Synthesis of

Falsework, Formwork and Scaffolding for Highway Bridge Structures

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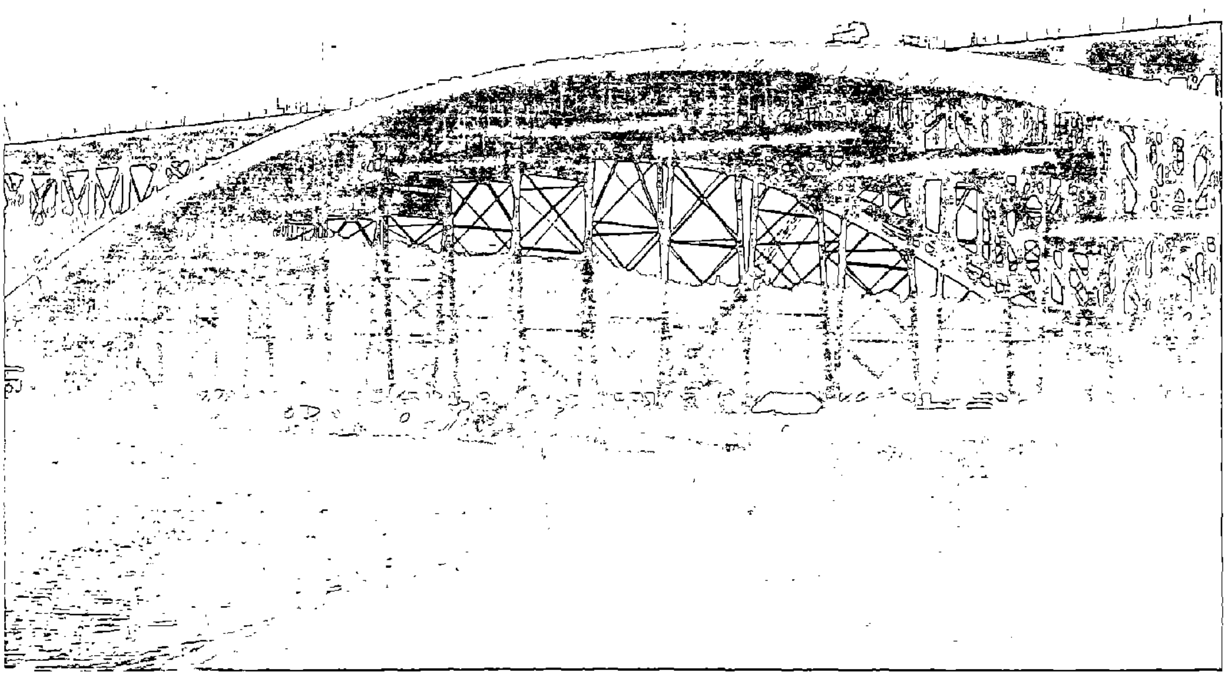

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Federal Highway Administration

Research and Development
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FOREWORD

This report synthesizes codes and standards on bridge temporary works both in the United States and abroad. It will be of particular interest to bridge designers and bridge construction inspectors.

In addition to the synthesis of codes, it contains valuable information on States' submittal, review and inspection policy, and review and inspection guidelines.

Additional copies may be obtained from the National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161.

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Director, Office of Engineering and
Highway Operations Research and Development

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16. Abstract

Following the collapse of the Route 198 bridge over the Baltimore-Washington Parkway in 1989, the FHWA determined that there was a need to reassess, on a national level, the specifications currently used to design, construct, and inspect falsework and formwork for highway bridge structures. Towards that end, the FHWA commissioned this synthesis to identify existing information on this subject and present it in one document. This effort has included a survey of United States and Canadian highway departments, and a comprehensive literature search for related publications. The objective of the study has been to identify the current state-of-the-practice in the United States and abroad, based on a review of available standards, specifications, literature, and published research.

Published literature from the United States, Canada, Great Britain, Australia, New Zealand, Japan, and several European countries was identified and forms the basis of this report. This information is summarized and discussed under the general headings of falsework, formwork, and scaffolding. This discussion is followed by an examination of review and inspection procedures. The development of a unified standard, or code of practice, is recommended.

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PREFACE

This synthesis identifies an extensive collection of literature related to the design, review, and inspection of temporary structures used in highway bridge construction. For the purpose of this study, temporary structures have been defined as falsework or shoring, formwork, and access scaffolding. It is not the intent of this document to serve as a guideline, specification, or manual for design of temporary structures. Instead, this synthesis identifies the available literature on this subject and briefly summarizes the state-of-the-practice. For more coverage of a particular topic, the reader can refer to the specific reference.

The project was directed by the Scaffolding, Shoring, and Forming Task Group of the FHWA, whose comments and review were very helpful in the preparation of this document. The United States and Canadian transportation departments are thanked for their time and cooperation in responding to the questionnaire and requests for additional information. Special recognition is extended to Kenneth F. Hurst, Engineer Manager of the Kansas State Bridge Office, Thomas P. Hallenbeck, Senior Bridge Engineer with Caltrans, and John C. Cole, Bridge Construction Engineer with the South Dakota DOT. Gratitude is expressed to Margaret L. Rothschild of the Shoring, Scaffolding, and Forming Institute (SSFI) and the SSFI member companies for their input and help in furnishing engineering and product literature.

The assistance of our professional colleagues abroad in locating foreign literature is also gratefully acknowledged. Without their help, the foreign documents located within the performance period would have been quite limited. In particular, individual recognition is expressed to Dr. John Badoux at the Institute of Construction Materials, Ecole Polytechnique Federale de Lausanne, Switzerland; H.E. Chapman, Manager of Works Consultancy Services, Wellington, New Zealand; M. Donzel, Head of the Bridge Section, Swiss Federal Highways office, Bern; H.-H. Gotfredsen, Chief Engineer with Great Belt A.S., Copenhagen, Denmark; Jens Holm at G.M. Idorn Consult A/S, Birkerod, Denmark; Mike Leahy, Bridge Design Engineer with the Roads and Traffic Authority of New South Wales, Australia; Dr. Atsuhiko Machida, Director of Engineering, Saitama University in Urawa Saitama, Japan; Dr. Peter Marti, Professor at the Institute of Structural Engineering, Swiss Federal Institute of Technology, Zurich; Dr. R.E. Rowe of Great Britain; B.J. Schischka, Research and Development Department, Transit New Zealand, Wellington; and Markus Wyss, Bridge Engineer with Emch & Berger, Bern, Switzerland.

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yards	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	ml
gal	gallons	3.785	liters	l
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: Volumes greater than 1000 l shall be shown in m^3.				
		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 or (F-32)/1.8	Celcius temperature	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	l
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
psi	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	ac
ha	hectares	2.47	acres	mi^2
km^2	square kilometers	0.386	square miles	
		VOLUME		
ml	milliliters	0.034	fluid ounces	fl oz
l	liters	0.264	gallons	gal
m^3	cubic meters	35.71	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg	megagrams	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact)		
°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	psi

* SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380.

(Revised August 1992)

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LIST OF ABBREVIATIONS

AASHTO	- American Association of State Highway and Transportation Officials
ACI	- American Concrete Institute
AISC	- American Institute of Steel Construction
AISI	- American Iron and Steel Institute
AITC	- American Institute of Timber Construction
ANSI	- American National Standards Institute
APA	- American Plