to be made.

Drums, Pulleys, and Sheaves

Drums are used to wind a rope several times around to extend or retract it. Pulleys and sheaves change the direction of the rope or guide it at intermediate points between ends of the rope.

Span and Counterweight Guides

Span and counterweight guides are located between tower and span or counterweight to prevent misalignment.

Balance Chains

Balance chains are provided to compensate for the weight of counterweight rope which travels from the span side to the counterweight side of the sheaves at the top of the tower as the span is raised. Weight of chain is removed from the counterweight and is supported by the tower as rope weight is increased on the counterweight side of the sheaves on the tower.

Span Leveling Devices

Whether mechanical or electrical, span leveling devices compensate and adjust the movement of the two ends of the span during operation to prevent unsynchronized movement.

20.3 Special Elements - Inspection Procedures

20.3.1 Safety of Movable Bridge Inspectors

It is imperative that all movable bridge inspectors coordinate their work with the Bridge Operator and emphasize the need for advance warning of a bridge opening. The Bridge Operator should not operate the bridge until being notified by all inspectors that they are ready for an opening. There are many ways that this can be accomplished, such as placing a warning note on the control console or opening the circuit breakers and locking the compartment to the equipment that they will be inspecting.

20.3.2 Inspection Considerations

Important considerations for a movable bridge inspector include observing and making comments in the inspection report on the following.

Public Safety

Public safety considerations include:

- Good visibility of roadway and sidewalk for Bridge Operator.
- Adequate time delay on traffic signals for driver reaction.
- Adequate time delay before lowering gates.
- Interlock - all "gates down" before raising bridge (bypass available if traffic signals are on).
- Interlock - bridge must be closed before gates can be raised (bypass available if locks are driven).
- Interlock - traffic signals do not turn off until all gates are fully raised (bypass available).
- Observe the location of the bridge opening in relation to the gates, traffic lights and bells, and determine whether they can easily be seen by approaching motorists. Check their operation and physical condition to determine if they are functioning and well maintained. Recommend replacement when conditions warrant it.
- Unprotected approaches, such as both ends of a swing bridge and vertical lift bridge and the open end of a single-leaf bascule bridge, should preferably have positive resistance barriers across the roadway, with flashing red lights as provided on the gate arms.
- High speed roadways and curved approaches to a movable bridge should preferably have advanced warning lights (flashing yellow).

Navigational Safety

Navigational safety considerations include:

- Minimum underclearance designated on the permit drawing should be provided. Compliance with minimum channel width with any restriction on vertical clearance when span is open for navigation.
- All navigation lights should have a relay for backup light, and red span lights should not change to green until both leaves are fully open.
- Marine radio communication (depends on the need).
- Operator should be able to automatically sound the emergency signal to navigation vessels if bridge cannot be opened.
- Navigation lights are very important and should be checked for broken lenses, deteriorated insulation of wiring and cable, and dry and clean interior.
- Underclearance gauges for closed bridges must be inspected for accuracy, visibility, and legibility.

Structure Safety

Structure safety considerations include:

- Structural ability to carry the anticipated loads.
- Presence of pressure relief valves on hydraulic power units to limit hydraulic forces applied to machinery and structure.
- Keeping horsepower applied to machinery and structure within design limits by limiting speed.

Dependable Operation

The movable bridge should be operated in the normal and emergency modes to check all interrelated interlocks and to be sure every component is operational.

20.3.3 Interlocking for Normal Operation

During normal operation, the inspector should verify that each interlock functions properly and can be bypassed (when provided). The controls for the traffic signals, traffic gates, center or rear locks, emergency brakes, and the bridge operation should be so interlocked that they can only be operated in the following sequences.

20.3.4 Opening Sequence

The bridge opening sequence should be as follows:

1. Activate traffic signals.
2. Lower oncoming gates and, when traffic has cleared, lower off-going gates. "All gates down" interlocked for withdrawing locks (bypass provided).
3. Press "raise" button if automatic operation is provided or, if manual operation is provided, proceed as follows:

    a. Withdraw locks - "Locks Withdrawn." Interlocked for bridge operation (no bypass).
    b. Release emergency brakes - no interlock provided. Warning buzzer sounds if brakes are not released when power is applied to motors to move bridge.
    c. Accelerate leaves to full speed.
    d. When advanced to nearly open position, decelerate leaves to slow speed and stop at nearly open position.
    e. At nearly open position, with reduced power, lower leaves to stop at fully open position.
    f. Set emergency brakes.

20.3.5 Closing Sequence

The bridge closing sequence should be as follows:

1. Press "lower" button if automatic operation is provided or, if manual operation is provided, proceed as follows:

    a. Release emergency brakes.
    b. Accelerate leaves to full speed.
    c. For all types of bridges with lock bars:

        (1) At advanced nearly closed position, decelerate leaves to slow speed. Leaves should stop at nearly closed position by action of the bridge limit switch.
        (2) At nearly closed position with reduced power, lower leaves to stop at fully closed position.
        (3) With machinery wound up (bascule bridges and counterweight heavy vertical lift bridges) or when span

is fully closed (swing bridges and span heavy vertical lift bridges), set the brakes and drive lock bars.

d. For rolling lift bridges having jaw and diagram shear locks with no moving parts:

(1) At advanced nearly closed position, decelerate to slow speed. The jaw leaf should stop at the "locking position" (within the "window" to receive the diaphragms) by action of the bridge limit switch.
(2) At advance nearly closed position, decelerate to slow speed. The diaphragm leaf should stop in the "clear position" (where the lower jaw will clear the diaphragm) by action of the bridge limit switch.
(3) Foot switch must be depressed to provide reduced power from this point until both leaves are closed.
(4) Lower the diaphragm leaf to make "soft" contact with lower jaw.
(5) Close both leaves together with diaphragm castings against lower jaws.
(6) When leaves are fully closed, drive the rear locks. "Fully closed" interlock provided for rear lock operation (no bypass).
(7) Set emergency brakes with reduced power applied to motors to hold machinery wound up.

2. Deactivate automatic traffic control, or manually raise gates:

a. All gates raise, off-going gates should start up before oncoming gates raise.
b. Warning signals and red lights should not turn off until all gates are raised, even if the power switch is turned "off" (bypass should be provided), after which the green traffic lights are turned "on."

Bypass Note: All bypass switches should have handles that are spring returned to "off." When the switch is turned to bypass momentarily, a holding relay should hold the bypass activated until power is removed from the controls or the switch is turned to cancel bypass. These circuits should be provided in order to prevent inadvertent use of any bypass. Until a malfunction is corrected, the operator must therefore initiate the use of any bypass switch that is needed every time the bridge is operated.

20.3.6 Control House

The operator is responsible for public and navigational safety during operation and, together with maintenance personnel, should be most familiar with any known structural or operational defects. Operational and maintenance log books should be kept in the control house for reference. The resources within the control house can therefore provide a great deal of general information, through the knowledge of its personnel and the records stored there. The position of the control house should provide the best general view of the bridge itself.

Inspection of the control house should include:

- Consult with the bridge operators to ascertain whether there are any changes from the normal operation of the bridge.
- Note where the control panel is located in relation to roadway and waterway, and also whether the bridge operator has a good view of approaching boats, vehicles, and pedestrians. Check operation of all closed circuit TV equipment, and evaluate its position for safe operation.
- Note whether the structure shows cracks, and determine whether it is windproof and insulated.
- If controls are in more than one location, note description of the other locations and include their condition as well as the information about the control house.
- Note whether all Coast Guard, Corps of Engineers, and local instructional bulletins are posted.
- Note whether alternate warning devices such as bull horns, lanterns, flasher lights, or flags are available.
- Check for obvious hazardous operating conditions involving the safety of the operator and maintenance personnel.
- Check for any accumulations of debris which may be readily combustible.
- Check controllers while bridge is opening and closing. Look for excess play and for sparking during operation.
- Note whether the submarine cables are kinked, hooked, or deteriorated, especially at the exposed area above or below the water. In tidal areas, check for marine and plant growth. Note if the ends of the cable have been protected from moisture.

20.3.7 Structural Inspection Considerations

Defects, Damage, and Deterioration

Defects, damage, and deterioration, typically detrimental to all steel and concrete structures, must be noted during the inspection of all types of movable bridges. Most of the bridge structure defects and deterioration listed elsewhere as potential problems apply to movable spans also.

Fatigue

Fatigue can be a problem with movable bridges due to the reversal or the fluctuation of stresses as the spans open and close. Any member or connection subject to such stress variations should be carefully inspected for fatigue failure.

Counterweights and Attachments

Inspection of counterweights and attachments should include:

- Inspect the counterweights to determine if they are sound and are properly affixed to the structure. Also check temporary supports for the counterweights that are to be used during bridge repair and determine their availability should such an occasion arise.
- Where steel members pass through or are embedded in the concrete check for any corrosion of the steel member and for rust stains on the concrete.

- Look for cracks and spalls in the concrete.
- Check for debris, birds, animals, and insect nests in the counterweight pockets.
- Where lift span counterweight ropes are balanced by chains (or other means), make sure the links hang freely, and check these devices along with slides, housings, and storage devices for deterioration and for adequacy of lubrication, where applicable.
- Determine whether the bridge is balanced and whether extra balance blocks are available. A variation in the power demands on the motor, according to the span's position, is an indication of an unbalanced leaf or span. If the controls provide a "drift" position, it should be used to test the balance.
- Paint must be periodically removed from a lift span proper; otherwise, the counterweights will eventually be inadequate.
- Determine whether the counterweight pockets are properly drained. On vertical lift bridges, be sure that the sheaves and their supports are well drained. Examine every portion of the bridge where water can collect. All pockets that are exposed to rain and snow should have a removable cover.

Piers

Inspection of piers on movable bridges should include:

- Take notice of any rocking of the piers when the leaf is lifted. This is an indicator of a serious deficiency and should be reported at once.
- Check the braces, bearings, and all housings for cracks, especially where stress risers would tend to occur.
- Inspect the concrete for cracks in areas where machinery bearing plates or braces are attached. Note the tightness of bolts and the tightness of other fastening devices used.
- Survey the spans including towers to check both horizontal and vertical displacements. This will help to identify any foundation movements that have occurred.

Open Grid Decks

Structural welds should be sound and the grid decks should have adequate skid resistance. Check the roadway surface for evenness of grade and for adequate clearance at the joints where the movable span meets the fixed span.

Concrete Decks

A solid concrete roadway is used over the pier areas (pivot or bascule pier) to keep water and debris from falling through onto the piers. Since the machinery room is usually under the concrete deck, check the ceiling for leaks or areas that allow debris and rust to fall on the machinery.

Other Structural Considerations

Other structural considerations include:

- On swing bridges, check the wedges and the outer bearings at the rest piers for alignment and amount of lift. This can be recognized by excessive vibration of span or uplift when load comes upon the other span.
- Examine the live load bearings and wedges located under the trusses or girders at the pivot pier for proper fit alignment and amount of lift.
- On double-leafed bascule bridges, measure the differential vertical movement at the joint between the two leaves under heavy loads. On other types, check for this type of movement at deck joints (breaks in floor) between movable and fixed portions of the structure. This can

indicate excessive wear on lock bars or shear lock members.

- Inspect the joint between the two leaves on double-leaf bascule bridges, or the joints between fixed and movable portions of the structure for adequate longitudinal clearance for change in temperature (thermal expansion).
- On bascule bridges, see if the front live load bearings fit snugly. Also observe the fit of tail locks at rear arm and of supports at outer end of single-leaf bridges.
- Inspect the fully open bumper blocks and the attaching bolts for cracks in the concrete bases.
- Examine the counterweight pit for water. Check the condition of the sump pump, the concrete for cracks, and the entire area for debris.
- See if the shear locks are worn. Measure the exterior dimensions of the lock bars or diaphragm casting and the interior dimensions of sockets or space between jaws to determine the amount of clearance (wear). Excessive movement should be reported and investigated further.
- On rolling lift bascule bridges, check the segmental and track castings and their respective supporting track girders (if used) for wear on sides of track teeth due to movement of sockets on segmental castings. Compare all wear patterns for indications of movement of the leaves. Check for cracking at the fillet of the angles forming the flanges of the segmental and track girders, cracking in the flanges opposite joints in the castings, and cracking of the concrete under the track. Inspect rack support for lateral movement when bridge is in motion.
- On multi-trunnion (Strauss) bascule bridges, check the strut connecting the counterweight trunnion to the counterweight for fatigue cracks. On several bridges, cracking has been noted in the web and lower flanges near the gusset connection at the end nearer the counterweights. The crack would be most noticeable when the span is opened.

20.3.8 Mechanical, Electrical, and Hydraulic Equipment

Mechanical, electrical, and hydraulic equipment includes specialized areas which are beyond the scope of this manual. Since operating equipment is the heart of the movable bridge, it is recommended that expert assistance be obtained when conducting an inspection of movable spans. It should be noted that in many cases, the owners of these movable bridges follow excellent programs of inspection, maintenance, and repair. However, there is always the possibility that some important feature may have been overlooked.

20.3.9 Trial Openings

Conduct trial openings as necessary to insure proper operational functioning and that the movable span is properly balanced. Trial openings should be specifically for inspection. During the trial openings, the safety of the inspection personnel should be kept in mind.

20.3.10 Machinery Inspection Considerations

On all movable structures, the machinery is so important that considerable time should be devoted to its inspection. The items covered and termed as machinery include all motors, brakes, gears, tracks, shafts, couplings, bearings, locks, linkages, over-speed controls, and any other integral part that transmits the necessary mechanical power to operate the movable portion of the bridge. Machinery should be inspected not only for its current condition, but operational and maintenance procedures and characteristics of operation should also be analyzed. The items listed below and items similar to them should be inspected and analyzed by a machinery or movable bridge specialist. Refer to FHWA-IP-77-10, *Bridge Inspector's Manual for Movable Bridges* for further information on inspecting these items. It is published by the Federal Highway Administration (FHWA), but is currently out of print.

Operation and General System Condition

Observe the general condition of the machinery as a whole, and its performance during operation. Check for smoothness of operation, and note any abnormal performance of components. Noise and vibration should also be noted, and the source determined. Unsafe or detrimental procedures followed by the operator should be noted to prevent injury to the public or to personnel, or damage to the equipment. The condition of the paint system should also be noted.

Maintenance Procedures

An evaluation of maintenance procedures in light of design details for the equipment should be done. Application methods and frequency of lubrication should be checked in the maintenance log book, if available. General appearance of existing applied lubricant should be noted.

20.3.11 Mechanical Elements

The following are condensed guidelines for various mechanical elements.

Open Gearing

Check open gearing for tooth condition and alignment including over- and under-engagement. The pitch lines should match. Excessive or abnormal wear should be noted. Inspect the teeth, spokes, and hub for cracks. Examine lubrication quality and quantity. Check the teeth of all gears for wear, cleanliness, corrosion, and for proper alignment.

Speed Reducers Including Differentials

The exterior of the housing and mountings should be examined for cracks and damage. Check bolts for tightness and note any corrosion. The interior of the housing should be inspected for condensation and corrosion. Check the condition of gears. Watch for abnormal shaft movement during operation, indicating bearing and seal wear. Oil levels and condition of lubricant should be checked periodically through the use of sampling and analysis techniques. Circulating pumps and lubricating lines should be observed for proper operation. Abnormal noise should be noted.

Shafts and Couplings

Shafts should be examined for damage, twisting, and strain. Cracks, if suspected, may be detected using dye penetrant. Misalignment with other parts of the machinery system should be noted. Coupling hubs, housings, and bolts should be checked for condition. Seals and gaskets should be inspected for leaks. Internal inspection of couplings is warranted if problems are suspected and can be used to determine tooth wear in gear couplings.

Bearings

Bearing housings, pedestals, and supports should be examined for external condition. Any cracks should be noted. Bolts in housings and those used for anchors should be checked for tightness, damage, and corrosion. Apparent lubrication characteristics should be noted. In sleeve bearings, the bushings should be inspected for damage and excessive wear. Evidence of seal damage in antifriction bearings should be noted. Unusual noise should be investigated. Check the trunnion bearings for excessive wear, lateral slip, and loose bolts.

Brakes

Inspect all braking devices for proper setting of braking torque and for complete release of the brakes when actuated. On shoe brakes, check drums and shoes for wear, damage, and corrosion, for misalignment of shoes with drums, and for clearance when released. Determine if worn linings need replaced. Check for proper actuation without leakage by actuators. Linkages and hand releases should be free but not sloppy. On enclosed hydraulic disc brakes, make certain there is proper actuation without leakage at connections or seals. Check the brakes, limit switches, and stops (cylinders and others) for excessive wear and slip movement. Note whether the cushion cylinder ram sticks or inserts too easily. The brake limit switches should be inspected for proper setting.

Drives - Electric Motors

Check the housing and mountings for damage, corrosion, and fastener condition. Inspect bearings for lubrication and note indications of wear (movement) and seal leakage at shaft extensions.

Drives - Hydraulic Equipment

Look for any leakage at connections and seals. Note any corrosion on the cylinder rods. Listen to motors and pumps, and note any unusual noise. Power units should be checked to make sure all components are functioning and that pressures are properly adjusted. Fluid should be sampled periodically and examined for contamination and wear metal.

Auxiliary Drives

Check emergency generators for operation and readiness. There should be no oil leaks or abnormal noises. Mechanical service specialists and electrical inspectors are required for more thorough inspections. Auxiliary motors and hand operators, with their clutches and other transmission components, should be checked for adjustment and readiness to perform when called upon.

Drives - Internal Combustion Engines

The detailed inspection of internal combustion engines should be made by mechanical engine specialists. Inspection should also include but not be limited to the checking of the following conditions:

- If a belt drive is used, look for any wear or slippage. Note the condition of all belts and the need for replacement, if any.
- If a friction drive is used, all bracings and bearings should be tight.
- If a liquid coupling is used, make sure that the proper quantity of fluid is used. Look for leaks.

Locks

Examine the center locks and tail locks (if used) on double-leafed bascule spans, and the end locks on single-leaf bascule bridges, swing bridges, and vertical lift bridges. Note whether there is excessive deflection at these joints or vibration on the bridge. Inspect the locks for fit and for movement of the span or leaf (or leaves). Check lubrication and for loose bolts. The lock housing and its braces should have no noticeable movement or misalignment. The paint adjacent to the locks will have signs of paint loss or wear if there is movement. Check lock bars, movable posts, linkages, sockets, bushings, and supports for damage, cracks, wear, and corrosion.

Actuators should be examined for operational characteristics, including leakage if hydraulic. The quantity and quality of lubricant should be noted. Check for alignment, and analyze the type of wear which is occurring. Note condition of movable operators.

Live Load Shoes and Strike Plates

The fasteners and structure should be inspected for defects and corrosion. Contact surface conditions should be noted. Check for alignment and movement under load.

Air Buffer Cylinders and Shock Absorbers

Note indications of lack of pressure or stickiness during operation. Check piston rod alignment with strike plate. Note the condition of the rod and housing. There should be no hydraulic leakage. Check the air filter and function of any pressure reading or adjusting devices and the operating pressure, if possible. The air buffers should have freedom of movement and development of pressure when closing.

Machinery Frames, Supports, and Foundations

There should be no cracking in steel or concrete. Note corrosion and damage. Check for deflection and movement under load. The linkages and pin connections should have proper adjustment and functional condition. Check motor mounting brackets to ensure secure mounting.

Fasteners

Inspect the fasteners for corrosion, loss of section, and tightness.

Special Machinery for Swing Bridges

Check center bearings for proper and adequate lubrication, oil leaks, and noise. Examine the housing for cracking, pitting, fit of joints, and note indications of span translation (irregular rotation) at racks and track. Measure for proper clearance of balance wheels above track. The tracks and balance wheels should be free of wear, pitting, and cracking. Check for proper and adequate lubrication at all lubrication points.

Balance characteristics should be noted as indicated by loads taken by balance wheels, and by drag on the rest pier rail.

Check the rim bearing for wear on tracks and rollers, particularly at rest positions where the bridge is carrying traffic. Examine the center pivots and guide rings for proper fit, and for wear, pitting, and cracking. Check for proper and adequate lubrication at all lubrication points.

The center (live load) wedges located under the trusses or girders at the pivot pier must be examined for proper fit (no lifting) and alignment. Check end wedges and bearings at the rest piers for alignment and amount of lift. This can be recognized by excessive vibration of the span or uplift when live load crosses the other span. The end lift jacks, shoes, and all linkages must be inspected for wear, proper bearing under load, and proper adjustment.

Note the condition of end latches, including any modification which adversely affects their functional design.

Special Machinery for Bascule Bridges

Check the condition of tracks and segmental (rolling) castings on rolling lift bridges. The trunnion assemblies must be inspected for deflection, buckling, lateral slip, and loose bolts. The trunnions themselves should have no corrosion, pitting, and cracking, particularly at stress risers. Check the balance of each leaf.

Special Machinery for Vertical Lift Bridges

The condition of wire ropes and sockets, including wire rope lubrication, is important. Look for flattening or fraying of the strands and deterioration between them. This is reason for replacement. Similarly, check the up-haul and down-haul ropes to see if they are winding and unwinding properly on the drums. The need for any tension adjustments in up-haul and down-haul ropes should be noted. Determine whether ropes have freedom of movement and are running properly in sheave grooves. Look for any obstructions to prevent movement of the ropes through the pulley system, and check the supports on span drive type bridges. Check rope guides for alignment, proper fit, free movement, wear, and structural integrity of the longitudinal and transverse grooved guide castings. The grooved guide castings must be inspected closely for wear in the grooves. The cable hold-downs, turnbuckles, cleats, guides clamps, splay castings, and the travel rollers and their guides must be examined.

Check for damage, including cracking, at drums and sheaves. Note the condition and alignment of span guides.

Check that balance chains hang freely, that span leveling devices are functioning, and that span and counterweight balance closely. Observe if span becomes "out of level" during lifting operation. Inspect spring tension, brackets, braces, and connectors of power cable reels.

20.3.12 Electrical Inspection Considerations

An electrical specialist should be available for the inspection of the electrical equipment. The inspection should be made using FHWA-IP-77-10, *Bridge Inspector's Manual for Movable Bridges* (FHWA-IP-77-10 is currently out of print). The inspector should observe the functional operation of the bridge and look for abnormal performance of the equipment. Check the operational procedures and safety features provided. Evaluate the maintenance procedures being followed and check the frequency of services performed.

Power Supplies

The normal power supply, standby power supply, and standby generator set (for emergency operation of bridge and service lighting) should be examined and the following noted:

- Take megger readings on the cable insulation values, noting the weather conditions, namely temperature and humidity.
- Make sure all cable connections are properly tightened.
- Measure the voltage and the current to the motors at regular intervals during the operation of the bridge.
- Check the collector rings and windings on the generator set.
- Test starting circuitry for automatic starting and manual starting.
- See if the unit is vibrating while running under load.

If the power cable has been repaired with a splice, note the condition of the splice box seal.

If no standby power supply has been provided, determine whether a portable generator could be used. A manual transfer switch would be a convenient way of connecting it.

Motors

Span drive motors, lock motors, brake thrustor motors, and brake solenoids should be examined for the same items as given for power supplies.

Transformers

Check dry transformer coil housings, terminals, and insulators, including their temperature under load. Observe the frames and supports for rigidity to prevent vibration. The liquid filled transformer should be checked in the same way, and the oil level should be checked while looking for leakage. Examine oil insulation test records.

Circuit Breakers

Check circuit breakers (e.g., air, molded case, and oil) and fuses, including the arc chute, contact surfaces, overload trip settings, insulation, and terminal connections. Examine oil insulation test records, and observe the closing and tripping operation. Record all fuse types and sizes being used.

Wires and Cables

Examine the wiring and cables for both power and control. Note whether the submarine cables are kinked, hooked, or deteriorated, especially at the exposed area above and below the water. In tidal areas, look for marine and plant growth. Note if the ends of the cable have been protected from moisture. Record the insulation value of each wire as measured by megger. Look for cracking, overheating, and deterioration of the insulation. Check for wear against surfaces and especially sharp edges. Check the adequacy of supports and that dirt and debris do not accumulate against the conduit and supports. Terminal connections, clamps, and securing clips should be checked for tightness, corrosion, and that there are wire numbers on the end of each wire. The weight of the wires or cables must be carried by the clamps and not by the wire connections at the terminal strips.

Cabinets

Examine the programmable logic controller (PLC) cabinets, control consoles and stations, switchboards, relay cabinets, motor control centers (MCC), and all enclosures for deterioration, debris inside, drainage, operations of heater to prevent condensation, and their ability to protect the equipment inside. Check the operation of all traffic signals, traffic gates, traffic barriers, and navigation lights. Verify that the bridge is open to provide the clearance shown on the permit drawing before the green span light turns on. Check the traffic warning equipment and control circuits, including the advanced warning signals (if used), traffic lights/signals, gates, barriers, and the public address and communication equipment.

Conduit

See if all conduit is far enough away from all surfaces to avoid debris from collecting against it. Note if it is adequately supported and pitched to drain away from junction boxes and pull boxes, so that water is not trapped within. Also, note if all conduits have covers with seals. Report deteriorated conduit so that it can be replaced with new conduit. The connectors at the ends of all PVC coated conduit must be sealed and re-coated after all fittings are installed.

Junction Boxes

The covers on all junction boxes (JB's) should be examined for an effective seal, dry interior, functioning breather-drains, heaters having enough power to prevent condensation inside, and terminal strips all secured to the bottom of horizontal JB's or to the back of vertical JB's.

Meters

Observe if all voltmeters, ammeters, and watt meters are freely fluctuating with a change in load. Switches for meters should all be operable.

Control Starters and Contactors/Relays

Check the operation of this equipment under load, and watch for arcing between contacts, snap action of contacts, deterioration of any surfaces, and drainage of any moisture. Look for signs of corrosion and overheating.

Limit Switches

All limit switches should be set so they do not operate until they are intended to stop the equipment or complete an interlock. The interior should be clean and dry, with all springs active.

Selsyn Transmitters and Receivers

Check for power to the field and signal being sent from the transmitter to the receiver. Observe the receiver tracking the rotation of the bridge as it operates. Observe the mechanical coupling between the driving shaft and the transmitter, checking for damage and misalignment.

Service Light and Outlet

Power should be going to each light and outlet. Note if there is a shield or bar for protecting each bulb and socket. It is desirable to have service lights available when power is removed from all movable bridge controls and equipment.

20.3.13 Hydraulic Inspection Considerations

A hydraulic power specialist should be available for the inspection of the hydraulic equipment. The inspector should observe the functional operation of the bridge and look for abnormal performance of the equipment. Check the safety features provided and evaluate the maintenance procedures being followed, checking the frequency of services performed. Due to the interrelated function of components, the requirements for fluid cleanliness, and the need for personnel safety, the reservoir and hydraulic lines should not be opened. In addition, no components or parts of the power circuit should be shut off or adjusted without complete understanding of their function and knowledge of the effect such action will have upon the system. Items which should be checked during a hydraulic inspection include the following:

- Leakage anywhere in the system should be noted. Significant leakage should immediately be brought to the attention of the bridge authority.
- Check for corrosion of reservoir, piping, and connections.
- Sight gauges should be inspected for proper fluid level in reservoir. Particular note should be taken of low fluid levels and of gauges which cannot be read.
- Unusual noises from any part of the system should be noted.
- Check filter indicators to make sure filters are clean.
- A sample of the hydraulic fluid should be taken for analysis by a testing laboratory during periodic inspections.

20.4 Recordkeeping and Documentation

General

The owner of a movable bridge must keep a complete file available for the engineer who is responsible for the operation and maintenance of the bridge. The file should include (if applicable), but not be limited to, the following:

- Copy of the latest approved permit drawing
- Complete set of design plans and special provisions
- "As-built" shop plans for the structural steel, architectural, mechanical, electrical, and hydraulic
- Machinery Maintenance Manual
- Electrical Maintenance Manual
- Hydraulic Maintenance Manual
- Copy of maintenance procedures being followed
- Copy of the latest Operator's Instruction being followed
- Copies of all inspection reports
- Copy of all maintenance reports

- Copy of all repair plans
- Up-to-date running log on all spare parts that are available, on order, or out of stock

Inspection and maintenance reports should be reviewed with preventative maintenance measures in mind. An example would be the "megger" readings on wiring insulation, especially those taken on damp rainy days when moisture could influence (reduce) the values. An acceptable minimum reading is usually 1 megohm. If the value on a wire is decreasing on progressive reports, preventative maintenance may save a "short" that could burn out equipment and put the bridge out of operation.

Inspection and Maintenance Data

Examples of inspection and maintenance records that should be kept are shown in Figures 20-19 through 20-25.

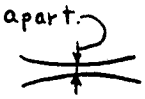
South Tower	Differential Assembly GEARS - General					1.
Gear	General Condition	Lubrication	Keys	Alignment		
				Center Distance	Axial	Parallel
Pinion P5	Very Good. Tooth profiles show normal wear	Very Good	Good	Good. Pitch Lines Tangent	Good	Good
Gear I5	Very Good. Tooth profiles normal.	Very Good	Good			
Gear G5	Very Good. Tooth profiles normal	Very Good	Good	No Pitch Line on G5. Looks good. Measured backlash.		
Pinion P4	Very Good. Tooth profiles normal.	Very Good	Integral with shaft	No pitch line on P4. Center distance looks. Looks good. Measured backlash.	Good	Good
Gear G4	Very Good. Tooth profiles normal.	Very Good	Not keyed to shaft. Clutch locks G4 to shaft.			
Bevel Gears BG3 (2)	Very Good. Tooth profiles normal.	Very Good	Integral with sleeves.	Good. Pitch Lines 1/16" to 1/8" apart. 	Good	Good
Bevel Pinions BP3 (2)	Very Good. Tooth profiles normal.	Very Good	Integral with shafts.			

Figure 20-19 Example of Notes on Operating Machinery (Gears-General)

South Tower Differential Assembly GEARS - Teeth										2.
Gear	Chordal Thickness		Backlash		Condition of Teeth					
					Normal	Pitting	Rolling-Peening	Abnormal		
	Original	Measured	Original	Measured				Scor-ing	Inter-ference	Rust & Corr.
Pinion P5	.625"	Did not measure	.011" min to .020" max.	Did not measure. Pitch lines indicate good backlash.	✓					
Gear I5	.625"		.011" min		✓					
Gear G5	.625"		to .020" max.	.0135" Good.	✓					
Pinion P4	.625"		.011" min to	.020" Good	✓					
Gear G4	.625"		.020" max		✓					
Bevel Gears BG3 (2)	.875" at large end of teeth		.015" min to	Did not	✓					
Bevel Pinions BP3 (2)	.875" at large end of teeth		.029" max	measure. Pitch lines indicate good backlash.	✓					

Figure 20-20 Example of Notes on Operating Machinery (Gears-Teeth)

South Tower Differential Assembly		BEARINGS			3
Bearing	General Condition	Clearance		Bolts	Lubri-cation
		Original	Measured		
West end Emer. Motor Shaft	Good. Fairly clean, paint good. Bearing has 45° angle lube fitting w/dust cap.	.0025" min. to .0073" max.	.006" Good	Good. Nuts tight. Clean, paint good.	Good.
East end Emer. Motor Shaft		.0025" min. to .0073" max.	.006" Good		
West end Intermediate Shaft		.0025" min. to .0073" max.	.007" Good		
East end Intermediate Shaft		.0025" min. to .0073" max.	.005" Good		
West end Normal Motor Shaft		.0025" min. to .0073" max.	.007" Good		
East end Normal Motor Shaft		.0025" min to .0073" max	.009" Fair		

Figure 20-21 Example of Notes on Operating Machinery (Bearings)

South Tower Differential Assembly	MECHANICAL COMPONENTS 4.
Item	General Condition
Housing Cover	Very good condition. Cover has four hinged maintenance panels, secured with studs and wingnuts. Cover bolted to lower supports with 20 bolts.
Normal (Main) Drive Clutch Cone	Very good condition. No slippage during span operation, starting or stopping. Clutch cone is inside differential assembly and impossible to inspect without disassembly of differential.
Emergency Drive Clutch Cone Assembly	Very good condition. Design plans show cone type clutch. Actually have jaw type clutch.
Differential Clutch Operating Linkage	Very good condition. Well lubricated. Linkage operates smooth and quiet.
Emergency Drive Clutch Operating Linkage	Very good condition. Well lubricated. Linkage operates smooth and quiet.
Gear Motor for operation of Differential Clutch	Good condition. Operates smoothly. Operated with hand crank, turned fairly easy. GE AC Gearmotor, Model KY3AC2345, Motor 1800 rpm, 1/6 HP, 250:1 ratio
Support for above Gear Motor	Good. Some debris and oil on support.
Gear Motor for operation of Emer. Drive Clutch	Good. Operates smoothly. Turned easily with hand crank. Same gearmotor as at differential clutch
Support for above Gear Motor	Good. Some debris and oil on support.
Housing Support	Good condition. Some debris and oil on support and floor. Paint good. 2 lights attached to supports inside

Figure 20-22 Example of Notes on Operating Machinery (Mechanical Elements)

Electrical Equipment 125HP, 600RPM, 3ϕ, 60H				
Motor A (Normal-Traction) Tower South Side W				
General Items	General Condition			
Stiffness of Supports	Good			
Connection to "	Bolts tight			
Condition of Frame	Dirty & Dusty Inside & out			
Inspection Covers	Wire Mesh, 2 on Top (2 on Bott. missing)			
Gaskets on "	None			
Bolts on "	Tight			
Ventilation	Open Ends			
Operation-Noise	Normal			
" -Vibration	Minimal			
" - -Bearings	Normal wear			
Lubrication	Needs normal application			
Oil-Dirt Build-Up	None (Except at couplings)			
Insulation	See Megger test			
Cable Connections	Good			
Wound Rotor Motors	Wire No.	Raising Span Amps.	Lowering Span Amps.	
Motor Current-ϕ A	T1A	122	91	
B	T3A	124	93	
C	T2A	124	92	
Motor Voltage - A-B				460V
A-C				
B-C				
Rings - Surface	Normal wear			
" - Arcing	None Visible			
Brushes - Contact	Good			
" - Spring Pressure	Good, Springs Rusty			
" - Condition	Good, 2¼" length			
Wiring-Connection	Tight, Bolts Rusty			
" - Insulation	Good			
Rotor Current 3 ϕ A	M1A	50	31	
B	M3A	48	32	
C	M2A	50	32	

Figure 20-23 Example of Notes on Electrical Equipment (Motors)

21

Special Bridges

21

Special Bridges

21.1 Introduction

There are several bridge types which feature special elements and which require special inspection procedures. The most notable special bridge types are:

- Suspension bridges
- Cable-stayed bridges
- Segmental concrete bridges

For each of the above bridge types, this chapter provides:

- A general description
- Identification of special elements
- An inspection procedure for special elements
- Methods of recordkeeping and documentation

Inspection Procedures

The inspection procedures presented in this chapter are not exhaustive, but rather are those that are unique to the particular bridge type. Therefore, the inspection of special bridges should include both those procedures presented in this chapter and the general procedures presented previously in this manual.

Due to the specialized nature of these bridges and because no two special bridges are identical, the inspection should generally be led by a specialist in that bridge type. Also, an inspection and maintenance manual is often developed by the bridge engineer for each special bridge structure. The inspector should use this valuable tool throughout the inspection process and should verify that specified routine maintenance has been performed. Customized, preprinted inspection forms should be used wherever possible to enable the inspector to report the findings in a rigorous and systematic manner.

21.2 Suspension Bridges

21.2.1 General

A suspension bridge is a bridge in which the superstructure is supported by vertical suspender ropes which, in turn, are supported by main suspension cables (see Figure 21-1). These suspension cables are supported by saddles atop towers and are anchored at their extreme ends. Suspension bridges are normally constructed only when the more conventional types of bridges are impractical because of clear span requirements or because the use of intermediate piers is not feasible.

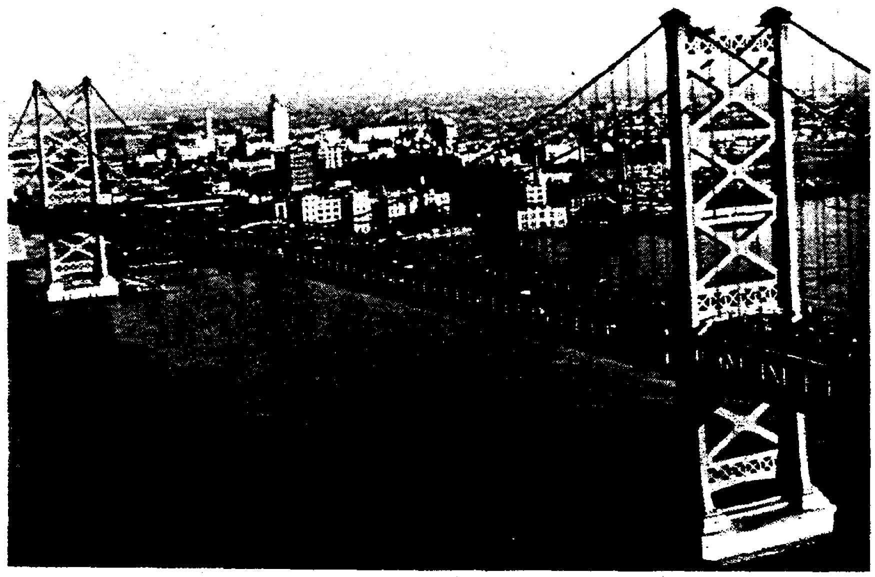


Figure 21-1 Suspension Bridge

21.2.2 Special Elements

There are several special elements that are unique to suspension bridges, and the bridge inspector should be familiar with them (see Figure 21-2).

Anchor Bars or Rods

Inspect the anchor bars or rods for:

- Corrosion, deterioration, or movement at the face of their concrete embedment
- Corrosion or other signs of distress over the entire visible (unencased) portion

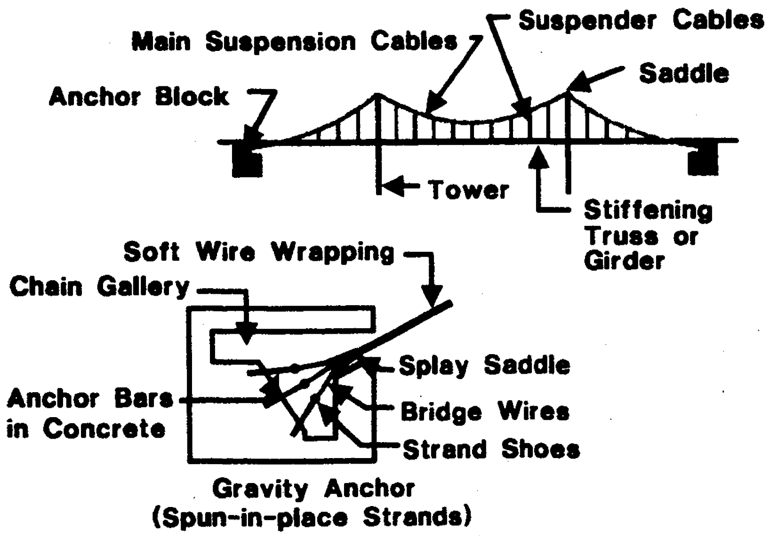


Figure 21-2 Special Elements of a Suspension Bridge

Anchor Blocks

The concrete anchor blocks should be inspected for:

- Cracks and spalling
- Rebar corrosion
- Condition of the dampers
- Proper drainage

Strand Shoes

At the anchorages of parallel wire type suspension bridges (main cables consist of a series of parallel wires that are spun in place, compressed, and wrapped), inspect the strand shoes for:

- Signs of displaced shims
- Movement, corrosion, and misalignment
- Cracks in the shoes

Strand Sockets

At the anchorages of prefabricated strand type suspension bridges (main cables are fabricated, stretched, and socketed in the shop and then shipped to the bridge site), inspect the strand sockets for:

- Signs of movement
- Slack or sag
- Corrosion
- Broken sockets
- Unpainted or rusty threads at the face of the sockets; this may indicate possible "backing off" of nuts

Wires in Anchorage

In parallel wire type suspension bridges, inspect the unwrapped wires between the strand shoes and the splay saddle. Carefully insert a large screwdriver between the wires and apply leverage. This test will reveal the presence of broken wires for some distance beyond the splay saddle under the wrappings. Only random inspecting is required.

Strands at Anchor Sockets

Inspect the strands at their entrance to the anchor sockets for:

- Abrasion
- Corrosion
- Movement

Main Suspension Cables

Inspect the main suspension cables for corroded wires. Inspect the condition of the protective covering or coating, especially at:

- Areas adjacent to the cable bands
- Saddles over towers
- Cable bent piers
- Anchorages

Splay Saddles

Inspect the splay saddles for:

- Missing or loose bolts
- Movement up the cable away from the splay; signs of this movement may be the appearance of unpainted strands on the lower side or "bunched up" wrapping on the upper side
- The presence of cracks in the casting itself

Cable Bands

Inspect the cable bands for:

- Missing or loose bolts
- Possible slippage; signs of this movement are caulking that has pulled away from the casting or "bunching up" of the soft wire wrapping adjacent to the band
- The presence of cracks in the band itself
- Broken suspender saddles
- Corrosion or deterioration of the band
- Loose wrapping wires at the band

Saddles

Inspect the saddles for:

- Missing or loose bolts
- Slippage of the main cable
- Corrosion or cracks in the casting
- Proper connection to top of tower or supporting member

Hand Ropes and Connections

Inspect the hand ropes and connections for:

- Loose connections of stanchion to cable bands
- Too much slack in rope
- Bent or twisted stanchions
- Loose connections at anchorages or towers
- Corroded or deteriorated ropes or stanchions

Suspender Ropes

Inspect the suspender ropes for:

- Corrosion or deterioration
- Kinks or slack
- Abrasion or wear at sockets, saddles, clamps, and spreaders
- Broken wires

Suspension Rope Sockets

Inspect the suspender rope sockets for:

- Corrosion, cracks, or deterioration
- Abrasion at connection to bridge superstructure
- Possible movement

Anchorages

The anchor chain gallery of the anchorage is usually a dark, damp enclosure with a very corrosive environment. Therefore, inspect the interior of the anchorage for:

- Corrosion and deterioration of any steel hardware
- Protection against water entering or collecting where it may cause corrosion
- Proper ventilation

Wrapping Wire

Inspect the wrapping wire for:

- Loose wrapping wires
- Cracks in the caulking where water can enter and cause corrosion of the main suspension cable
- Evidence of water seepage at the cable bands, saddles, and splay castings

Advanced Inspection Techniques

In bridge cables, the greatest problems generally occur due to corrosion and fracture of individual wires. Visual inspection of unwrapped cables is limited to the outer wires, while visual inspection of wrapped cables is limited to the protective sheathing. Therefore, advanced inspection techniques should be used to achieve a more rigorous and thorough inspection of the cables, including:

- Magnetic induction
- Electrical resistivity
- Dye penetrant
- Ultrasonic testing
- Radiographic testing
- Acoustic emission
- Accelerometers
- Strain measurements
- Vibration measurements
- Leakage magnetic flux
- Measurement of loads
- Measurement of stress ranges

For a description of advanced inspection techniques for bridge cables, refer to Chapter 15.

21.2.3 Recordkeeping and Documentation

A set of customized, preprinted forms should be prepared for documenting all defects encountered in the cable system of a suspension bridge. A suggested sample form is presented in Figure 21-3. A separate form should be used for each main suspension cable. Designations used to identify the suspender ropes and the panels provide a methodology for locating the defects in the structure.

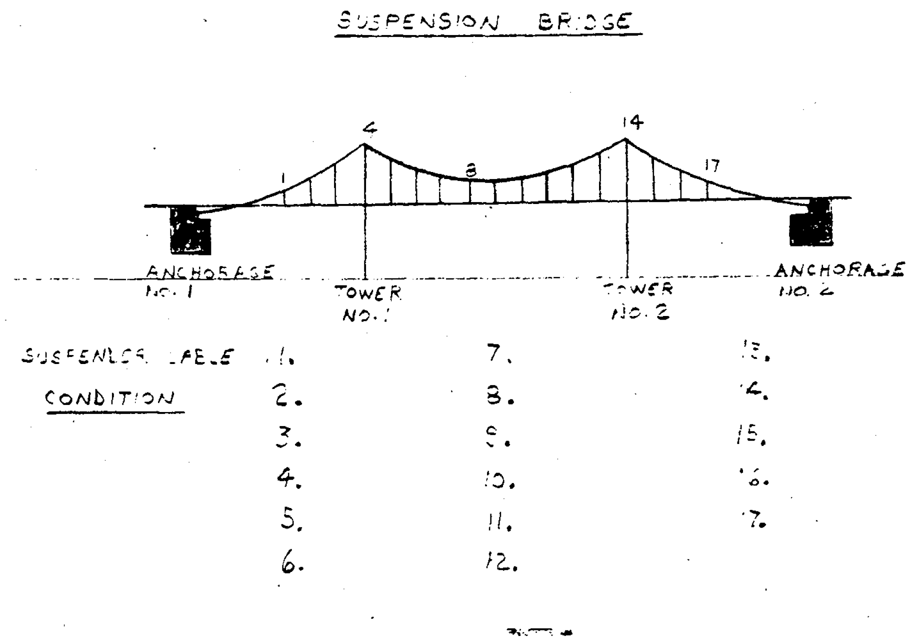


Figure 21-3 Form for Recording Defects in the Cable System of a Suspension Bridge

21.3 Cable-Stayed Bridges

21.3.1 General

A cable-stayed bridge is a bridge in which the superstructure is supported by cables, or stays, passing over or attached directly to towers located at the main piers (see Figure 21-4). The superstructure generally consists of an orthotropic deck and continuous girders. Some of the most common longitudinal cable arrangements are presented in Figure 21-5.

21.3.2 Special Elements

There are several special elements that are unique to cable-stayed bridges, and the bridge inspector should be familiar with them.

Cable System

The inspection of the cable system should include:

- Exterior of the cables (cable wrapping)
- Cable anchorages
- Anchor pipe clearances
- Flange joints
- Sheathing pipe welds (polyethylene or steel)
- Sheathing expansion joints
- Wrap ends near the tower and deck
- Reading the load cells and recording the forces in the cables, noting the loads on the deck at the time of the readings
- Type and amplitude of cable vibrations, noting the direction and speed of wind

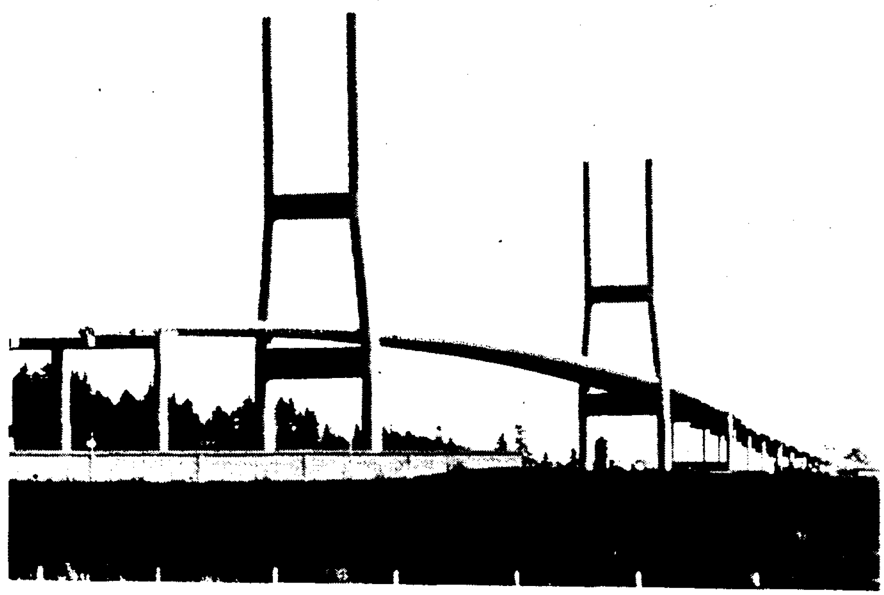


Figure 21-4 Cable-Stayed Bridge

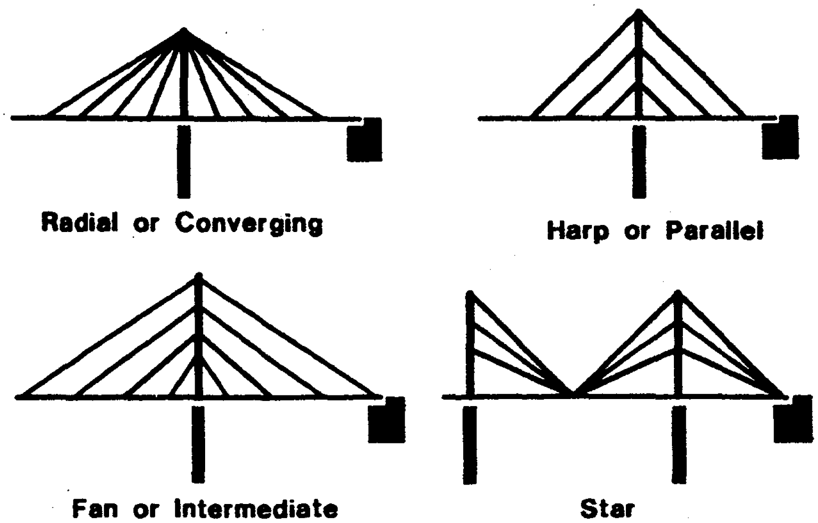


Figure 21-5 Longitudinal Cable Arrangements

Cable Pipes

Inspect the cable pipes for:

- Corrosion
- Splitting
- Cracking
- Excessive bulging

Cable pipes should be inspected carefully. Special concern should be given to the connections with the cable dampers, the tower exits, and anywhere pipes are welded together.

Cable Damper System

The most commonly used cable damper system is a shock absorber type. Inspect this cable damper system for:

- Corrosion
- Tightness in the connection to the cable pipe
- Oil leakage in the shock absorbers
- Deformations in the bushings
- Torque in the bolts

Cable Anchorages

Inspect the cable anchorages for:

- Watertightness of neoprene boots at the upper ends of the guide pipes
- Drainage between the guide pipe and transition pipe
- Corrosion of the anchor system
- Defects, such as splits and tears, in the neoprene boots
- Sufficient clearance between the anchor pipe and cable, noting rub marks and kinks
- Cracks and nut rotation at the socket and bearing plate
- Seepage of grease from the protective hood

Advanced Inspection Techniques

Since visual inspection is often insufficient to detect corrosion and fracture of individual cable wires, advanced inspection techniques may be used. For a description of these techniques, refer to Section 21.2.2 and Chapter 15.

Superstructure

If the superstructure of the cable-stayed bridge is segmental in nature, then the inspection should include the procedures presented in Section 21.4.2.

21.3.3 Recordkeeping and Documentation

A set of customized, preprinted forms should be prepared for documenting all defects encountered in the cable system of a cable-stayed bridge. A suggested sample form is presented in Figure 21-6. A separate form should be used for each plane or set of cables. Designations used to identify the cables and the panels provide a methodology for locating the defects in the structure.

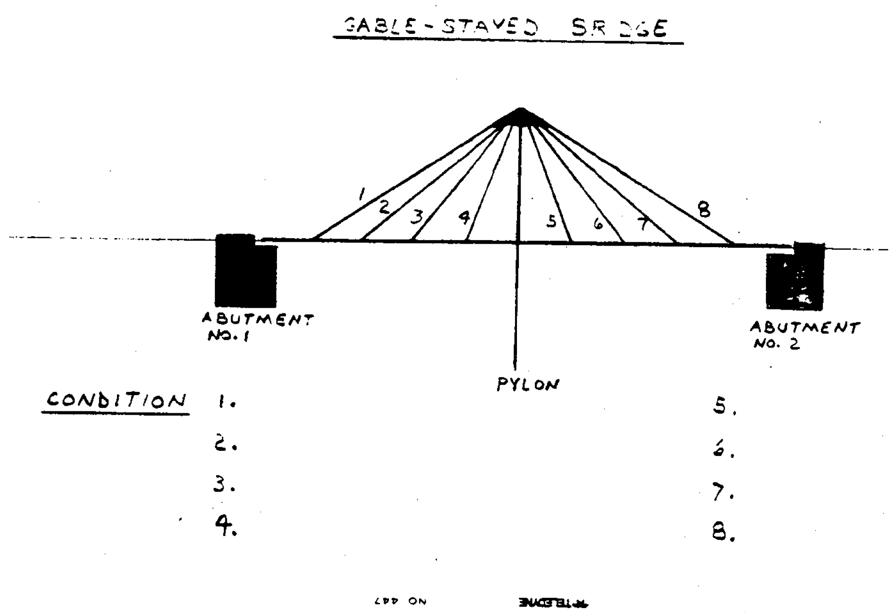


Figure 21-6 Form for Recording Defects in Cable System of a Cable-Stayed Bridge

21.4 Segmental Concrete Bridges

21.4.1 General

A segmental concrete bridge is fabricated piece by piece. These pieces, or segments, are posttensioned together during the construction of the bridge (see Figure 21-7). The superstructure can be constructed of precast concrete or cast-in-place concrete. Several characteristics are common to most segmental bridges:

- Used with long span bridges
- Generally comprised of box girder segments
- For most bridges, each segment is the full width and depth of the bridge; for very wide decks, many segmental box girders may consist of two-cell boxes or adjacent single boxes
- The length of the segments is determined by the construction methods and equipment available to the contractor
- Depending on the construction method, a new segment may be supported from previously erected segments

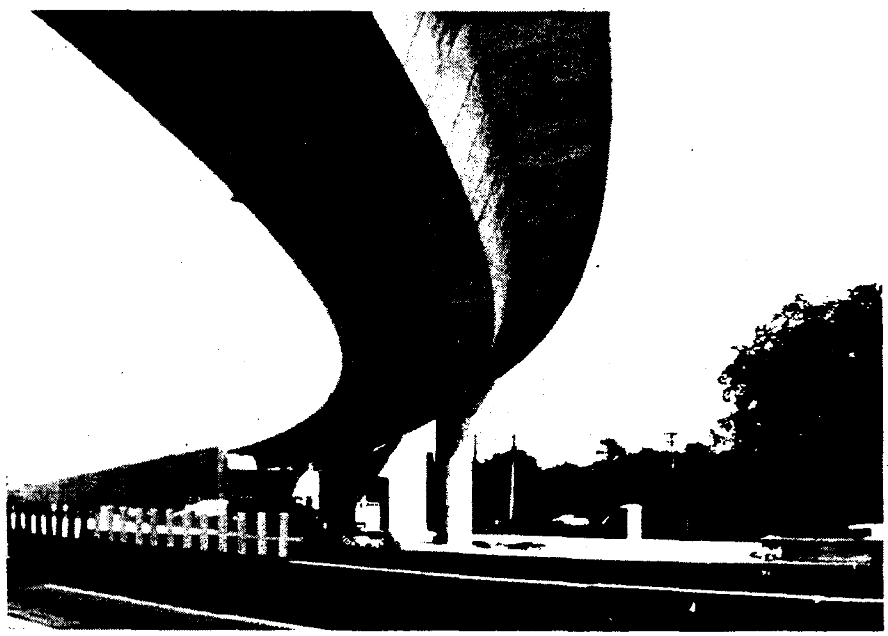


Figure 21-7 Segmental Concrete Bridge

21.4.2 Special Elements

There are several special elements that are unique to segmental bridges, and the bridge inspector should be familiar with them (see Figure 21-8).

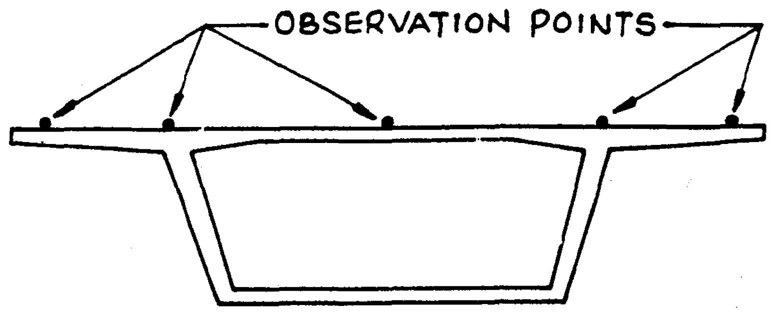


Figure 21-8 Location of Observation Points Across the Deck

Box Girders

Inspect both the interior and the exterior surfaces of the box girder for:

- All defects noted in the previous inspection
- Cracks induced by direct tension (see Figure 21-9)
- Cracks induced by flexure (see Figures 21-10 and 21-11); these cracks will be enhanced by differential temperature with bottom fiber cracks being more visible on sunny days and in the early evening
- Cracks induced by flexure shear (see Figure 21-12)
- Cracks induced by shear (see Figure 21-13)
- Cracks induced by torsion and shear (see Figure 21-14)
- Thermally induced cracks in the slab (see Figure 21-15)
- Thermally induced cracks at a change in the cross section (see Figure 21-16)
- Cracks induced by concentrated loads and which follow the tendon paths (see Figure 21-17)
- Cracks adjacent to the anchorage blocks (see Figure 21-18)
- Spalling
- Rust or lime stains, which may indicate that deep cracks have penetrated the prestressing tendon assemblies or the reinforcing bars
- Delamination or staining along the tendon paths, which may indicate a potential for voids in the ducts and perhaps corrosion
- Cracks and other forms of distress at all diaphragm regions
- Cracks and other forms of distress in all joints between the segments
- Cracks which may have occurred during fabrication, curing, form removal, or storage
- Crushing and movement of the shear keys in the joints
- Corrosion at the posttension anchorages
- Creep and relaxation losses within the coupler zones at closure joints

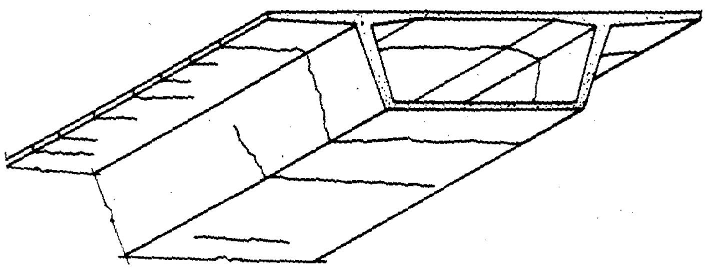


Figure 21-9 Box Girder Cracks Induced by Direct Tension

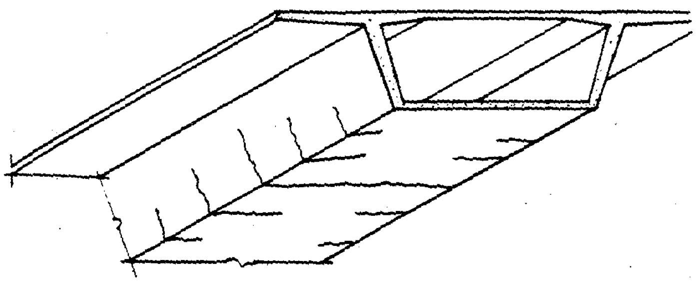


Figure 21-10 Box Girder Cracks Induced by Flexure (Positive Moment)

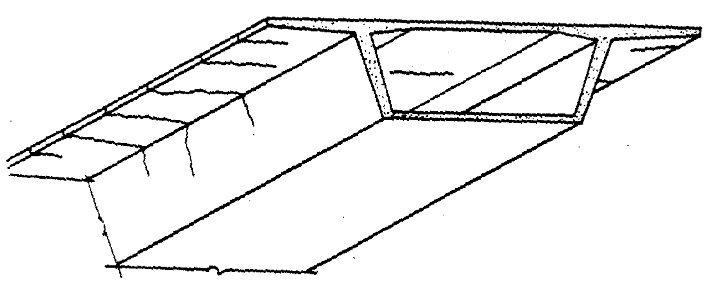


Figure 21-11 Box Girder Cracks Induced by Flexure (Negative Moment)

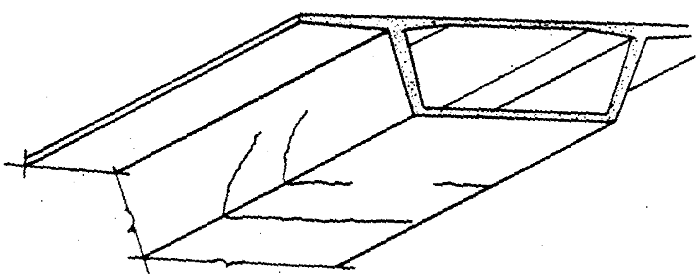


Figure 21-12 Box Girder Cracks Induced by Flexure Shear

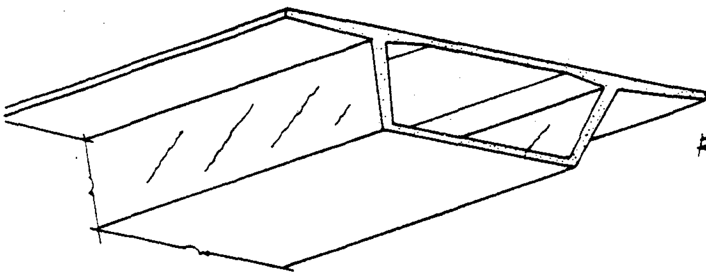


Figure 21-13 Box Girder Cracks Induced by Shear

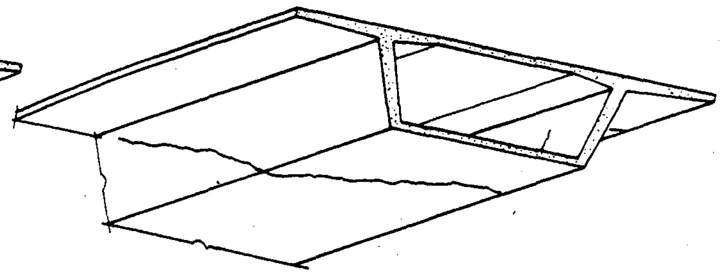


Figure 21-14 Box Girder Cracks Induced by Torsion and Shear

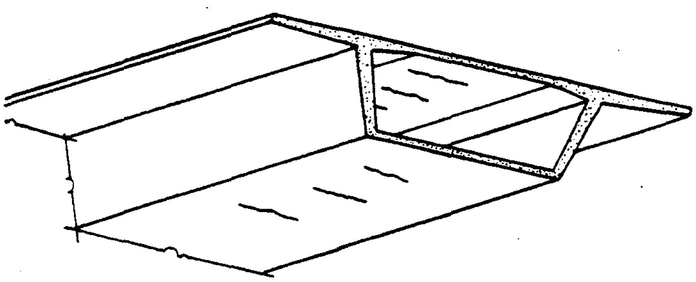


Figure 21-15 Thermally Induced Cracks in Box Girder Slab

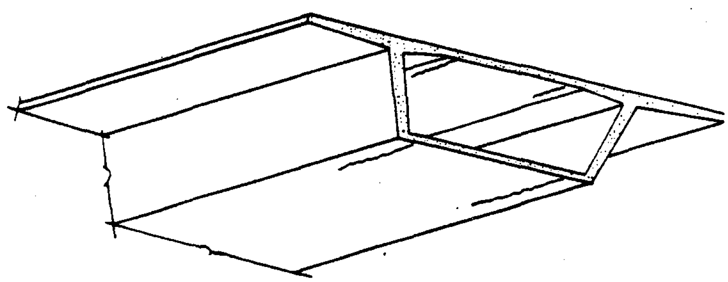


Figure 21-16 Thermally Induced Cracks at Change in Box Girder Cross Section

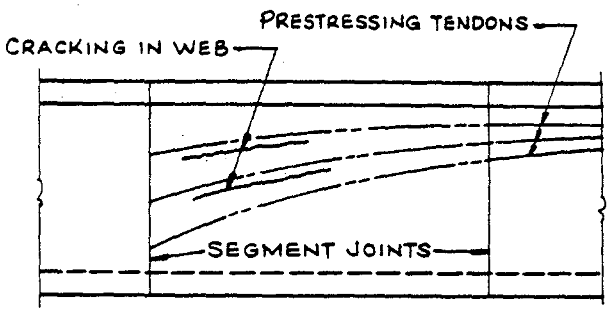


Figure 21-17 Box Girder Cracks Induced by Concentrated Loads

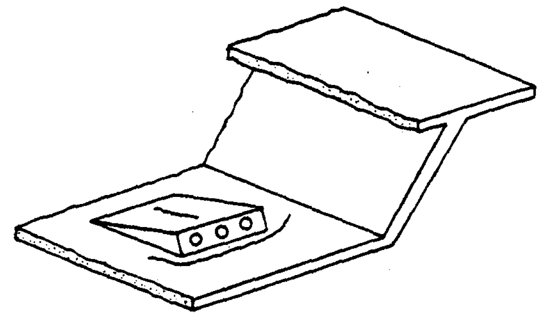


Figure 21-18 Box Girder Cracks Adjacent to Anchorage Block

Miscellaneous Procedures

In addition to the above inspection procedures for the interior and exterior surfaces of the box girder, the inspection of a segmental concrete bridge should also include:

- Inspection of the roadway surface for cracking, spalling, twisting, and deformation; the presence of these defects can increase the impact effect of traffic; also this may be of great significance since, in many segmental bridges, the top of the structural member is the riding surface
- Investigation of unusual noises, such as banging and screeching, which may be the result of structural distress
- Observation and recording of data from any monitoring instrumentation (e.g., strain gauges, displacement meters, or transducers) that has been installed on or within the bridge

Importance of Observing Cracks

The most important feature to be observed during the inspection of segmental bridges is the existence and extent of cracking throughout the structure. While small surface cracks in segmental bridges may have little structural significance, major cracking may be caused by the failure of a vital element. Cracks can lead to the corrosion and failure of prestressing tendons.

Destructive Testing

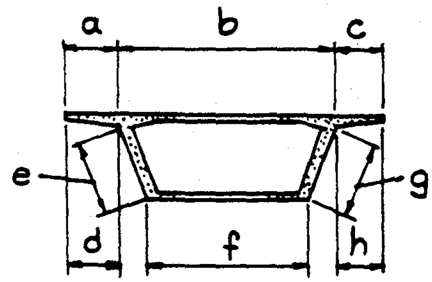
Due to the active nature of the prestressing effect, any destructive testing may seriously alter the structural behavior of a segmental bridge. Therefore, it is important that no cutting or drilling of the concrete box girder be undertaken during the course of the inspection without prior approval of the bridge engineer.

21.4.3 Recordkeeping and Documentation

A set of customized, preprinted forms should be prepared for documenting cracks, spalls, and other defects encountered in the box girder. A suggested format for the forms is presented in Figure 21-19. Designations used to identify the plan surfaces, together with segment numbers, provide a methodology for locating the defects in the superstructure.

The maps of cracking must be prepared with care, since they should provide the bridge engineer with sufficient information upon which to base a study of the causes and effects of the cracking. The inspection report must describe all narrow, medium, and wide cracks in the concrete with respect to their location, orientation, width, and length. Any variation in width due to temperature change, temperature differential, or external load should be noted, and large cracks should be physically marked for future measurement and comparison.

In recording spalling, it is important to note the exact location, size, shape, and depth, as well as whether any reinforcement or prestressing duct is exposed. If possible, a sample of the displaced concrete should be submitted to the bridge engineer for evaluation.



SURFACE INDEX / SEGMENT NO.	a	b	c	d	e	f	g	h
1								
2								
3								
4								
5								
6								
7								
8								
9								
10								
11								

PLAN (columns a–c) REFLECTED PLAN (columns d–h)

Figure 21-19 Form for Recording Cracks and Spalls in a Box Girder

Appendices

Appendix A

National Bridge Inspection Standards

CODE OF FEDERAL REGULATIONS

23 HIGHWAYS PART 650
Subpart C - National Bridge Inspection Standards

§650.301 Application of standards.

The National Bridge Inspection Standards (NBIS) in this part apply to all structures defined as bridges located on all public roads. In accordance with the *AASHTO* (American Association of State Highway and Transportation Officials) *Transportation Glossary*, a "bridge" is defined as a structure including supports erected over a depression or an obstruction, such as water, highway, or railway, and having a track or passageway for carrying traffic or other moving loads, and having an opening measured along the center of the roadway of more than 20 feet between undercopings of abutments or spring lines of arches, or extreme ends of openings for multiple boxes; it may also include multiple pipes, where the clear distance between openings is less than half of the smaller contiguous opening.

§650.303 Inspection procedures.

(a) Each highway department shall include a bridge inspection organization capable of performing inspections, preparing reports, and determining ratings in accordance with the provisions of the *AASHTO Manual*[1] and the Standards contained herein.

---

[1]*The AASHTO Manual referred to in this part is the Manual for Maintenance Inspection of Bridges 1983 together with subsequent interim changes or the most recent version of the AASHTO Manual published by the American Association of State Highway and Transportation Officials. A copy of the Manual may be examined during normal business hours at the office of each Division Administrator of the Federal Highway Administration, at the office of each Regional Federal Highway Administrator, and at the Washington Headquarters of the Federal Highway Administration. The addresses of those document inspection facilities are set forth in Appendix D to Part 7 of the regulations of the Office of the Secretary (40 CFR Part 7). In addition, a copy of the Manual may be secured upon payment in advance by writing to the American Association of State Highway and Transportation Officials, 444 N. Capitol Street, N.W., Suite 225, Washington, D.C. 20001.*

(b) Bridge inspectors shall meet the minimum qualifications stated in §650.307.

(c) Each structure required to be inspected under the Standards shall be rated as to its safe load carrying capacity in accordance with Section 4 of the *AASHTO Manual.* If it is determined under this rating procedure that the maximum legal load under State law exceeds the load permitted under the Operating Rating, the bridge must be posted in conformity with the *AASHTO Manual* or in accordance with State law.

(d) Inspection records and bridge inventories shall be prepared and maintained in accordance with the Standards.

(e) The individual in charge of the organizational unit that has been delegated the responsibilities for bridge inspection, reporting and inventory shall determine and designate on the individual inspection and inventory records and maintain a master list of the following:

(1) Those bridges which contain fracture critical members, the location and description of such members on the bridge and the inspection frequency and procedures for inspection of such members. (Fracture critical members are tension members of a bridge whose failure will probably cause a portion of or the entire bridge to collapse.)

(2) Those bridges with underwater members which cannot be visually evaluated during periods of low flow or examined by feel for condition, integrity and safe load capacity due to excessive water depth or turbidity. These members shall be described, the inspection frequency stated, not to exceed five years, and the inspection procedure specified.

(3) Those bridges which contain unique or special features requiring additional attention during inspection to ensure the safety of such bridges and the inspection frequency and procedure for inspection of each such feature.

(4) The date of last inspection of the features designated in paragraphs (e)(1) through (e)(3) of this section and a description of the findings and follow-up actions, if necessary, resulting from the most recent inspection of fracture critical details, underwater members or special features of each so designated bridge.

§650.305 Frequency of inspections.

(a) Each bridge is to be inspected at regular intervals not to exceed 2 years in accordance with Section 2.3 of the *AASHTO Manual.*

(b) Certain types or groups of bridges will require inspection at less than 2-year intervals. The depth and frequency to which bridges are to be inspected will depend on such factors as age, traffic characteristics, state of maintenance, and known deficiencies. The evaluation of these factors will be the responsibility of the individual in charge of the inspection program.

(c) The maximum inspection interval may be increased for certain types or groups of bridges where past inspection reports and favorable experience and analysis justifies the increased interval of inspection. If a State proposes to inspect some bridges at greater than the specified 2-year interval, the State shall submit a detailed proposal and supporting data to the Federal Highway Administrator for approval.

§650.307 Qualifications of personnel.

(a) The individual in charge of the organizational unit that has been delegated the responsibilities for bridge inspection, reporting, and inventory shall possess the following minimum qualifications:

(1) Be a registered professional engineer; or

(2) Be qualified for registration as a professional engineer under the laws of the State; or

(3) Have a minimum of 10 years experience in bridge inspection assignments in a responsible capacity and have completed a comprehensive training course based on the *Bridge Inspector's Training Manual*[2], which has been developed by a joint Federal State task force, and subsequent additions to the manual.[3]

---

[2]*The Bridge Inspector's Training Manual may be purchased from the Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402.*

---

[3]*The following publications are supplements to the Bridge Inspector's Training Manual: Bridge Inspector's Manual for Movable Bridges, 1977, GPO Stock No. 050-002-00103-5; Culvert Inspector's Training Manual, July 1986, GPO Stock No. 050-001-0030-7; and Inspection of Fracture Critical Bridge Members, 1986, GPO Stock No. 050-001-00302-3.*

(b) An individual in charge of a bridge inspection team shall possess the following minimum qualifications:

(1) Have the qualifications specified in paragraph (a) of this section; or

(2) Have a minimum of 5 years experience in bridge inspection assignments in a responsible capacity and have completed a comprehensive training course based on the *Bridge Inspector's Training Manual,* which has been developed by a joint Federal State task force.

(3) Current certification as a Level III or IV Bridge Safety Inspector under the National Society of Professional Engineer's program for National Certification in Engineering Technologies (NICET)[4] is an alternative acceptable means for establishing that a bridge inspection team leader is qualified.

§650.309 Inspection report.

The findings and results of bridge inspections shall be recorded on standard forms. The data required to complete the forms and the functions which must be performed to compile the data are contained in Section 3 of the *AASHTO Manual.*

§650.311 Inventory.

(a) Each State shall prepare and maintain an inventory of all bridge structures subject to the Standards. Under these Standards, certain structure inventory and appraisal data must be collected and retained within the various departments of the State organization for collection by the Federal Highway Administration as needed. A tabulation of this data is contained in the structure inventory and appraisal sheet distributed by the Federal Highway Administration as part of the *Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges* (*Coding Guide*) in January of 1979. Reporting procedures have been developed by the Federal Highway Administration.

---

[4]*For information on NICET program certification contact: National Institute for Certification in Engineering Technologies, 1420 King Street, Alexandria, Virginia 22314. Phone (703) 684-2835.*

(b) Newly completed structures, modification of existing structures which would alter previously recorded data on the inventory forms or placement of load restriction signs on the approaches to or at the structure itself shall be entered in the State's inspection reports and the computer inventory file as promptly as practical, but no later than 90 days after the change in the status of the structure for bridges directly under the State's jurisdiction and no later than 180 days after the change in status of the structure for all other bridges on public roads within the State.

Effective date October 25, 1988.

Appendix B

Sample
Bridge Inspection Report

PINE CREEK BRIDGE

(Bridge No. 123)

Main Street Over Pine Creek
City, County, State

for

Operating Agency

January, 1991

TABLE OF CONTENTS

Preceding page blank

1. INTRODUCTION

Pine Creek Bridge (Bridge No. 123) is located in City, County, State and carries Main Street over Pine Creek. The structure was inspected on November 2, 1990 and is in fair condition. The weather was sunny, and the temperature was 45°F.

2. BRIDGE DESCRIPTION AND HISTORY

The structure is a two-lane, single-span, steel through girder bridge with a span length of 61 feet (see Photo No. 1). The total out-to-out width of the bridge is 25.7 feet. The skew angle between the stream and bridge centerlines is 72 degrees. The structure consists of a 2-inch asphalt wearing surface on a 12-inch concrete deck, supported by steel floorbeams (18W86) and girders (36W230). The bridge has a 6.3 foot wide sidewalk with a pedestrian railing located on the upstream side of the structure. The stone masonry abutments have concrete caps, and there is a concrete apron around the base of the east abutment. The bridge is currently posted for 22 tons for single vehicles and 36 tons for combination vehicles. The bridge was built in 1919 and rehabilitated in 1975 (superstructure and deck replacement and abutment repairs). The previous inspection was performed on October 7, 1988.

3. INSPECTION PROCEDURES

The field inspection included a complete visual inspection by one professional engineer and one bridge inspector of all bridge components above ground and water level. Hammers, probing rods, and tape measures were used. An inspection form was completed, and photographs were taken to record measurements and deficiencies (see Appendix).

4. INSPECTION RESULTS

<u>Approach Roadway</u>:

The approach roadway is constructed of bituminous pavement which is in good condition (see Photo No. 2). It appears to have been recently resealed. There is standard guardrail on both sides of the east approach, but there is no rigid connection or transition to the bridge rail. A blunt barrier of concrete and a deficient post and cable guardrail are present at the west approach.

The horizontal curved approach alignment requires a minor reduction in speed. A railroad crossing is located adjacent to the bridge at the west approach. A sharp horizontal curve which limits sight distance follows this railroad crossing. The railroad tracks cross at grade.

<u>Deck</u>:

The concrete deck is covered by an asphalt wearing surface that is in good condition. The stay-in-place forms that prevent an inspection of the deck underside are typically in good condition. The condition of the deck is assumed unchanged since the previous inspection. The concrete curbs were poured integral with the girder top flange and are in good condition (see Photo No. 3). The north bridge rail consists of aluminum posts while the south rail consists of guardrail posts. The south rail is substandard in size and is oriented such that the weak axis would resist any impact.

Superstructure:

The superstructure is in fair condition. The existing superstructure was replaced in 1975 with a new girder-floorbeam system. The new girders consist of 36 inch rolled members with cover plates welded to the bottom flanges of the girders (see Photo No. 4). The south girder exhibits minor section loss of the web near the bottom flange, generally less than 1/16 inch. The top of the girders extend above the roadway and serve as curbs (see Photo No. 3). There are seven 18W86 rolled floorbeams, and they are in fair condition with minor scaly rust. Random plates have been welded to the tops of the bottom flanges of the floorbeams with no distress detected around the welds. The purpose of these plates is not clear. The expansion bearings show heavy rust with no evidence of movement.

Substructure:

The substructure is in fair condition. The stone masonry abutments were rehabilitated in 1975 by placing concrete caps on the abutments. There is also a concrete apron around the east abutment. The bearing cap on the northeast corner of the east abutment has recently been patched. Since that time, additional spalling has occurred. The northwest corner of the abutment backwall is spalled due to the girder embedment into the wall.

Traffic Safety Features:

The structure has a sidewalk along the north side with a pedestrian railing along the fascia of the bridge. There is no barrier between the traffic and the sidewalk. There should be proper guardrail transitions at both approaches with new guardrail at the west approach.

Channel:

The channel is in fair condition. The stream flow is straight and free of obstructions. The east abutment is in the channel and has been rehabilitated with a concrete apron. An 8 foot diameter (by 1 foot depth) scour hole is present at the northeast abutment corner.

5. CONCLUSIONS

This structure is in fair condition. The scour hole at the east abutment requires attention. Most of the problems with this structure relate to traffic and pedestrian safety. These include inadequate bridge rail, lack of proper approach guardrail and transitions, and inadequate signing.

6. RECOMMENDATIONS

This bridge should remain as presently posted in accordance with the previous inspection report and existing field conditions.

Immediate Repairs:

- Provide channel protection at scour hole at the east abutment.
- Install adequate bridge rail on both sides of the bridge.

- Protect blunt ends on west approach with proper guardrail and transitions.

Programmed Repairs:

- Install barriers along curbs to prevent vehicles from impacting girder top flange.
- Install "Narrow Bridge" signs and advance posting signs at approaches.
- Clean and spot paint girders and floorbeams.

APPENDIX

PHOTO NO. 1
DOWNSTREAM ELEVATION

PHOTO NO. 2
WEST APPROACH

Preceding page blank

PHOTO NO. 3
TOP FLANGE OF NORTH GIRDER

NOTE:
1. *Paint worn away due to vehicle impact.*
2. *Sidewalk poured integral with girder flange prohibiting girder expansion*

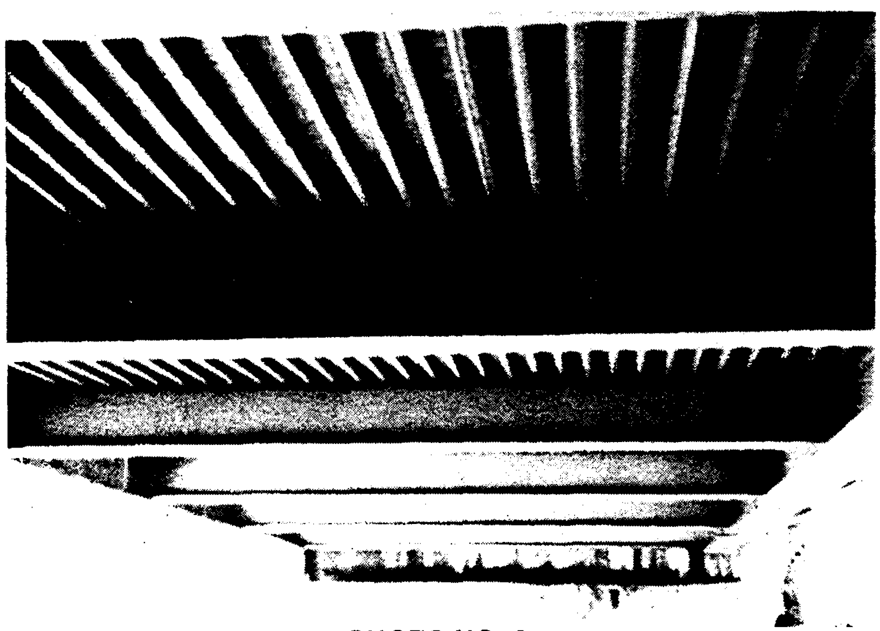
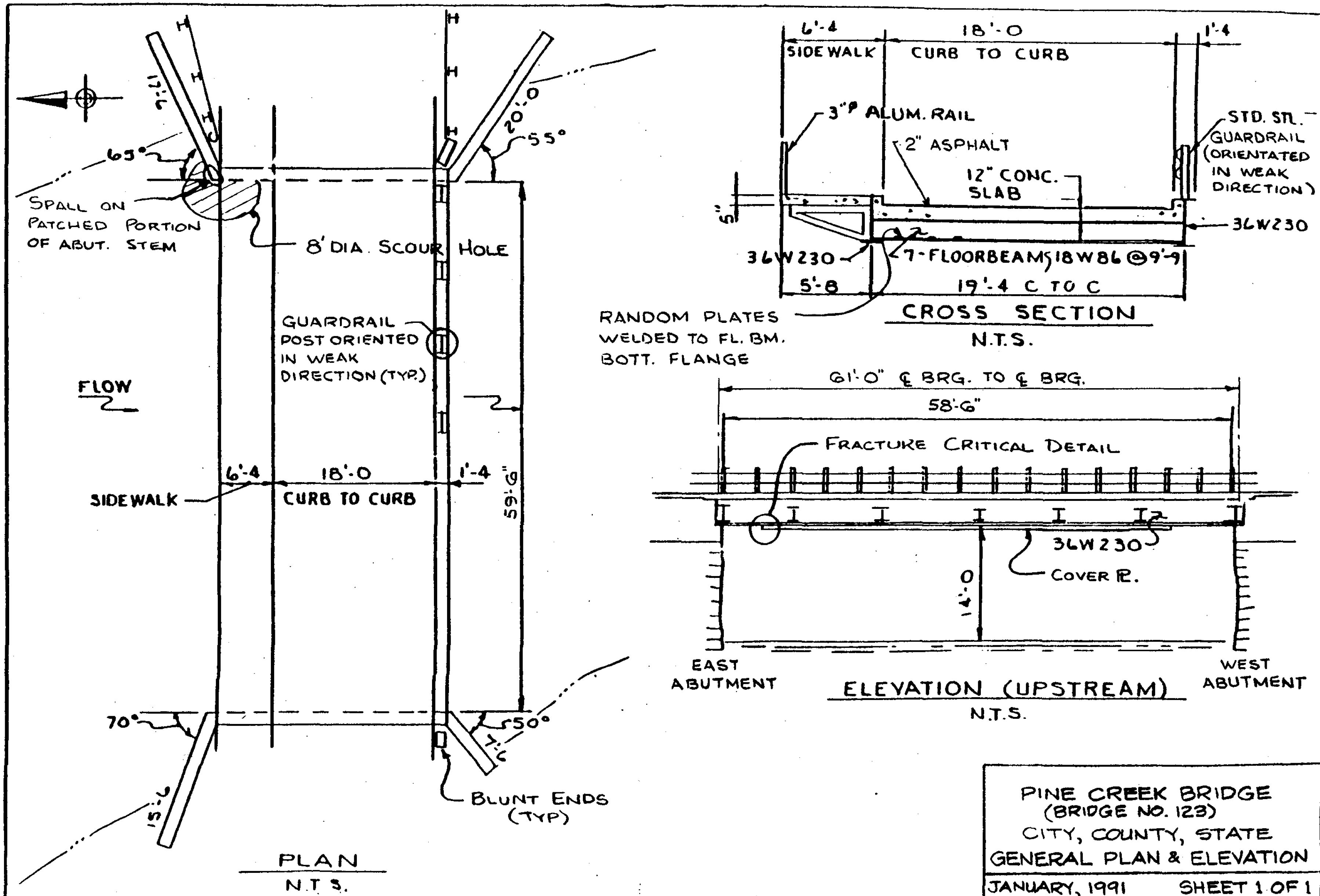


PHOTO NO. 4
GENERAL UNDERSIDE OF BRIDGE

Preceding page blank

Preceding page blank



BRIDGE INSPECTION FORM

Date	11-2-90	Structure Name	PINE CREEK BRIDGE
Temperature	45° F	Structure No.	123
Inspected By	BJB, HRH	Structure Type	STEEL, THROUGH GIRDER
Field Book No.	—	Location	MUNICIPALITY
District	1	Features Intersected	MAIN ST. OVER PINE CREEK
County	COUNTY	ADT/Year	5000 / 1985
Weather	SUNNY	Functional Classification	COLLECTOR

58 OVERALL DECK CONDITION RATING: N 9 8 7 6 5 4 3 2 1 0

Comments: THE ASPHALT WEARING SURFACE PREVENTS VISUAL INSPECTION OF THE TOPSIDE OF DECK. THE STAY-IN-PLACE FORMS PREVENT VISUAL INSPECTION OF UNDERSIDE OF DECK. KEEP RATING SAME AS LAST INSPECTION.

Deck Elements	Rating (Good/Fair/Poor/Not Applicable)				Remarks
Wearing Surface	G	F	P	N/A	
Deck - Topside	G	F	P	N/A	NOT VISIBLE DUE TO W. SURFACE
Deck - Underside	G	F	P	N/A	NOT VISIBLE DUE TO S.I.P. FORMS
SIP Forms	G	F	P	N/A	
Curbs	G	F	P	N/A	INTEGRAL W/TOP FLG. OF GIRDER
Medians	G	F	P	N/A	
Sidewalks	G	F	P	N/A	
Parapets	G	F	P	N/A	
Railing	G	F	P	N/A	WEAK AXIS ORIENTATION
Expansion Joints	G	F	P	N/A	TRANSVERSE CRKS. IN W.S. @ BOTH ABUTS.
Drainage System	G	F	P	N/A	NATURAL - NONE PROVIDED
Lighting	G	F	P	N/A	
Utilities	G	F	P	N/A	
	G	F	P	N/A	
	G	F	P	N/A	

Record Elevations

@ NOT REQUIRED

@

72 APPROACH ROADWAY ALIGNMENT APPRAISAL RATING: N 9 8 7 6 5 4 3 2 1 0

Comments: AT GRADE R.R. CROSSING FOLLOWED BY A SHARP HORIZONTAL CURVE IS LOCATED AT THE WEST APPROACH. THE HORIZONTAL CURVE LIMITS SIGHT DISTANCE.

Approach Elements	Rating				Remarks
Pavement Condition	G	F	P	N/A	
Vertical Alignment (Abut. 1)	G	F	P	N/A	
Horizontal Alignment (Abut. 1)	G	F	P	N/A	LIMITS SIGHT DISTANCE
Vertical Alignment (Abut. 2)	G	F	P	N/A	
Horizontal Alignment (Abut. 2)	G	F	P	N/A	

Speed Limit = 35 MPH

Speed Limit Reduction: None Minor Substantial

Preceding page blank

59 OVERALL SUPERSTRUCTURE CONDITION RATING: N 9 8 7 6 5 4 3 2 1 0

Comments: THE ROLLED STEEL GIRDERS W/ COVER PLATES ARE IN FAIR CONDITION W/ 1/8" PITTING ON LOWER 6" OF DOWNSTREAM GIRDER WEB. THE ROLLED FLOORBEAMS ARE IN FAIR CONDITION. THE FLOORBEAMS HAVE RANDOM STEEL PLATES WELDED TO BOTTOM FLANGES.

Superstructure Elements	Rating				Remarks
Stringers	G	F	P	N/A	
Floorbeams	G	F	P	N/A	NO CRACKS @ WELDED PLATES
Floor System Bracing	G	F	P	N/A	
Multibeams	G	F	P	N/A	
Girders	G	F	P	N/A	1/8" PITTING LOWER 6" OF D.S. GIRDER WEB, FULL LENGTH - OUTSIDE FACE
Trusses - General	G	F	P	N/A	
Upper Chords	G	F	P	N/A	
Web Members	G	F	P	N/A	
Lower Chords	G	F	P	N/A	
Lateral Bracing	G	F	P	N/A	
Sway Bracing	G	F	P	N/A	
Portals	G	F	P	N/A	
Arches	G	F	P	N/A	
Cables	G	F	P	N/A	
Paint	G	F	P	N/A	LOCAL SCALING
Bearing Devices	G	F	P	N/A	ROCKERS HAVE HEAVY RUST
Connections	G	F	P	N/A	
Welds	G	F	P	N/A	
	G	F	P	N/A	
	G	F	P	N/A	
	G	F	P	N/A	

Timber Decay	N/A
Concrete Deterioration	N/A
Steel Corrosion	MINOR SECTION LOSS
Collision Damage	NONE
LL Deflection	MINIMAL
Vibration	MINIMAL
Member Alignment	NO VISIBLE PROBLEMS
Utilities	N/A

60 OVERALL SUBSTRUCTURE CONDITION RATING: N 9 8 7 6 5 4 3 2 1 0

Comments: THE SUBSTRUCTURE IS IN FAIR CONDITION. IT HAS AREAS OF MINOR SPALLING, CRACKING AND DELAMINATION.

Substructure Elements	Rating				Remarks
Abutments	G	F	P	N/A	W. ABUT. - MINOR CRACKS; DELAM; EFFL.
Piles	G	F	P	N/A	NOT EVIDENT
Footing	G	F	P	N/A	NOT VISIBLE
Stem	G	F	P	N/A	MASONRY CAPPED W/ REINF. CONC.
Bearing Seat	G	F	P	N/A	MINOR SPALLS; DELAMINATION
Backwall	G	F	P	N/A	
Wingwalls	G	F	P	N/A	
Piers and Bents	G	F	P	N/A	
Piles	G	F	P	N/A	
Footing	G	F	P	N/A	
Column(s)/Stem	G	F	P	N/A	
Cap	G	F	P	N/A	
	G	F	P	N/A	
	G	F	P	N/A	
	G	F	P	N/A	

Scour/Undermining	1' DEEP x 8' DIA. ADJ. TO NORTH END OF EAST ABUT.
Settlement	NONE
Substructure Protection	N/A
Fender System	N/A
Collision Damage	NONE
High-water Mark	VISIBLE + OR − 1 FT. ABOVE NORMAL POOL
Timber Decay	N/A
Concrete Deterioration	MINOR SPALLS, DELAMINATION & CRACKING
Steel Corrosion	N/A
Paint	N/A

61 OVERALL CHANNEL AND CHANNEL PROTECTION CONDITION RATING: N 9 8 7 6 5 4 3 2 1 0

Comments: STREAM FLOWS AGAINST EAST ABUTMENT

Channel Elements	Remarks
Channel	
Streambed (align., scour, etc.)	4' DEEP x 8' DIA. HOLE ADJ. TO NORTH END OF E. ABUT.
Embankments (vegetation, etc.)	TREES & BRUSH W/ LIGHT EROSION
Streamflow (velocity, etc.)	MODERATE
Drift and Debris	CLEAR

	Rating				Remarks
Channel Protection	G	F	P	N/A	
Riprap	G	F	P	N/A	
Guidebanks or Spur Dikes	G	F	P	N/A	
Gabions	G	F	P	N/A	
Slope Protection	G	F	P	N/A	
Footing Aprons	G	F	P	N/A	LOCATED AROUND E. ABUT.
______	G	F	P	N/A	

71 WATERWAY ADEQUACY APPRAISAL RATING: N 9 8 7 6 5 4 3 2 1 0

Comments: DECK IS ABOVE ROADWAY APPROACHES. OCCASIONAL OVERTOPPING OF ROADWAY APPROACHES WITH INSIGNIFICANT TRAFFIC DELAYS

Waterway Elements	Remarks
Hydraulic Opening	ADEQUATE
Freeboard	
Span	
Floodplain	
Chance of Overtopping	
Remote	
Slight	
Occasional	FLOODED 6 YRS. AGO
Frequent	
Overtopping Traffic Delays	
Insignificant	APPROXIMATELY ONE HOUR
Significant	
Severe	

GEOMETRIC DATA

Structure Dimensions:

No. of Traffic Lanes 2 ; 1-way 2-way
Curb-to-Curb Dimension: 1 8 . 0 feet
Deck Width, Out-to-Out: 2 5 . 7 feet
Curb or Sidewalk Width: 6 . 3 feet
Structure Length: 6 1 . 0 feet
Vertical Overclearance: ___ . ___ inches
Vertical Underclearance: ___ . ___ inches
Lateral Underclearance (Right): ___ . ___ feet
Lateral Underclearance (Left): ___ . ___ feet
N/A

Maintenance Comments: IMMEDIATE - INSTALL ADEQUATE BRIDGE RAIL ON BOTH SIDES, INSTALL GUARDRAIL TRANSITIONS. PROGRAMMED - INSTALL BARRIERS ALONG CURBS, INSTALL "NARROW BRIDGE" SIGNS, CLEAN AND SPOT PAINT GIRDERS AND FLOORBEAMS, REPAIR SCOUR HOLE @ NORTHWEST CORNER AT EAST ABUTMENT.

Bridge Signing:

Speed Limit = ____MPH (SAME AS ROADWAY)
Weight Restrictions = 22 Tons; 36 Tons/Comb.
Narrow Bridge; one truck at a time; paddle boards "NARROW BRIDGE" SIGNS NEEDED
Speed Reduction
Vertical Clearance - Overhead: — Ft. ___ In.; Under: ___Ft. ___In.

36A	BRIDGE RAILING	0	1	N	
36B	TRANSITIONS	0	1	N	
36C	APPROACH GUARDRAIL	0	1	N	
36D	APPROACH GUARDRAIL ENDS	0	1	N	

Comments: NARROW BRIDGE SIGNS NEEDED AT BOTH APPROACHES

Follow-Up Comments:

Underwater Inspection: NOT REQUIRED
Fracture Critical Inspection: 24 MONTH
NDT: NOT REQUIRED
Load Rating: NOT REQUIRED – NO SIGNIFICANT DETERIORATION SINCE LAST RATING
Inspection Frequency: 24 MONTH
Special Equipment: NONE
General:

Additional comments or sketches:

Signature: Beth [illegible]
Harry Holler

Bibliography

<u>*CASE STUDIES*</u>

1. FHWA. *Fatigue Cracking of Steel Bridge Structures, Volume I: A Survey of Localized Cracking in Steel Bridges - 1981 to 1988*. Report No. FHWA-RD-89-166. Washington, D.C.: United States Department of Transportation, 1990.

2. Fisher, J.W. *Fatigue and Fracture in Steel Bridges - Case Studies*. New York: John Wiley and Sons, 1984.

<u>*HANDBOOKS AND SPECIFICATIONS*</u>

3. AASHTO. *Standard Specifications for Highway Bridges*. 14th Edition. Washington, D.C.: American Association of State Highway and Transportation Officials, 1989.

4. Abbett, R.W. *American Civil Engineering Practice*. Volume III. New York: John Wiley and Sons, 1957.

5. AISC. *Iron and Steel Beams 1873 to 1952*. Chicago: American Institute of Steel Construction, 1953.

6. AISC. *Manual of Steel Construction*. 9th Edition. Chicago: American Institute of Steel Construction, 1989.

7. AITC. *Timber Construction Manual*. 3rd Edition. New York: John Wiley and Sons, 1985.

8. Gaylord, E.H., Jr. and C.N. Gaylord, ed. *Structural Engineering Handbook*. 2nd Edition. New York: McGraw-Hill, 1979.

9. McGannon, H.E., ed. *The Making, Shaping and Treating of Steel*. 9th Edition. Pittsburgh, Pennsylvania: United States Steel Corporation, 1971.

10. Merritt, F.S., ed. *Standard Handbook for Civil Engineers*. 2nd Edition. New York: McGraw-Hill, 1976.

11. NFPA. *Design Values for Wood Construction*. Washington, D.C.: National Forest Products Association, 1981.

<u>*HISTORICAL*</u>

12. ASCE. *American Wooden Bridges*. New York: American Society of Civil Engineers, 1976.

13. ASCE. *Repair and Strengthening of Old Steel Truss Bridges.* New York: American Society of Civil Engineers, 1979.

14. Cassady, S. *Spanning the Gate - The Golden Gate Bridge.* Mill Valley, California: Squarebooks, 1986.

15. Fisher, D.A. *Steel Serves the Nation, 1901-1951, The Fifty Year Story of United States Steel.* Pittsburgh, Pennsylvania: United States Steel Corporation, 1951.

16. Jackson, D.C. *Great American Bridges and Dams.* Washington, D.C.: National Trust for Historic Preservation, 1988.

17. Jacobs and Neville. *Bridges, Canals and Tunnels.* New York: Van Nostrand, 1968.

18. Mock, E.B. *The Architecture of Bridges.* New York: The Museum of Modern Art, 1949.

19. Pennsylvania Historical and Museum Commission and the Pennsylvania Department of Transportation. *Historic Highway Bridges in Pennsylvania.* Harrisburg, Pennsylvania: Commonwealth of Pennsylvania, 1986.

20. Plowden, D. *Bridges - The Spans of North America.* New York: W.W. Norton, 1974.

21. Shank, W.H. *Historic Bridges of Pennsylvania.* York, Pennsylvania: American Canal and Transportation Center, 1980.

22. Stackpole, P. *The Bridge Builders - Photographs and Documents of the Raising of the San Francisco Bay Bridge 1934-1936.* Corte Madera, California: Pomegranate Artbooks, 1984.

23. Whitney, C.S. *Bridges - Their Art, Science and Evolution.* New York: Greenwich House, 1983.

INSPECTION

24. AASHTO. *Manual for Maintenance Inspection of Bridges.* Washington, D.C.: American Association of State Highway and Transportation Officials, 1983.

25. Baker, Michael, Jr., Inc. *State-of-the-Art Report - Short Span Timber Bridges.* Beaver, Pennsylvania: Michael Baker, Jr., Inc., 1979.

26. Dickson, B. and H. Gangarao. *Field Monitoring of a Stressed Timber Bridge over Elk Two-Mile Creek, West Virginia.* 6th Annual International Bridge Conference. Pittsburgh, Pennsylvania: Engineers' Society of Western Pennsylvania, 1989.

27. Eslyn, W.E. and J.W. Clark. *Wood Bridges - Decay Inspection and Control.* Agriculture Handbook No. 557. Washington, D.C.: United States Department of Agriculture, 1979.

28. FHWA. *Advanced Bridge Inspection Methods: Applications and Guidelines.* Report No. FHWA-TS-89-017. Washington, D.C.: United States Department of Transportation, 1989.

29. FHWA. *Benchmark for Maine Department of Transportation's A588 Weathering Steel.* Report No. FHWA-ME-90-8. Washington, D.C.: United States Department of Transportation, 1989.

30. FHWA. *Bridge Inspector's Manual for Movable Bridges.* Report No. FHWA-IP-77-10. Washington, D.C.: United States Department of Transportation, 1977.

31. FHWA. *Bridge Inspector's Training Manual 70*. Washington, D.C.: United States Department of Transportation, 1979.

32. FHWA. *Corrosion and Cathodic Protection of Steel Reinforced Concrete Bridge Decks*. Report No. FHWA-IP-88-007. Washington, D.C.: United States Department of Transportation, 1988.

33. FHWA. *Culvert Inspection Manual*. Report No. FHWA-IP-86-2. Washington, D.C.: United States Department of Transportation, 1986.

34. FHWA. *Design, Develop and Fabricate a Prototype Nondestructive Inspection and Monitoring System for Structural Cables and Strands of Suspension Bridges*. Volume 1. Report No. FHWA-RD-89-158. Washington, D.C.: United States Department of Transportation, 1989.

35. FHWA. *Guidelines for Developing Inspection Manuals for Segmental Concrete Bridges*. Report No. FHWA-IP-88-038. Washington, D.C.: United States Department of Transportation, 1988.

36. FHWA. *Inspection of Bridge Timber Piling - Operations and Analysis Manual*. Report No. FHWA-IP-89-017. Washington, D.C.: United States Department of Transportation, 1989.

37. FHWA. *Inspection of Fracture Critical Bridge Members*. Report No. FHWA-IP-86-26. Washington, D.C.: United States Department of Transportation, 1986.

38. FHWA. *Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges*. Report No. FHWA-ED-89-044. Washington, D.C.: United States Department of Transportation, 1988.

39. FHWA. *Underwater Inspection of Bridges*. Report No. FHWA-DP-80-1. Washington, D.C.: United States Department of Transportation, 1989.

40. Fisher, J.W. *Inspecting Steel Bridges for Fatigue Damage*. Harrisburg, Pennsylvania: Commonwealth of Pennsylvania Department of Transportation, 1981.

41. Graham, R.D. and G.G. Helsing. *Wood Pole Maintenance Manual: Inspection and Supplemental Treatment of Douglas-fir and Western Redcedar Poles*. Corvallis, Oregon: Forest Research Laboratory, Oregon State University, 1979.

42. Hoadley, R.B. *Understanding Wood*. Newtown, Connecticut: Taunton Press, 1980.

43. Maeglin, R.R. *Increment Cores - How To Collect, Handle, and Use Them*. General Technical Report FPL 25. Madison, Wisconsin: United States Department of Agriculture, 1979.

44. Naval Facilities Engineering Command. *Inspection of Wood Beams and Trusses*. NAVFAC MO-111.1, 1985.

45. NCHRP. *Legal Implications of Highway Departments' Failure to Comply with Design, Safety, or Maintenance Guidelines*. Research Results Digest No. 129, 1981.

46. NCHRP. *Liability of State Highway Departments for Defects in Design, Construction, and Maintenance of Bridges*. Research Results Digest No. 141, 1983.

47. NCHRP. *Pot Bearings and PTFE Surfaces*. Research Results Digest No. 171, 1989.

48. Park, S.H. *Bridge Inspection and Structural Analysis*. Trenton, New Jersey: S.H. Park, 1980.

49. PennDOT. *Bridge Safety Inspection: Quality Assurance Manual.* 1989 Edition. Harrisburg, Pennsylvania: Commonwealth of Pennsylvania Department of Transportation, 1989.

50. Taylor, R.J. and H. Walsh. *Prototype Prestressed Wood Bridge.* Second Bridge Engineering Conference. TRB 950. Washington, D.C.: National Research Council, 1984.

51. Timber Bridge Information Resource Center. *Crossings.* Issue 1, 1990.

52. TRB. *Bridge Bearings.* NCRP 41. Washington, D.C.: National Research Council, 1977.

53. TRB. *Condition Surveys of Concrete Bridge Components - User's Manual.* NCHRP Report 312. Washington, D.C.: National Research Council, 1988.

54. TRB. *Timber Bridges.* TRB 1053. Washington, D.C.: National Research Council, 1986.

55. U.S. Forest Service. *Timber Bridges - Design, Construction, Inspection, and Maintenance.* Washington, D.C.: United States Department of Agriculture, 1990.

56. U.S. Forest Service. *Wood Bridges - Decay Inspection and Control.* Washington, D.C.: United States Department of Agriculture, 1979.

57. White, K.R., et. al. *Bridge Maintenance Inspection and Evaluation.* New York: Marcel Decker, 1981.

58. Yen, B.T., et. al. *Manual for Inspecting Bridges for Fatigue Damage Conditions.* Harrisburg, Pennsylvania: Commonwealth of Pennsylvania Department of Transportation, 1990.

MATERIALS

59. Derucher, K.N. and G.P. Korfiatis. *Materials for Civil and Highway Engineers.* 2nd Edition. Englewood Cliffs, New Jersey: Prentice Hall, 1988.

60. FHWA. *Forum on Weathering Steel for Highway Structures: Summary Report.* Report No. FHWA-TS-89-016. Washington, D.C.: United States Department of Transportation, 1989.

61. Industrial Fasteners Institute. *The Heritage of Mechanical Fasteners.* Cleveland, Ohio: Industrial Fasteners Institute, 1974.

62. Mantell, C.L., ed. *Engineering Materials Handbook.* New York: McGraw-Hill, 1958.

63. PCA. *Design and Control of Concrete Mixtures.* Skokie, Illinois: Portland Cement Association, 1979.

MECHANICS

64. Beer, F.P. and E.R. Johnston, Jr. *Mechanics of Materials.* New York: McGraw-Hill, 1981.

65. Hool, G.A., W.S. Kinne, et. al. *Structural Members and Connections.* New York: McGraw-Hill, 1923.

66. Kurtz, M. *Structural Engineering for Professional Engineers' Examinations.* 3rd Edition. New York: McGraw-Hill, 1978.

67. Merriman, M. *Mechanics of Materials*. New York: John Wiley and Sons, 1912.

68. Merritt, F.S., ed. *Structural Steel Designers' Handbook*. New York: McGraw-Hill, 1972.

69. Popov, E.P. *Mechanics of Materials*. 2nd Edition. Englewood Cliffs, New Jersey: Prentice-Hall, 1976.

STRUCTURAL ANALYSIS AND DESIGN

70. Beedle, L., et. al. *Structural Steel Design*. New York: Ronald, 1964.

71. Blodgett, O.W. *Design of Welded Structures*. Cleveland, Ohio: The James F. Lincoln Arc Welding Foundation, 1966.

72. Brockenbrough, R.L. and B.G. Johnston. *Steel Design Manual*. Pittsburgh, Pennsylvania: United States Steel Corporation, 1974.

73. FHWA. *Cable-Stayed Bridges*. Washington, D.C.: United States Department of Transportation, 1978.

74. FHWA. *Fatigue Cracking of Steel Bridge Structures, Volume II: A Commentary and Guide for Design, Evaluation, and Investigation of Cracking*. Report No. FHWA-RD-89-167. Washington, D.C.: United States Department of Transportation, 1990.

75. FHWA. *Fatigue Cracking of Steel Bridge Structures, Volume III: Executive Summary*. Report No. FHWA-RD-89-168. Washington, D.C.: United States Department of Transportation, 1990.

76. Fisher, J.W. and J.H.A. Struik. *Guide to Design Criteria for Bolted and Riveted Joints*.. New York: John Wiley and Sons, 1974.

77. Gimsing, N.J. *Cable Supported Bridges: Concept and Design*. New York: John Wiley and Sons, 1983.

78. Gurfinkel, G. *Wood Engineering*. New Orleans: Southern Forest Products Association, 1973.

79. Heins, C.P. and D.A. Firmage. *Design of Modern Steel Highway Bridges*. New York: John Wiley and Sons, 1979.

80. Hool, G.A., W.S. Kinne, et. al. *Movable and Long-Span Steel Bridges*. New York: McGraw-Hill, 1923.

81. McCormac, J.C. *Structural Steel Design*. 2nd Edition. New York: Harper and Row, 1971.

82. Podolny, W., Jr. and J.B. Scalzi. *Construction and Design of Cable-Stayed Bridges*. 2nd Edition. New York: John Wiley and Sons, 1986.

83. Troitsky, M.S. *Cable-Stayed Bridges: An Approach to Modern Bridge Design*. 2nd Edition. New York: Van Nostrand Reinhold, 1988.

84. White, R.N., P. Gergely and R.G. Sexsmith. *Structural Engineering*. Volumes 1-3. New York: John Wiley and Sons, 1976.

WATERWAYS

85. FHWA. *Countermeasures for Hydraulic Problems at Bridges, Final Report.* Volumes 1 and 2. Report No. FHWA-RD-78-162. Washington, D.C.: United States Department of Transportation, 1978.

86. FHWA. *Highways in the River Environment.* Revision. Washington, D.C.: United States Department of Transportation, 1988.

87. FHWA. *Methods for Assessment of Stream Related Hazards to Highways and Bridges.* Report No. FHWA-RD-80-160. Washington, D.C.: United States Department of Transportation, 1981.

88. New York State Department of Transportation. *Bridge Inspection Manual 82.* Bridge Inventory and Inspection System. Albany, New York: New York State Department of Transportation, 1982.

Glossary

A

abrasion - wearing or grinding away of material by water laden with sand, gravel, or stones

abutment - a substructure supporting the end of a single span or the extreme end of a multispan superstructure and, in general, retaining or supporting the approach embankment

aggredation - general and progressive raising of the streambed by deposition of sediment

aggregate - the sand, gravel, or broken stone with which a cementing material is mixed to form a mortar or concrete

alignment - the relative horizontal and vertical positioning between the bridge and approaches

alloy - a mixture of two or more metals to form a new base metal

anchorage - the complete assemblage of members and parts, designed to hold in correct position a portion or part of a structure

anchor bolt - a shaft-like piece of metal commonly threaded and fitted with a nut and washer at one end only, used to secure in a fixed position upon the substructure the bearings of a bridge, the base of a column, a pedestal, shoe, or other member of a structure

anchor span - the span which counterbalances and holds in equilibrium the fully cantilevered portion of an adjacent span; see CANTILEVER BEAM, GIRDER, or TRUSS

angle - a basic member shaped like an L, usually made of steel

anisotropy - the property of some materials, such as wood, exhibiting different strengths in different directions

anode - the positively charged pole of a corrosion cell at which oxidations occurs

anti-friction bearing - a ball or roller-type bearing; a bearing that does not resist horizontal or frictional loads

appraisal rating - a judgment of a bridge component condition in comparison to current standards

approach slab - a reinforced concrete slab placed on the approach embankment adjacent to and usually resting upon the abutment back wall; the function of the approach slab is to carry wheel loads on the approaches directly to the abutment, thereby eliminating any approach roadway misalignment due to approach embankment settlement

apron - a form of scour protection consisting of timber, concrete, riprap, paving, or other construction placed adjacent to abutments and piers to prevent undermining

arch - a curved structure element primarily in compression, producing at its supports reactions having both vertical and horizontal components

arch barrel - a single arch member that extends the width of the structure

arch rib - the main support element used in open spandrel arch construction; also known as arch ring

armor - a secondary steel member installed to protect a vulnerable part of another member, e.g., steel angles placed over the edges of a joint

asphalt - black surface material made from mineral hydrocarbons containing petroleum; the distinction between asphalt and bitumen is mainly chemical, in that asphalt is for solid surfacing and bitumen is a liquid suitable for coating aggregates

ASTM - American Society for Testing and Materials

axial - in line with the centroid of the area

axle load - the load borne by one axle of a traffic vehicle, a movable bridge, or other motive equipment or device and transmitted through a wheel or wheels

B

back - see EXTRADOS

backfill - material, usually soil used to fill the unoccupied portion of a substructure excavation

backstay - cable or chain attached at the top of a tower and extending to and secured upon the anchorage to resist overturning stresses exerted upon the tower by a suspended span

backwall - the topmost portion of an abutment above the elevation of the bridge seat, functioning primarily as a retaining wall with a live load surcharge; it may serve also as a support for the extreme end of the bridge deck and the approach slab

backwater - the water upstream from an obstruction in which the free surface is elevated above the normal water surface profile

bank - sloped sides of a waterway channel or approach roadway, short for embankment

bascule bridge - a bridge over a waterway with one or two leaves which rotate from a horizontal to a near-vertical position, providing unlimited clear headway

base metal - the surface metal of a steel element to be incorporated in a welded joint; also known as structure metal, parent metal

base plate - a rectangular slab of steel, whether cast, rolled or forged, connected to a column, bearing or other member to transmit and distribute its load to the substructure

batten plate - a plate used in lieu of lacing to tie together the shapes comprising a built-up member

batter - the inclination of a surface in relation to a horizontal or a vertical plane; commonly designated on bridge detail plans as so many feet to one foot; see RAKE

battered pile - a pile driven in an inclined position to resist horizontal forces as well as vertical forces

bay - the area of a bridge floor system between adjacent multibeams or between adjacent floor beams

beam - a linear structural member designed to span from one support to another

bearing - a support element transferring loads from superstructure to substructure while permitting limited movement capability

bearing capacity - the load per unit area which a structural material, rock, or soil can safely carry

bearing failure - a crushing of material under extreme compressive load

bearing pile - a pile which provides support through the tip (or lower end) of the pile

bearing pressure - the bearing load divided by the area to which it is applied

bearing seat - a prepared horizontal surface at or near the top of a substructure unit upon which the bearings are placed

bearing stiffener - a vertical web stiffener at the bearing location

bearing stress - see BEARING PRESSURE

bedding - the soil or backfill material used to support pipe culverts

bed rock - the undisturbed hard rock layer below the surface of the soil

bench mark - an established reference point used to document dimensions, elevations and movement

bending moment - the internal force within a beam which causes a bending effect

bent - a substructure unit made up of two or more column or column-like members connected at their top-most ends by a cap, strut, or other member holding them in their correct positions

berm - the line which defines the location where the top surface of an approach embankment or causeway is intersected by the surface of the side slope

bevelled washer - a wedge-shaped washer used in connections involving members with sloped flange legs, e.g. channels and S-beams

bituminous - a black sticky mixture of hydrocarbons obtained from natural deposits or from distilling petroleum

blanket - a stream bed protection against scour placed adjacent to abutments and piers

bolt - a mechanical fastener with machine threads at one end to receive a nut, and a hexagonal head at the other end

bolster - a block-like member used to support a bearing on top of a pier cap or abutment bridge seat; see PEDESTAL

bond - in reinforced concrete, the grip of the concrete on the reinforcing bars, thereby preventing slippage of the bars

bond stress - a term commonly applied in reinforced concrete construction to the stress developed by the force tending to produce movement or slippage at the interface between the concrete and the reinforcement bars

bowstring truss - a general term applied to a truss of any type having a polygonal arrangement of its top chord members conforming to or nearly conforming to the arrangement required for a parabolic truss

box beam - a hollow structural beam with a square, rectangular, or trapezoidal cross-section

box culvert - a culvert of rectangular or square cross-section

bracing - a system of secondary members that maintain the geometric configuration of primary members

bracket - a projecting support fixed upon two intersecting members to strengthen and provide rigidity to the connection

breastwall - the portion of an abutment between the wings and beneath the bridge seat; the breast wall supports the superstructure loads, and retains the approach fill; see STEM

bridge - a structure spanning and providing passage over a river, chasm, road, or the like

bridge deficiency - a defect in a bridge component or member that makes the bridge less capable or less desirable for use

bridge pad - the raised, leveled area upon which the pedestal, masonry plate or other corresponding element of the superstructure takes bearing by contact; also called bridge seat bearing area

bridge seat - the top surface of an abutment or pier upon which the superstructure span is placed and supported; for an abutment it is the surface forming the support for the superstructure and from which the backwall rises; for a pier it is the entire top surface

bridge site - the selected position or location of a bridge and its surrounding area

bridging - a carpentry term applied to the cross-bracing fastened between timber beams to increase the rigidity of the floor construction, distribute more uniformly the live load and minimize the effects of impact and vibration

brush curb - a narrow curb, 9 inches or less in width, which prevents a vehicle from brushing against the railing or parapet

buckle - to fail by an inelastic change in alignment as a result of compression

built-up member - a column or beam composed of plates and angles or other structural shapes united by bolting, riveting or welding

bulkhead - a retaining wall-like structure commonly composed of driven piles supporting a wall or a barrier of wooden timbers or reinforced concrete members

buoyancy - upward pressure exerted by the fluid in which an object is immersed

buried pipe - a subsurface structure that incorporates both the strength properties of the pipe and the support properties of the soil surrounding the pipe

buttress - a bracket-like wall, of full or partial height, projecting from another wall; the buttress strengthens and stiffens the wall against overturning forces; all parts of a buttress act in compression

buttressed wall - a retaining wall designed with projecting buttresses to provide strength and stability

butt weld - a weld joining two abutting surfaces by combining weld metal and base metal within an intervening space

C

cable - a tension member comprised of numerous individual steel wires twisted and wrapped in such a fashion to form a rope of steel; see SUSPENSION BRIDGE

cable band - a steel casting with clamp bolts which fixes a floor system suspender cable to the catenary cable of a suspension bridge

cable-stayed bridge - a bridge in which the superstructure is directly supported by cables, or stays, passing over or attached to towers located at the main piers

caddisfly - a winged insect closely related to the moth and butterfly whose aquatic larvae seek shelter by digging small shallow holes into submerged timber elements

caisson - a rectangular or cylindrical chamber for keeping water or soft ground from flowing into an excavation

camber - the slightly arched form or convex curvature provided in beams to compensate for dead load deflection, in general, a structure built with perfectly straight lines appears slightly sagged

cantilever - a structural member which has a free end projecting beyond its supporting wall or column; length of span overhanging the support

cantilever abutment - an abutment which resists the lateral thrust of earth pressure through the opposing cantilever action of a vertical stem and horizontal footing

cantilever bridge - a general term applying to a bridge having a superstructure utilizing cantilever design

cantilever span - a superstructure span composed of two cantilever arms, or of a suspended span supported by one or two cantilever arms

cap - the topmost piece of a pier or a pile bent serving to distribute the loads upon the columns or piles and to hold them in their proper relative positions; see PIER CAP, PILE CAP

capstone - the topmost stone of a masonry pillar, column or other structure requiring the use of a single capping element

carbon steel - steel owing its properties principally to its carbon content; ordinary, unalloyed steel

cast-in-place - the act of placing and curing concrete within formwork to construct a concrete element in its final position

cast iron - relatively pure iron, smelted from iron ore, containing 1.8 to 4.5% free carbon and cast to shape

catch basin - a receptacle, commonly box shaped and fitted with a grilled inlet and a pipe outlet drain, designed to collect the rain water and floating debris from the roadway surface and retain the solid material so that it may be periodically removed

catchment area - see DRAINAGE AREA

catenary - the curve obtained by suspending a uniform rope or cable between two points

cathode - the negatively charged pole of a corrosion cell that accepts electrons and does not corrode

cathodic protection - a means of preventing metal from corroding; this is done by making the metal a cathode through the use of impressed direct current and by attaching a sacrificial anode

catwalk - a narrow walkway for access to some part of a structure

cellular abutment - an abutment in which the space between wings, breast wall, approach slab, and footings is hollow. Also known as a vaulted abutment

cement - a powder that hardens when mixed with water; an ingredient used in concrete

cement mortar - a mixture of four parts sand to one part cement with enough water to make it plastic

cement paste - the plastic combination of cement and water that supplies the cementing action in concrete

center of gravity - the point at which the entire mass of a body acts; the balancing point of an object

centroid - that point about which the static moment of all the elements of area is equal to zero

chain drag - a series of short medium weight chains attached to a T-shaped handle; used as a preliminary technique for inspecting a large deck area for delamination

channel - a waterway connecting two bodies of water or containing moving water; a rolled steel member having a C-shaped cross section

channel profile - a cross-section of a channel along its centerline

check - a crack in wood occurring parallel with the grain and through the rings of annual growth

cheek wall - see KNEE WALL

chipping hammer - a welders tool for cleaning slag from steel after welding

chord - a generally horizontal member of a truss

circular arch - an arch in which the intrados surface has a constant radius

clearance - the unobstructed vertical and horizontal space provided between two objects

clear headway - the vertical clearance beneath a bridge structure available for navigational use

clear span - the unobstructed space or distance between support elements of a bridge or bridge member

clip angle - see CONNECTION ANGLE

closed spandrel arch - a stone or reinforced concrete arch span having spandrel walls to retain the spandrel fill or to support either entirely or in part the floor system of the structure when the spandrel is not filled

coarse aggregate - aggregate which stays on a sieve of 5 mm square opening

coating - a material that provides a continuous film over a surface; a film formed by the material

coefficient of thermal expansion - the unit strain produced in a material by a change of one degree in temperature

cofferdam - a temporary dam-like structure constructed around an excavation to exclude water; see SHEET PILE COFFERDAM

cold chisel - a fitter's chisel used for cold-cutting soft metals when struck with a hammer

column - a general term applying to a vertical member resisting compressive stresses and having, in general, a considerable length in comparison with its transverse dimensions

compaction - the process by which a sufficient amount of energy is applied to soil to achieve a specific density

component - a general term reserved to define a bridge deck, superstructure or substructure; subcomponents e.g. floor beams are considered elements

composite action - the contribution of a concrete deck to the moment resisting capacity of the superstructure beams

composite construction - a method of construction where by a concrete deck is mechanically attached to a steel floor system by shear connectors

compression - a type of stress involving pressing together; tends to shorten a member; opposite of tension

compression failure - buckling, crushing, or collapse caused by compression stress

compression flange - the part of a beam which is compressed; due to a bending moment

concentrated load - a force applied over a small contact area; also known as point load

concrete - a mixture of aggregate, water, and a binder, usually portland cement, which hardens to a stone-like mass

concrete beam - a structural member of reinforced concrete

concrete pile - a pile constructed of reinforced concrete either precast and driven into the ground or cast-in-place in a hole bored into the ground

condition rating - a judgment of a bridge component condition in comparison to its original as-built condition

conductor - a metal that is suitable for carrying electric current

connection angle - a piece of angle serving to connect two elements of a member or two members of a structure; also known as clip angle

consolidation - the time dependent change in volume of a soil mass under compressive load caused by pore-water slowly escaping from the pores or voids of the soil

construction joint - a pair of adjacent surfaces in reinforced concrete where concreting was intentionally stopped and continued later

contaminant - a salt or other element not normally present in the atmosphere which may react with the steel to produce corrosion

continuous beam - a general term applied to a beam which spans uninterrupted over one or more intermediate supports

continuous bridge - a bridge designed to extend without joints over one or more interior supports

continuous spans - spans designed to extend without joints over one or more intermediate supports

continuous truss - a truss having its chord and web members arranged to continue uninterrupted over one or more intermediate points of support

continuous weld - a weld extending throughout the entire length of a connection

contraction - the action of drawing together

coping - a course of stone laid with a projection beyond the general surface of the masonry below it and forming the topmost portion of a wall; a course of stone capping the curved or V shaped extremity of a pier, providing a transition to the pier head proper, when so used it is commonly termed the "starling coping," "nose coping," the "cutwater coping" or the "pier extension coping"

corbel - a piece constructed to project from the surface of a wall, column or other portion of a structure to serve as a support for an other member

core - a cylindrical sample of concrete removed from a bridge component for the purpose of destructive testing

corrosion - the general disintegration of surface metal through oxidation

counter - a truss web member which functions only when the span is partially loaded; the dead load of the truss does not stress the counter; see WEB MEMBERS

counterfort - a bracket-like wall projecting from a retaining wall on the side of the retained material to stabilize it against overturning; a counterfort, as opposed to a buttress, acts entirely in tension

counterforted abutment - an abutment which develops resistance to bending moment in the stem by use of counterforts. This permits the breast wall to be designed as a horizontal beam or slab spanning between counterforts, rather than as a vertical cantilever slab

counterforted wall - a retraining wall designed with projecting counterforts to provide strength and stability

counterweight - a weight which is used to balance the weight of a movable member; in bridge applications counterweights are used to balance a movable span so that it rotates or lifts with minimum resistance.

couple - two forces that are equal in magnitude, opposite in direction, and parallel with respect to one another

course - a layer of bricks or stone bedded in mortar

cover - in reinforced concrete, the clear thickness of concrete between a reinforcing bar and the surface of the concrete; the depth of backfill over the top of a pipe

covered bridge - an indefinite term applied to a wooden bridge having its roadway protected by a roof and enclosing sides

cover plate - a plate used in conjunction with flange angles or other structural shapes to provide additional flange section in a beam, column, or similar member

crack - a break without complete separation of parts; a fissure

cracking (reflection) - visible cracks in an overlay indicating cracks in the concrete underneath

crack initiation - the beginning of a crack usually at some submicroscopic defect

crack propagation - the growth of a crack due to energy supplied by repeated stress cycles

creep - an inelastic deformation that increases with time while the stress is constant

creosote - an oily liquid obtained by the distillation of wood tar and used as a wood preservative

crib - a structure consisting of a foundation grillage combined with a superimposed framework providing compartments or coffers which are filled with gravel, concrete or other material satisfactory for supporting the structure to be placed thereon

cribbing - a construction consisting of wooden, metal or reinforced concrete units so assembled as to form an open cellular-like structure for supporting a superimposed load or for resisting horizontal or overturning forces acting against it.

cribwork - large timber cells which are submerged full of concrete to make an underwater foundation

cross bracing - transverse bracings between two main longitudinal members; see DIAPHRAGM, BRACING

cross girders - girders supported by bearings which supply transverse support for longitudinal beams or girders

cross section - the shape of an object cut transversely to its length

cross-sectional area - the area of a cross-section

crown - the highest point along the internal surface of the transverse cross section of a pipe or arch; also known as soffit or vortex

crown of roadway - the vertical dimension describing the total amount the surface is convexed or raised from gutter to centerline; this is sometimes termed the cross fall of roadway

culvert - a drainage structure beneath an embankment

curb - a short barrier paralleling the side limit of the roadway to guide the movement of vehicle wheels and safeguard constructions and pedestrian traffic existing outside the roadway limit from collision with vehicles and their loads

curb inlet - see SCUPPER

curtain wall - a term commonly applied to a thin wall between main supports not designed to withstand superimposed loads either vertically or transversely

curvature - the degree of curving of a line or surface

cutwater - a sharp-edged structure built around a bridge pier to protect if from the flow of water and debris in the water

cyclic stress - the variation in stress at a point from initial dead load value to the maximum additional live load value and hence back to dead load value with passage of live load

D

dead load - a static load due to the weight of the structure itself

debris - any material including floating wood trash, suspended sediment, or bed load, moved by a flowing stream

deck - that portion of a bridge which provides direct support for vehicular and pedestrian traffic

deck bridge - a bridge in which the supporting members are all beneath the roadway

decking - a term specifically applied to bridges having wooden floors and used to designate the flooring only; it does not include the members serving to support the flooring

deficiency - see BRIDGE DEFICIENCY

deflection - elastic movement of a structural member under a load

deformation - distortion of a loaded structural member; includes plastic, non-recoverable movement

deformed bars - concrete reinforcement consisting of steel bars with projections or indentations to increase the mechanical bond between the steel and concrete

degradation - general progressive lowering of the channel stream bed by erosion

delamination - subsurface separation of concrete into layers

design load - the force for which a structure is designed; the worst possible combination of loads

deterioration - decline in quality over a period of time due to chemical or physical action of the environment

diagonal - a sloping structural member of a truss or bracing system

diagonal stay - a cable support in a suspension bridge extending diagonally from the tower to the roadway system to add stiffness to the structure and diminish the deformations and undulations resulting from traffic service

diagonal tension - the principal tensile force due to horizontal and vertical shear in a beam

diaphragm - a member placed within a member or superstructure system to distribute stresses and improve strength and rigidity; see BRACING

diaphragm wall - a wall built transversely to the longitudinal centerline of a spandrel arch serving to tie together and reinforce the spandrel walls, together with providing a support for the floor system in conjunction with the spandrel walls; also known as cross wall

differential settlement - uneven settlement of individual or independent elements of a substructure

dike - an earthen embankment constructed to retain floodwater; when used in conjunction with a bridge, it prevents stream erosion and localized scour and/or so directs the stream current such that debris does not accumulate; also known as dyke; see SPUR DIKE

discharge - the volume of fluid per unit of time flowing along a pipe or channel

displacement induced stress - stresses caused by differential deflection of adjacent parts

distributed load - a load uniformly applied along the length of an element or component of a bridge

ditch - a trough-like excavation made to collect water

diver - a specially trained individual who inspects the underwater portion of a bridge substructure and the surrounding channel

dolphin - a group of piles driven close together and placed to protect portions of a bridge exposed to possible damage by collision with river or marine traffic

double movable bridge - a bridge in which the clear span for navigation is produced by joining the arms of two adjacent swing spans or the leaves of two adjacent bascule spans at or near the center of the navigable channel; see MOVABLE BRIDGE

dowel - a short length of bar embedded in two parts of a structure to hold the parts in place and to transfer stress

drainage - a system designed to remove water from a structure

drainage area - an area in which surface run-off collects and from which it is carried by a drainage system; also known as catchment area

drain hole - hole in a box shaped member or a wall to provide means for the exit of accumulated water or other liquid matter; also known as drip hole; see WEEP HOLE

drain pipes - pipes below the ground that remove rainwater

drawbridge - a general term applied to a bridge over a navigable body of water having a movable superstructure span of any type permitting the channel to be freed of its obstruction to navigation; popular but imprecise term

drift bolt - a short length of metal bar used to connect and hold in position wooden members placed in contact; similar to a dowel

drip notch - a recess cast on the underside of a parapet which prevents water from following the concrete into the supporting beams and causing deterioration of the members

drop inlet - a type of inlet structure which conveys the water from a higher elevation to a lower outlet elevation smoothly without a free fall at the discharge

ductile - capable of being molded or shaped without breaking; plastic

ductile fracture - a fracture characterized by plastic deformation

ductility - the ability to withstand non-elastic deformation without rupture

dumbbell pier - a pier consisting of two cylindrical or rectangular shaped piers joined by a web constructed integral with them

E

E - modulus of elasticity of a material; the stiffness of a material

efflorescence - a white deposit on concrete or brick caused by crystallization of soluble salts brought to the surface by moisture in the masonry or concrete

elastic - capable of sustaining deformation without permanent loss of shape

elastic deformation - non-permanent deformation; when the stress is removed, the material returns to its original shape

elasticity - the property whereby a material changes its shape under the action of loads but recovers its original shape when the loads are removed

elastomer - a natural or synthetic rubber-like material

electrolyte - a medium of air, soil, or liquid carrying ionic current between two metal surfaces, the anode and the cathode

electrolytic cell - a device for producing electrolysis consisting of the electrolyte and the electrodes

electrolytic corrosion - corrosion of a metal associated with the flow of electric current in an electrolyte

elliptic arch - an arch in which the intrados surface is a full half of the surface of an elliptical cylinder; this terminology is sometimes incorrectly applied to a multicentered arch (an elliptic arch is fitted to stone masonry arches)

elongation - the elastic or plastic extension of a member

embankment - a bank of earth constructed above the natural ground surface to carry a road or to prevent water from passing beyond desirable limits; also known as bank

end block - on a prestressed concrete beam, the increase in beam web width at the end to provide adequate anchorage bearing for the post tensioning steel and to resist high cracking stresses

end post - the end compression member of a truss, either vertical or inclined in position and extending from top chord to bottom chord

end section - a concrete or steel appurtenance attached to the end of a culvert for the purpose of hydraulic efficiency and anchorage

end span - a span adjacent to an abutment

epoxy - a synthetic resin which cures or hardens by chemical reaction between components which are mixed together shortly before use

equilibrium - in statics, the condition in which the forces acting upon a body are such that no external effect (or movement) is produced

equivalent uniform load - a load having a constant intensity per unit of its length producing an effect equal to that of a live load consisting of vehicle axle or wheel concentrations spaced at varying distances

erosion - wearing away of soil by flowing water

expansion - an increase in size or volume

expansion bearing - a bearing designed to permit the longitudinal movements resulting from temperature changes and superimposed loads without transmitting a horizontal force to the substructure; see BEARING

expansion dam - the part of an expansion joint serving as an end form for the placing of concrete at a joint; also applied to the expansion joint device itself

expansion joint - a joint designed to provide means for expansion and contraction movements produced by temperature changes, loadings or other forces

expansion rocker - a bearing device at the expansion end of a beam or truss that allows the longitudinal movements resulting from temperature changes and superimposed loads through a rocking motion

expansion roller - a cylinder so mounted that by revolution it facilitates expansion, contraction or other movements resulting from temperature changes, loadings or other forces

expansion shoe - an expansion bearing member or assembly designed to provide means for expansion and contraction; also known as expansion pedestal; in general, the term "shoe" is applied to an assemblage of structural plates permitting movement by sliding while the term "pedestal" is used to describe assemblages of castings or built-up members providing for movement either by sliding or by rolling

exterior girder - an outermost girder supporting the bridge floor

extrados - the curve defining the exterior surface of an arch; also known as back

eyebar - a member consisting of a rectangular bar with enlarged forged ends having holes through them for engaging connecting pins

F

factor of safety - a factor applied to the failure stress assumed to exist in a structure to provide a conservative margin in the strength of a structure compensating for irregularities existing in structural materials and workmanship, uncertainties involved in mathematical analysis and stress distribution, service deterioration and other unevaluated conditions

failure - a condition at which a structure reaches a limit state such as cracking or deflection; usually does not involve fracture since failing structures are deemed unsafe, therefore unusable, before they collapse

falsework - a temporary wooden or metal framework built to support the weight of a structure during the period of its construction and until it becomes self-supporting

fascia - an outside, covering member designed on the basis of architectural effect rather than strength and rigidity although its function may involve both

fascia girder - an exposed outermost girder of a span sometimes treated architecturally or otherwise to provide an attractive appearance

fatigue - the tendency of a member to fail at a lower stress when subjected to cyclical loading than when subjected to static loading

fatigue crack - any crack caused by repeated cycle loading

fatigue damage - member damage (crack formation) due to cyclic loading

fatigue life - the length of service of a member

fender - a structure that acts as a buffer to protect the portions of a bridge exposed to floating debris and water-borne traffic from collision damage; sometimes called an ice guard in regions with ice flaws

fender pier - a pier-like structure which performs the same service as a fender but is generally more substantially built; see GUARD PIER

field coat - a coat of paint applied after the structure is assembled and its joints completely connected; quite commonly a part of the field erection procedure and is termed field painting

fill - material, usually earth, used to change the surface contour of an area, or to construct an embankment

filler - a piece used primarily to fill a space beneath a batten, splice plate, gusset, connection angle, stiffener or other element; also known as filler plate

filler metal - metal prepared in wire, rod, electrode or other adaptable form to be fused with the structure metal in the formation of a weld

filler plate - see FILLER

fillet - a curved portion forming a junction of two surfaces which would otherwise intersect at an angle

fillet weld - a weld of triangular or fillet shaped cross-section between two pieces at right angles

filling - see FILL

fine aggregate - sand or grit for concrete which passes a sieve mesh of 5 mm square

finger dam - expansion joint in which the opening is spanned by meshing steel fingers or teeth

fish belly - a term applied to a girder or a truss having its bottom flange or its bottom chord constructed either haunched or bow-shaped with the convexity downward; see LENTICULAR TRUSS

fixed beam - a beam with a fixed end

fixed bearing - a bearing which does not allow any longitudinal movement; see BEARING

fixed bridge - a bridge having its superstructure spans fixed in position except that provision may be made in their construction for expansion and contraction movements resulting from temperature changes, loadings, or other forces

fixed end - movement is restrained

fixed-ended arch - see VOUSSOIR ARCH

fixed span - a superstructure span having its position practically immovable, as compared to a movable span

flange - the horizontal parts of a rolled I-shaped beam or of a built-up girder extending transversely across the top and bottom of the web

flange angle - an angle used to form a flange element of a built-up girder, column, strut or similar member

floating bridge - see PONTOON BRIDGE

floating foundation - used to describe a soil-supported raft or mat foundation with low bearing pressures; sometimes applied to a "foundation raft" or "foundation grillage"

flood frequency - the average time interval in years in which a flow of a given magnitude will recur

flood plain - area adjacent to a stream or river subject to flooding

floor - see DECK

floorbeam - a horizontal member located transversely to the general bridge alignment

floor system - the complete framework of members supporting the bridge floor and the traffic loading

flow capacity - maximum flow rate that a channel, conduit, or culvert structure is hydraulically capable of carrying

flux - a material which protects the weld from oxidation during the fusion process

footbridge - a bridge designed and constructed to provide means of traverse for pedestrian traffic only; also known as pedestrian bridge

footing - the enlarged, lower portion of a substructure, which distributes the structure load either to the earth or to supporting piles; the most common footing is the concrete slab; footer is a local term for footing

foot wall - see TOE WALL

force - an influence that tends to accelerate a body or to change its movement

forms - the constructions that hold concrete in place while it is hardening; also known as form work, shuttering; see LAGGING, STAY-IN-PLACE FORMS

form work - see FORMS

foundation - the supporting material upon which the substructure portion of a bridge is placed

foundation excavation - the excavation made to accommodate a footing for a structure; also known as foundation pit

foundation failure - failure of a foundation by differential settlement or by shear failure of the soil

foundation grillage - a construction consisting of steel, timber, or concrete members placed in layers; each layer is normal to those above and below it and the members within a layer are generally parallel, producing a crib or grid-like effect. Grillages are usually placed under very heavy concentrated loads

foundation load - the load resulting from traffic, superstructure, substructure, approach embankment, approach causeway, or other incidental load increment imposed upon a given foundation area

foundation pile - see PILE

foundation pit - see FOUNDATION EXCAVATION

foundation seal - a mass of concrete placed underwater within a cofferdam for the base portion of structure to close or seal the cofferdam against incoming water; see TREMIE

fracture critical member - a member in tension or with a tension element whose failure would probably cause a portion of or the entire bridge to collapse

frame - a structure having its parts or members so arranged and secured that the entire assemblage may not be distorted when supporting the loads, forces, and physical pressures considered in its design

framing - the arrangement and manner of joining the component members of a bridge structure to insure a condition wherein each element and member may function in accord with the conditions governing its design

free end - movement is not restrained

friction pile - a pile which provides support through friction resistance along the lateral surface of the pile

friction roller - a roller placed between members intended to facilitate change in their relative positions by reducing the frictional resistance to translation movement

frost heave - the upward movement of and force exerted by soil due to freezing of retained moisture

frost line - the depth to which soil may be frozen

G

gabion - rock filled wire baskets used to retain earth and provide erosion control

galvanic action - electrical current between two unlike metals

galvanize - to coat with zinc

gauge - the distance between parallel lines of rails, rivet holes, etc; a measure of thickness of sheet metal, or wire; also known as gage

girder - a flexural member which is the main or primary support for the structure, and which usually receives loads from floor beams and stringers; any large beam, especially if built up

girder bridge - a bridge whose superstructure consists of two or more girders supporting a separate floor system as differentiated from a multi-beam bridge or a slab bridge

girder span - a span in which the major longitudinal supporting members are girders

grade - the fall or rise per unit horizontal length; see GRADIENT

grade crossing - a term applicable to an intersection of two highways, two railroads or one railroad and one highway at a common grade or elevation; now commonly accepted as meaning the last of these combinations

grade intersection - the location where two roadway slopes meet in profile; to provide an easy transition from one to the other they are connected by a vertical curve and the resulting profile is a sag or a crest

grade separation - roadways crossing each other at different elevations; see OVERPASS, UNDERPASS

gradient - the rate of inclination of the roadway and/or sidewalk surface(s) from horizontal applying to a bridge and its approaches; it is commonly expressed as a percentage relation of horizontal to vertical dimensions

gravity abutment - a heavy abutment which resists horizontal earth pressure through its own dead weight

gravity wall - a retaining which is prevented from overturning its weight alone

grid flooring - a steel floor system comprising a lattice pattern which may or may not be filled with concrete

grillage - a platform-like construction used to insure distribution of loads upon unconsolidated soil material; see FOUNDATION GRILLAGE

groin - a wall built out from a river bank to check scour

grout - a mortar having a sufficient water content to render it a free-flowing mass, used for filling (grouting) the joints in masonry, for fixing anchor bolts and for filling cored spaces where water may accumulate

guard pier - a pier-like structure built to protect the swing span in its open position from collision with passing vessels or other water-borne materials; may be equipped with a rest pier upon which the swing span in its open position may be latched; see FENDER PIER

guardrail - a safety feature element intended to redirect an errant vehicle - away from the approach embankment

guide rail - see GUARDRAIL

gusset - a plate which connects the members of a structure and holds them in correct position at a joint; see SPLICE PLATE, STAY PLATE

gutter - a paved drain commonly constructed in conjunction with the curbs of the roadway

gutter grating - a perforated or barred cover placed upon an inlet to a drain to prevent the entrance of debris

guy - a cable member to hold a structure in a desired position

H

hairline cracks - very small cracks that form in the surface of concrete due to tension caused by loading

hammer - hand tool used for pounding and surface inspection

hammerhead pier - a pier with a single cylindrical or rectangular shaft and a relatively long, transverse cap; also known as a tee pier

hand hole - holes provided in cover plates of built-up box sections to permit access to the interior for maintenance and construction purposes

hand rail - commonly applies only to sidewalk railing presenting a latticed, barred, balustered or other open web construction

hands-on access - close enough to the member or component so that it can be touched with the hands

hanger - a tension member serving to suspend an attached member

haunch - an increase in the depth of a member usually at points of support; the outside areas of a pipe between the spring line and the bottom of the pipe

H-beam - a rolled steel member having an H-shaped cross section and commonly used for piling; also H-pile

head - a measure of water pressure expressed in terms of an equivalent weight or pressure exerted by a column of water; the height of the equivalent column of water is the head

headloss - the loss of energy between two points along the path of a flowing fluid due to fluid friction reported in feet of head

headwall - a concrete structure at the ends of a culvert to protect the embankment slopes, anchor the culvert, and prevent undercutting

headwater - the source or the upstream waters of a stream

heat treatment - any of a number of various operations involving heating and cooling that are used to impart specific properties to metals; examples are tempering, quenching, annealing, etc.

helical - having the form of a spiral

high carbon steel - carbon steel containing 0.5 to 1.5% dissolved carbon

high strength bolt - bolt and nut made of high strength steel, usually A325 or stronger

hinge - a point in a structure at which a member is free to rotate

hinged joint - a joint constructed with a pin, cylinder segment, spherical segment or other device permitting movement by rotation

hip joint - the juncture of the inclined end post with the end top chord member of a truss; also known as the hip truss

hip vertical - the vertically placed tension member engaging the hip joint of a truss and supporting the first panel floor beam in a through truss span, or instead, only the bottom chord in a deck truss span

honeycomb - an area in concrete with a lack of mortar to fill in the spaces between the coarse aggregate

horizontal cracks - cracks which are parallel to the longitudinal axis of the member and thus parallel to the primary stress

horizontal curve - a curve in the plan location defining the alignment

Howe truss - a truss of the parallel chord type with a web system composed of vertical (tension) rods at the panel points with an X pattern of diagonals

hydraulics - the mechanics of fluids, primarily water

hydrology - the science of water related to its properties and distribution in the atmosphere, on the land surface, and beneath the surface of the land

hydroplaning - loss of contact between a tire and the deck surface when the tire planes or glides on a film of water covering the deck

I

I-beam - a structural member with a cross-sectional shape similar to the capital letter "I"

ice guard - see FENDER

impact - amplification effect on live load due to dynamic and vibratory effects of a moving load

incomplete fusion - a weld flaw where the weld metal has not combined metallurgically with the base metal

indeterminate stress - a stress induced by the use of a redundant member in a truss or an additional reaction in a beam rendering stress distributions unable to be determined by the principles of statics

inelastic compression - compression beyond the yield point

inlet - an opening in the floor of a bridge leading to a drain

inspection frequency - the frequency with which the bridge is inspected - normally every two years

inspection ladders - special devices or appliances designed to afford a safe and efficient means for making inspections and tests to determine the physical condition of a structure and to facilitate repair operations incident to its maintenance; to prevent displacement they will be, in general, rigidly fixed upon the structure; however, certain types of structures are adapted to the use of movable platform devices for suspension from the railings or other parts which are or may be adapted thereto

integral abutment - an abutment cast monolithically with the end diaphragm of the deck; such abutments usually encase the ends of the deck beams and are pile supported

integral deck - a deck which is design to share with the superstructure, the load carrying capabilities of the bridge and not merely to transfer loads to the superstructure

intercepting ditch - a ditch constructed to prevent surface water from flowing in contact with the toe of an embankment or causeway or down the slope of a cut

interior girder - an innermost girder supporting the bridge floor

interior span - a span of which both supports are intermediate substructure units

intermittent weld - a noncontinuous weld commonly composed of a series of short welds separated by spaces of equal length

intrados - the curve defining the interior surface of the arch; also known as soffit

inventory item - data contained in the structure file pertaining to bridge identification, structure type and material, age and service, geometric data, navigational data, classification, load rating and posting, proposed improvements, and inspections

invert - the bottom or lowest point of the internal surface of the transverse cross section of a pipe

iron - a metallic element used in cast or wrought iron and steel

isotropic - have the same material properties in all directions, e.g., steel

J

jack arch - a deck support system comprised of a brick or concrete arch springing from the bottom flanges of adjacent rolled steel beams

jack stringer - the outermost stringer supporting the bridge floor in a panel or bay

jacket - a protective lining surrounding a pile

joint - in stone masonry, the space between individual stones; in concrete, a division in continuity of the concrete; in a truss, point at which members of a truss frame are joined

K

keystone - the symmetrically shaped, wedge-like stone located in a head ring course at the crown of the arch; the final stone placed, thereby closing the arch

king-post - the post member in a "king-post" type truss; also known as king rod

king-post truss - two triangular panels with a common center vertical; the simplest of triangular system trusses

kip - a kilopound (1000 lb.); convenient unit for structural calculations

knee brace - a short member engaging at its ends two other members which are joined to form a right angle or a near-right angle to strengthen and stiffen the connecting joint

knee wall - a return of the abutment backwall at its ends to enclose the bridge seat on three of its sides; also called cheek wall

knife edge - a condition in which corrosion of a steel member has caused a sharp edge

knuckle - an appliance forming a part of the anchorage of a suspension bridge main suspension member permitting movement of the anchorage chain

K-truss - a truss having a web system wherein the diagonal members intersect the vertical members at or near the mid-height; the assembly in each panel forms a letter "K"

L

L-abutment - a cantilever abutment with the stem flush with the toe of the footing, forming an L in cross section

laced column - a column built up from several members with lacing

lacing - small flat plates used to connect individual sections of built up members; see LATTICE

lagging - forms used to produce curved surfaces; see FORMS

lamellar tear - incipient cracking between the layers of the base material (steel)

laminated timber - small timber planks glued together to form a larger member

lap joint - a joint between two members in which the end of one member overlaps the end of the other

lateral bracing - the bracing assemblage engaging a member perpendicular to the plane of the member; intended to resist lateral movement and deformation; also provides resistance against raking of primary parallel elements in truss bridges and girder bridges; see BRACING

lattice - a crisscross assemblage of diagonal bars, channels, or angles on a truss; also known as latticing, lacing

lattice truss - in general, a truss having its web members inclined but more commonly the term is applied to a truss having two or more web systems composed entirely of diagonal members at any interval and crossing each other without reference to vertical members

leaching - the action of removing substances from a material by passing water through it

lead line - a weighted cord incrementally marked, used to determine the depth of a body of water; also known as sounding line

leaf - the movable portion of a bascule bridge which forms the span of the structure

lenticular truss - a truss having parabolic top and bottom chords curved in opposite directions with their ends meeting at a common joint; also known as a fish belly truss

levee - an embankment built to prevent flooding of low-lying land

light-weight concrete - no-fines concrete, aerated concrete, or concrete made of lightweight aggregate

link - a hanger plate in a pin and hanger assembly whose shape is similar to an eyebar, i.e., the head (at the pinhole) is wider than the shank

link and roller - an adjustable device or assemblage consisting of a hinged strut-like link fitted with a roller at its bottom end, supported upon a shoe plate or pedestal and operated by a thrust strut serving to force it into a vertical position and to withdraw it therefrom; when installed at each outermost end of the girders or the trusses of a swing span their major function is to lift them to an extent that their camber or droop will be removed and the arms rendered free to act as simple spans; when the links are withdrawn to an inclined position fixed by the operating mechanism the span is free to be moved to an open position

live load - a dynamic load such as vehicular traffic that is applied to a structure suddenly; also accompanied by vibration or movement affecting its intensity

load - the weight carried by a structure

load indicating bolt - a bolt whose head carries small projections on its underside, which compress as the bolt is tightened; gives a direct indication of the bolt tension that has been achieved

load rating - an office exercise to determine the ability of a bridge to carry load based on the conditions reported by an inspector

longitudinal bracing - bracing that runs lengthwise with a bridge and provides resistance against longitudinal movement and deformation of transverse members

loss of prestress - loss of prestressing force due to shrinkage and creep of the concrete or creep of the prestressing tendon and loss of bond

low-carbon steel - steel with 0.04 to 0.25% dissolved carbon; also called mild steel

lower chord - the bottom horizontal member of a truss

M

macadam - uniformly sized stones rolled to form a road

main beam - a beam which supports the span and bears directly on to a column or wall

marine borers - mollusks and crustaceans which live in water and destroy wood by digesting it

masonry - that portion of a structure composed of stone, brick or concrete block placed in layers and in some cases cemented with mortar

masonry cement - a cement, usually Portland, that hardens slowly and holds water well

masonry plate - a steel plate attached to the substructure to support a superstructure bearing and to distribute the load to the masonry beneath

mattress - a mat-like protective covering composed of brush and poles compacted by wire and placed upon river beds and banks to prevent erosion and scour by stream flow

meander - a twisting, winding action from side to side; characterizes the serpentine curvature of a narrow, slow flowing stream in a wide flood plain

median - a strip of land between opposing lanes of highway traffic; also known as median strip

member - an individual angle, beam, plate, or built piece intended ultimately to become an integral part of an assembled frame or structure

metal corrosion - an electrical process involving an electrolyte (moisture), an anode (the metallic surface where oxidation occurs), a cathode (the metallic surface that accepts electrons and does not corrode), and a conductor (the metal piece itself)

midspan - a general reference point halfway between the supports of a beam or span

mild steel - steel containing from 0.15 to 0.25% carbon

mill scale - black iron oxide on iron or steel which has been forged or hot worked

moisture content - the amount of water in a soil mass expressed as a percent by weight

moment - the couple effect of forces about a given point; see BENDING MOMENT

monolithic - forming a single mass without joints

mortar - a paste of cement, sand, and water laid between bricks, stones or blocks

movable bridge - a bridge having one or more spans capable of being raised, turned, lifted, or slid from its normal service location to provide for the passage of navigation; see BASCULE BRIDGE, VERTICAL LIFT BRIDGE, PONTOON BRIDGE, RETRACTILE DRAW BRIDGE, ROLLING LIFT BRIDGE, and SWING BRIDGE

movable span - a general term applied to a superstructure span designed to be swung, lifted or otherwise moved longitudinally, horizontally or vertically

moving load - a live load which is moving, for example, vehicular traffic

multi-centered arch - an arch in which the intrados surface is outlined by two or more arcs symmetrically arranged and having different radii which intersect tangentially

N

NBIS - National Bridge Inspection Standards, first established in 1971 to set national policy regarding bridge inspection frequency, inspector qualifications, report formats, and inspection and rating procedures

NDT - nondestructive testing, a method of checking the structural quality of materials that does not damage them

necking - the elongation and contraction in area which occurs when a ductile metal fails in tension

negative bending - bending of a member characterized by the downward curvature of the member ends

negative moment - bending moment in a member such that tension stresses are produced in the top portions of the member; typically occurs in continuous beams and spans over the intermediate supports

neutral axis - the internal axis of a member in bending along which the strain is zero; on one side of the neutral axis the fibers are in tension, on the other side the fibers are in compression

nose - a projection acting as a cut water on the upstream end of a pier; see STARLING

notch effect - stress concentration caused by an abrupt discontinuity or change in section

O

offset - a horizontal distance measured at right angles to a survey line to locate a point off the line

on center - a description of a typical dimension between the centers of the objects being measured

open spandrel arch - a bridge which has open spaces between the deck and the arch members allowing "open" visibility through the bridge

open spandrel ribbed arch - a structure in which two or more comparatively narrow arch rings, called ribs, function in the place of an arch barrel; the ribs are rigidly secured in position by arch rib struts located at intervals along the length of the arch; the arch ribs carry a column type open spandrel construction which supports the floor system and its loads

operator's house - the building containing the power plant and operating machinery and devices required for the operator's (bridge tender's) work in executing the complete cycle of opening and closing a movable bridge span

orthotropic - a description of the physical properties of a material that has pronounced differences in two or more directions at right angles to each other; see ANISOTROPY

outlet - in hydraulics, the discharge end of drains, sewers, or culverts

out-of-plane distortion - distortion of a member in a plane other than that which the member was designed to resist

overload - a weight greater than the structure is designed to carry

overpass - the uppermost feature in a grade separated crossing

overturning - tipping over, rotational movement

oxidation - the chemical breakdown of a substance due to its reaction with oxygen from the air

oxidized steel - rust

P

pack - a steel plate inserted between two others to fill a gap and fit them tightly together; also known as packing

pack rust - rust forming in a restricted place that tends to "pack" itself into a tight fit as the oxide increases the thickness of the parts

paddleboard - striped, paddle-shaped signs or boards placed on the roadside in front of a narrow bridge as a warning of reduced roadway width

panel - the portion of a truss span between adjacent points of intersection of web and chord members

panel point - the point of intersection of primary web and chord members of a truss

parabolic arch - an arch in which the intrados surface is a segment of a symmetrical parabolic surface (suited to concrete arches)

parabolic truss - a polygonal truss having its top chord and end post vertices coincident with the arc of a parabola, its bottom chord straight and its web system either triangular or quadrangular; also known as a parabolic arched truss

parapet - a low wall along the outmost edge of the roadway of a bridge to protect vehicles and pedestrians

pedestal - concrete or built-up metal member constructed on top of a bridge seat for the purpose of providing a specific bearing seat elevation

pedestal pier - one or more piers built in block-like form that may be connected by an integrally built web between them; when composed of a single, wide block-like form, it is called a wall or solid pier

pedestrian bridge - see FOOT BRIDGE

penetration - when applied to creosoted lumber, the depth to which the surface wood is permeated by the creosote oil; when applied to pile driving; the depth a pile tip is driven into the ground

pier - a substructure unit that supports the spans of a multi-span superstructure at an intermediate location between its abutments

pier cap - the topmost portion of a pier which distributes uniformly over the pier the concentrated loads from the bridge

pile - a shaft-like linear member which carries loads through weak layers of soil to those which are capable of supporting such loads

pile bent - a row of driven or placed piles with a pile cap to hold them in their correct positions; see BENT

pile bridge - a bridge carried on piles or pile bents

pile cap - the uppermost portion of a pile which acts to secure the piles in position and provides a bridge seat to receive and distribute superstructure loads

pile foundation - a foundation reinforced by driving piles in sufficient number and to a depth adequate to develop the bearing resistance required to support the substructure load

pile pier - see PILE BENT

piling - general term applied to groupings of piles in a construction. see PILE, SHEET PILES

pin - a cylindrical bar used to connect

pin-connected truss - a general term applied to a truss of any type having its chord and web members connected at the panel points by pins

pin joint - a joint in a truss or other frame in which the members are assembled upon a cylindrical pin

pin packing - an arrangement of truss members on a pin at a pinned joint

pin plate - a plate rigidly attached upon the end of a member to develop the desired bearing upon a pin or pin-like bearing, and secure additional strength and rigidity in the member

pintle - a relatively small steel pin engaging the rocker of an expansion bearing, in a sole plate and masonry plate, thereby preventing translation of the rocker ends

pipe - a hollow cylinder used for the conveyance of water, gas, steam etc.

piping - a process of subsurface erosion in which surface runoff flows along the outside of a culvert and with sufficient hydraulic gradient erodes and carries away soil around the culvert

plain concrete - concrete with no structural reinforcement except light steel to reduce shrinkage and temperature cracking

plan - drawing that represents the top view of a structure and structure site

plastic deformation - deformation of material beyond the elastic range

plate - a flat sheet of metal greater than 1/8 inch thick

plate girder - a large I-shaped beam composed of a solid web plate with flange plates attached to the web plate by flange angles or fillet welds

plug weld - a weld joining two members produced by depositing weld metal within holes cut through one or more of the members; also known as slot weld

plumb bob - a weight hanging on a cord used to provide a true vertical reference

plumb line - a true vertical reference line established using a plumb bob

pneumatic caisson - a caisson in which the working chamber is kept full of compressed air at a pressure nearly equal to the water pressure outside it

pointing - the compacting of the mortar in the outermost portion of a joint and the troweling of its exposed surface to secure water tightness or desired architectural effect

ponding - water backed up in a channel or ditch as the result of a culvert of inadequate capacity

pontoon bridge - a bridge which floats on pontoons moored to the riverbed; a portion may be removable to facilitate navigation

pony truss - a through truss having insufficient height to use a top chord system of lateral bracing

pop-out - conical fragment broken out of a concrete surface by pressure from reactive aggregate particles usually found at the bottom of the hole

portable bridge - a bridge that may be readily erected for a temporary communication-transport service disassembled and its members again reassembled and the entire structure rendered ready for further service

portal - the clear unobstructed space of a through truss bridge forming the entrance to the structure

portal bracing - a system of sway bracing placed in the plane of the end posts of the trusses

post - a member resisting compressive stresses, located vertical to the bottom chord of a truss and common to two truss panels; sometimes used synonymously for vertical; see COLUMN

posted - a limiting dimension, speed, or loading indicating larger dimensions and higher speeds and loads can not be safely taken by the bridge

post-stressing - see POSTTENSIONING

posttensioning - a method of externally prestressing concrete in which the tendons are stressed after the concrete has been cast

pot bearing - a bearing type that allows for multi-dimensional rotation by using a neoprene or spherical bearing element

pot holes - irregular shaped,disintegrated areas of bridge deck or approach pavement concaved by the failure of the surface material

Pratt truss - a truss with parallel chords and a web system composed of vertical posts with diagonal ties inclined outward and upward from the bottom chord panel points toward the ends of the truss; also known as N-truss

precast concrete - concrete members which are cast and cured before being placed into their final positions on a construction site

prestressed concrete - concrete in which cracking and tensile forces are greatly reduced by compressing it with tensioned cables or bars

prestressing - applying forces to a structure to deform it in such a way that it will withstand its working loads more effectively; see POSTTENSIONING, PRETENSIONING

pretensioning - a method of prestressing concrete in which the cables are held in a stretched condition until the concrete has hardened, then the pull on the cables is released inducing internal compression into the concrete

priming coat - the first coat of paint applied to the metal or other material of a bridge; also known as base coat, shop coat

probing - investigating the location and condition of submerged footing foundation material using a rod or shaft of appropriate length; checking the surface condition of a timber member for decay using a pointed instrument, e.g., an ice pick

profile - a section cut vertically through the center line of a roadway or waterway to show the original and final ground levels

programmed repair - those repairs that may be performed in a prescheduled program over the next 2 to 24 months

protective system - a system used to protect bridges from environmental forces that cause steel and concrete to deteriorate and timber to decay, typically a coating system

punching shear - shear stress in a slab due to the application of a concentrated load

Q

quality assurance - an independent evaluation of a service (i.e., an inspection) to establish that a predescribed level of quality has been met

quality control - checks necessary to maintain a uniform level of quality

queen-post truss - a parallel chord type of truss having three panels with the top chord occupying only the length of the center panel; unless center panel diagonals are provided, it is a trussed beam

R

railing - a fence-like construction built at the outermost edge of the roadway or the sidewalk portion of a bridge to protect pedestrians and vehicles; see HANDRAIL

rake - an angle of inclination of a surface in relation to a vertical plane; also known as batter

ramp - an inclined traffic-way leading from one elevation to another

range of stress - the algebraic difference between the minimum and maximum stresses in a member

reaction - the resistance of a support against the pressure of a loaded member

rebar - see REINFORCING BAR

redundancy - a structural condition where there are more elements of support than are necessary for stability

redundant member - a member in a bridge which renders it a statically indeterminate structure; the structure would be stable without the redundant member whose primary purpose is to reduce the stresses carried by the determinate structure

reinforced concrete - concrete with steel reinforcing bars bonded within it to supply increased tensile strength and durability

reinforced concrete pipe - a concrete pipe designed with reinforcing bars to increase its surcharge carrying capability

reinforcement - rods or mesh embedded in concrete to strengthen it

reinforcing bar - a steel bar, plain or with a deformed surface, which bonds to the concrete and supplies tensile strength to the concrete

resistivity of soil - an electrical measurement in ohm-cm, that estimates the corrosion activity potential of a given soil

retaining wall - a structure designed to restrain and hold back a mass of earth

retractile draw bridge - a bridge with a superstructure designed to move horizontally either longitudinally or diagonally from "closed" to "open" position, the portion acting in cantilever being counterweighted by that supported on rollers; also known as traverse draw bridge

rib - curved structural member supporting a curved shape or panel

rigger - an individual who erects and maintains scaffolding or other inspection access equipment

rigid frame - a structural frame in which the members are connected together without hinges

rigid frame bridge - a bridge with moment resistant connections between the superstructure and the substructure to produce an integral, elastic structure

rigid frame pier - a pier with two or more columns and a horizontal beam on top constructed monolithically to act like a frame

rip-rap - gabions, stones, blocks of concrete or other protective covering material of like nature deposited upon river and stream beds and banks, lake, tidal or other shores to prevent erosion and scour by water flow, wave or other movement

rivet - a metal fastener used in pre-1970 construction; made with a rounded preformed head at one end and installed hot into a predrilled or punched hole; the other end was hammered into a similar shaped head thereby clamping the adjoining parts together

riveted joint - a joint in which the assembled members are fastened by rivets

roadway - the portion of the road intended for the use of vehicular traffic

roadway shoulder area - the area immediately adjoining the roadway, used to accommodate stopped vehicles in emergencies

rocker bearing - a bridge support which accommodates expansion and contraction of the superstructure through a rocking action

rocker bent - a bent hinged or otherwise articulated at one or both ends to provide the longitudinal movements resulting from temperature changes and superimposed loads

rolled shape - forms of rolled steel having "I", "H", "Z" or other cross sectional shapes

rolled-steel section - any hot-rolled steel section including wide flange shapes, channels, angles, etc.

roller - a steel cylinder intended to provide longitudinal movements by rolling contact

roller bearing - a single roller or a group of rollers so housed as to permit longitudinal movement of a structure

roller nest - a group of steel cylinders used to facilitate the longitudinal movements resulting from temperature changes and superimposed loads

rolling lift bridge - a bridge of bascule type devised to roll backward and forward upon supporting girders when operated through an "open and closed" cycle

rubble - irregularly shaped pieces of stone in the undressed condition obtained from a quarry and varying in size

runoff - the part of precipitation which flows from a catchment area past a given point over a certain period

S

sacrificial anode - the anode in a cathodic protection system

sacrificial coating - a coating over the base material to provide protection to the base material; examples include galvanizing on steel and alucladding on aluminum

sacrificial protection - see CATHODIC PROTECTION

sacrificial thickness - additional material thickness provided for extra service life of a member in an aggressive environment

saddle - a member located upon the topmost portion of the tower of a suspension bridge which acts as a bearing surface for the catenary cable passing over it

safe load - the load which a structure can safely support

safety belt - a harness or belt worn in conjunction with a safety line to prevent falling a long distance when working at heights

safety curb - a curb between 9 inches and 24 inches wide serving as a limited use refuge or walkway for pedestrians crossing a bridge

safety factor - see FACTOR OF SAFETY

sag - to sink or bend downward due to weight or pressure

scab - a plank bolted over the joint between two timber members to hold them in correct alignment and strengthen the joint; a short piece of I-beam or other structural shape attached to the flange or web of a metal pile to increase its resistance to penetration; also known as scab piece

scaling - the gradual deterioration of a concrete surface due to the failure of the cement paste caused by chemical attack or freeze/thaw cycles

scour - erosion of a river bed area caused by stream flow

scour protection - protection of submerged material by steel sheet piling, rip rap, a mattress, or combination of such methods

scuba - a portable breathing device for free swimming divers; self-contained underwater breathing apparatus

scupper - an opening in the floor portion of a bridge to provide means for rain or other water accumulated upon the roadway surface to drain through it into the space beneath the structure

seam weld - a weld joining the edges of two members placed in contact; in general, it is not a stress carrying weld

seat - a base on which an object or member is placed

seat angle - a piece of angle attached upon the side of a member to provide support for a connecting member either temporarily during its erection or permanently; also known as a shelf angle

secondary member - a member that is carried by other members and does not resist traffic loads

section loss - loss of a member's cross sectional area usually by corrosion or decay

seepage - the slow movement of water through a material

segmental - constructed of individual pieces or segments which are collectively joined to form the whole

segmental arch - a circular arch in which the intrados is less than a semi-circle

segregation - the state of being separated

semi-stub abutment - cantilever abutment founded part way up the slope, intermediate in size between a shoulder abutment and a stub abutment

shear - the load acting across a beam near its support

shear stress - the shear force per unit of cross-sectional area; also referred to as diagonal tensile stress

sheet pile cofferdam - a wall-like barrier composed of driven piling constructed to surround the area to be occupied by a structure and permit dewatering of the enclosure so that the excavation may be produced in the open air

sheet piles - flattened Z-shaped interlocking piles driven into the ground to keep earth or water out of an excavation or to protect an embankment

sheet piling - a general or collective term used to describe a number of sheet piles installed to form a crib, cofferdam, bulkhead, etc.; also known as sheeting

shelf angle - see SEAT ANGLE

shim - a thin plate inserted between two elements to fix their relative position and to transmit bearing stress

shoe - a pedestal-shaped member beneath the superstructure bearing that transmits and distributes loads to the substructure bearing area

shop - a factory or workshop

shore - a strut or prop placed against or beneath a structure to restrain movement

shoulder abutment - a cantilever abutment extending from the grade line of the road below to that of the road overhead. Usually set just off the shoulder

shoulder area - see ROADWAY SHOULDER AREA

sidewalk - the portion of the bridge floor area serving pedestrian traffic only

sidewalk bracket - frame attached to and projecting from the outside of a girder to serve as a support for the sidewalk stringers, floor and railing or parapet

silt - very finely divided siliceous or other hard rock material removed from its mother rock through erosive action rather than chemical decomposition

simple span - the span of a bridge or element which begins at one support and ends at an adjacent support

S-I-P forms - see STAY-IN-PLACE FORMS, FORMS

skew angle - the angle produced when the longitudinal members of a bridge are not perpendicular to the substructure; the skew angle is the acute angle between the alignment of the bridge and a line perpendicular to the centerline of the substructure units

skewback - the inclined support at each end of a segmental arch

skewback shoe - the member transmitting the thrust of an arch to the skewback course or cushion course of an abutment or piers; also known as skewback pedestal

slab - a flat beam, usually of reinforced concrete, which supports load by flexure

slab bridge - a bridge having a superstructure composed of a reinforced concrete slab constructed either as a single unit or as a series of narrow slabs placed parallel with the roadway alignment and spanning the space between the supporting abutments

slide - a sliding down of the soil on a slope because of an increase in load or a removal of support at the foot; also known as landslide

slope - the inclination of a surface expressed as one unit of rise or fall for so many horizontal units

slope protection - a thin surfacing of stone, concrete or other material deposited upon a sloped surface to prevent its disintegration by rain, wind or other erosive action; also known as slope pavement

slot weld - see PLUG WELD

soffit - see INTRADOS

soldier beam - a steel pile driven into the earth with its projecting butt end used as a cantilever beam

soldier pile wall - a series of soldier beams supporting horizontal lagging to retain an excavated surface; commonly used in limited right-of-way applications

sole plate - a plate attached to the bottom flange of a beam that distributes the reaction of the bearing to the beam

sounding - determining the depth of water by an echo-sounder or sounding line

spall - circular or oval depression in concrete caused by a separation of a portion of the surface concrete, revealing a fracture parallel with or slightly inclined to the surface

span - the distance between the supports of a beam; the distance between the faces of the substructure elements; the complete superstructure of a single span bridge or a corresponding integral unit of a multiple span structure; see CLEAR SPAN

spandrel - the space bounded by the arch extrados and the horizontal member above it

spandrel column - a column constructed on the rib of an arch span and serving as a support for the deck construction of an open spandrel arch; see OPEN SPANDREL ARCH

spandrel fill - the fill material placed within the spandrel space of a closed spandrel arch

spandrel tie - a wall or a beam-like member connecting the spandrel walls of an arch and securing them against bulging and other deformation; in stone masonry arches the spandrel tie walls served to some extent as counterforts

spandrel wall - a wall built on the extrados of an arch filling the space below the deck; see TIE WALLS

specifications - a detailed description of requirements, materials, dimensions, etc. for a bridge which cannot be shown on the drawings; also known as specs

spider - inspection access equipment consisting of a bucket or basket which is supported by a vertical wire rope cable; the cable spool is located under the floor of the bucket; the system is powered by compressed air

splice - a structural joint between members to extend their effective length

spread footing - a footing which is wide and usually made of reinforced concrete; ideally suited for foundation material with moderate bearing capacity

springing line - the horizontal line within the face surface of an abutment or pier at which the intrados of an arch takes its beginning or origin

spur dike - a projecting jetty-like construction placed adjacent to an abutment to prevent stream scour and undermining of the abutment foundation and to reduce the accumulation of stream debris against to the upstream side of the abutment

stage - inspection access equipment consisting of a flat platform supported by horizontal wire-rope cables; the stage is then slid along the cables to the desired position; a stage is typically 20 inches wide, with a variety of lengths available

statics - the study of forces and bodies at rest

stationing - a system of measuring distance along a baseline

stay-in-place forms - a prefabricated metal concrete deck form that will remain in place after the concrete has set; see FORMS

stay plate - a tie plate or diagonal brace to prevent movement

steel - an alloy of iron, carbon, and various other elements and metals

stem - the vertical wall portion of an abutment retaining wall, or solid pier; see BREASTWALL

stiffener - a small member attached to another member to transfer stress and to prevent buckling

stiffening girder - a girder incorporated in a suspension bridge to distribute the traffic loads uniformly among the suspenders and reduce local deflections

stiffening truss - a truss incorporated in a suspension bridge to distribute the traffic loads uniformly among the suspenders and reduce local deflections

stirrup - U-shaped bar providing a stirrup-like support for a member in timber and metal bridges; U-shaped bar placed in concrete constructions to resist diagonal tension (shear) stresses

stone masonry - the portion of a structure composed of stone

straight abutment - an abutment whose stem and wings are in the same plane or whose stem is included within a length of retaining wall

strain - the change in length of a body produced by the application of external forces, measured in units of length; this is the proportional relation of the amount of change in length divided by the original length

strand - a number of wires grouped together by twisting

stress - the force acting across a unit area in a solid material

stress concentration - those concentrations of stress caused by a sudden change of cross section in a member

stress cycle - the variation in stress at a point with the passage of live load; from initial dead load value to the maximum additional live load value and back

stress raiser - a detail which causes stress concentration

stress reversal - change of stress type from tension (+) to compression (-) or vice versa

stress sheet - a drawing showing all computed stresses resulting from the application of a system of loads together with the design composition of the individual members resulting from the application of assumed unit stresses for the material to be used in the structure

stringer - a longitudinal beam supporting the bridge deck

structural analysis - an analysis of a structure (bridge) to determine the interaction of members and their consequent stresses

structural member - an individual piece, like a beam or strut, which is an integral part of a structure

structural redundancy - that part of redundancy where the extra elements of support exist due to continuity in the framing element

structural shapes - the various types of rolled iron and steel having flat, round, angle, channel, "I", "H", "Z" and other cross-sectional shapes adapted to the construction of the metal members incorporated in reinforced foundations, substructures and superstructures

structural stability - the ability of a structure to maintain its normal configuration, not collapse or tip in any way, under existing and expected loads

structural tee - a tee-shaped rolled member formed by cutting a wide flange longitudinally along the centerline of web

structure - something, such as a bridge, that is built and designed to sustain a load

strut - a piece or member acting to resist compressive stress

stub abutment - an abutment within the topmost portion of the end of an embankment or slope and, therefore, having a relatively small vertical height; while often engaging and supported upon piles driven through the underlying embankment or in-situ material, stubs may also be founded on gravel fill, the embankment, or natural ground itself

sub-panel - a truss panel divided into two parts by an intermediate web member, generally by a subdiagonal or a hanger

substructure - the abutments, piers, or other constructions built to support the span of a bridge superstructure

superelevation - the difference in elevation between the inside and outside edges of a roadway in a horizontal curve; required to counteract the effects of centrifugal force

superimposed dead load - dead load that is applied to a bridge after the concrete deck has cured; for example, the weight of parapets or railings placed after the concrete deck has cured

superstructure - the entire portion of a bridge structure which primarily receives and supports traffic loads and in turn transfers these loads to the bridge substructure

surface corrosion - surface rust

suspended span - a simple span supported from the free ends of cantilevers

suspender - a wire cable, a metal rod or bar connecting to a catenary cable of a suspension bridge at one end and the bridge floor system at the other, thus transferring loads from the road to the main suspension members

suspension bridge - a bridge in which the floor system is supported by catenary cables which are supported upon towers and are anchored at their extreme ends

suspension cable - a catenary cable which is one of the main members upon which the floor system of a suspension bridge is supported

sway anchorage - a guy, stay cable or chain attached to the floor system of a suspension bridge and anchored upon an abutment or pier to increase the resistance of the suspension span to lateral movement; also known as sway cable

sway bracing - diagonal bracing located at the top of a through truss, perpendicular to the truss itself and usually in a vertical plane, to resist horizontal forces

sway frame - a complete panel or frame of sway bracing

swing span bridge - a movable bridge in which the span rotates in a horizontal plane on a pivot pier, to permit passage of marine traffic

T

tack welds - small welds used for temporary connections

tail water - water ponded below the outlet of a waterway, thereby reducing the amount of flow through the waterway; see HEADWATER

tape measure - a long, flexible strip of metal marked with subdivisions of the foot used for measuring

tee beam - a rolled steel section shaped like a T; part of a reinforced-concrete floor in which the beam projects below the slab

temperature steel - reinforcement in a concrete member to prevent cracks due to stresses caused by temperature changes

temporary bridge - a structure built for emergency or interim use to replace a previously existing bridge rendered unserviceable

tendon - a prestressing cable, strand, or bar

tensile force - a force caused by pulling at the ends of a member; see TENSION

tensile strength - the maximum load at which a specimen breaks under tension

tension - type of stress involving an action which pulls apart

thermal movement - movement of a bridge structure due to a change in temperature

three-hinged arch - an arch which is hinged at each support and at the crown

through bridge - a bridge where the floor elevation is nearly at the bottom and traffic travels between the supporting parts

tie - a member carrying tension

tie plate - see STAY PLATE

tie rod - a rod-like member in a frame functioning to transmit tensile stress; also known as tie bar

tie walls - one of the walls built at intervals above the arch ring to tie together and reinforce the spandrel walls; any wall designed to serve as a restraining member to prevent bulging and distortion of two other walls connected thereby; see DIAPHRAGM WALL

timber - wood suitable for building purposes

toe - the front portion of a footing from the intersection of the front face of the abutment to the front edge of the footing; the line where the side slope of an embankment meets the existing ground

toe of slope - the location defined by the intersection of the embankment with the surface existing at a lower elevation; also know as toe

toe wall - a relatively low retaining wall placed near the "toe-of-slope" location of an embankment to protect against erosion or to prevent the accumulation of stream debris; also known as footwall

ton - a unit of weight equal to 2,000 pounds

torque - the angular force causing rotation

torque wrench - a hand or power tool used to turn a nut on a bolt that can be adjusted to deliver a predetermined amount of torque

torsion - twisting perpendicular to the longitudinal axis of a member

tower - a pier or frame supporting the catenary cables of a suspension bridge

traffic control - modification of normal traffic patterns by signs, cones, flagmen, etc.

transducer - a device that converts one form of energy into another form, usually electrical into mechanical or the reverse

transverse bracing - the bracing assemblage engaging the columns of bents and towers in planes transverse to the bridge alignment that resists the transverse forces tending to produce lateral movement and deformation of the columns

transverse girder - see CROSS GIRDER

travel way - the roadway

trestle - a bridge structure consisting of spans supported upon frame bents

truss - a jointed structure made up of individual members arranged and connected usually in a triangular pattern, so as to support longer spans

truss bridge - a bridge having a pair of trusses for a superstructure

trussed beam - a beam stiffened to reduce its deflection by a steel tie-rod which is held at a short distance from the beam by struts

truss panel - see PANEL

tubular sections - structural steel tubes, rectangular, square or circular; also known as hollow sections

tubular truss - a truss whose chords and struts are composed of pipes or cylindrical tubes

tunnel - an underground passage, open to daylight at both ends

turnbuckle - a long, cylindrical, internally threaded nut used to connect the elements of adjustable rod and bar members

two-hinged arch - a rigid frame which may be arch-shaped or rectangular but is hinged at both supports

U

U-bolt - a bar bent in the shape of the letter "U" and fitted with threads and nuts at its ends

ultimate strength - the highest stress which a material can withstand before breaking

ultrasonic testing - nondestructive testing of a material's integrity using sound waves

underpass - the lowermost feature of a grade separated crossing; see OVERPASS

uniform load - a constant load across a member

unit stress - the stress per unit of surface or cross-sectional area

uplift - a negative reaction or a force tending to lift a beam, truss, pile, or any other bridge element upwards

upper chord - the top longitudinal member of a truss

V

vertical curve - a sag or crest in the profile of a roadway

vertical lift bridge - a bridge in which the span moves up and down while remaining parallel to the roadway

viaduct - a series of spans carried on piers at short intervals

vibration - the act of vibrating concrete to compact it

Vierendeel truss - a Pratt truss without diagonal members and with rigid joints between top and bottom chords and the verticals

voided slab - a precast concrete deck unit containing cylindrical voids to reduce dead load

voids - an empty or unfilled space in concrete

Voussoir - one of the truncated wedge shaped stones composing a ring course in a stone arch; also known as ring stone

voussoir arch - an arrangement of wedge shaped blocks set to form an arched bridge

W

Warren truss - a triangular truss consisting of sloping members between the top and bottom chords and no verticals; members form the letter W

washer - a small metal ring used beneath the nut or the head of a bolt to distribute the pressure

water/cement ratio - the weight of water divided by the weight of cement in a concrete; ratio controls the strength of the concrete

waterway - the available width for the passage of water beneath a bridge

wearing surface - the topmost layer of material applied upon a roadway to receive the traffic loads and to resist the resulting disintegrating action; also known as wearing course

web - the portion of a beam located between and connected to the flanges; the stem of a dumbbell type pier

web members - the intermediate members of a truss, not including the end posts, usually vertical or inclined

web plate - the plate forming the web element of a plate girder, built-up beam or column

web stiffener - a small member welded to a beam web to prevent buckling of the web

weephole - a hole in a concrete retaining wall to provide drainage of the water in the retained soil

weld -a joint between pieces of metal at faces which have been made plastic by heat or pressure

weldability - a property of electrode and parent metal combined, estimated by the ability to make good welds by as many processes as possible

welded bridge structure - a structure whose metal elements are connected by welds

welded joint - a joint in which the assembled elements and members are united through fusion of metal

welding - the process of making a welded joint

weld layer - a single thickness of weld metal composed of beads (runs) laid in contact to form a pad weld or a portion of a weld made up of superimposed beads

weld metal - the fused filler metal which is added to the fused structure metal to produce a welded joint or a weld layer

weld penetration - the depth beneath the original surface, to which the structure metal has been fused in the making of a fusion weld; see PENETRATION

weld sequence - the order of succession required for making the welds of a built-up piece or the joints of a structure, to avoid producing residual stresses

weld toe - particularly in a filet weld, the thin end of the taper furthest from the center of the weld cross section

wheel guard - a raised curb along the outside edge of traffic lanes to safeguard constructions outside the roadway limit from collision with vehicles

wheel load - the load carried by and transmitted to the supporting structure by one wheel of a traffic vehicle, a movable bridge, or other motive equipment or device; see AXLE LOAD

Whipple truss - a double-intersecting through Pratt truss where the diagonals extend across two panels

wide flange - a rolled I-shaped member having flange plates of rectangular cross section, differentiated from an S-beam (American Standard) in that the flanges are not tapered

wind bracing - the bracing systems which function to resist the stresses induced by wind forces

wind lock - a lateral restraining device found on steel girder and truss bridges with large pin and hanger assemblies

wingwall - the retaining wall extension of an abutment intended to restrain and hold in place the side slope material of an approach roadway embankment

wire mesh reinforcement - a mesh made of steel wires welded together at their intersections used to reinforce concrete

wire rope - steel cable

working stress - the unit stress in a member under service or design load

wrought iron - cast iron which has been mechanically worked to remove slag and undissolved carbon

Y

yield - permanent deformation (permanent set) which a metal piece takes when it is stressed beyond the elastic limit

yield point - see YIELD STRESS

yield stress - the stress at which noticeable, suddenly increased deformation occurs under slowly increasing load

Index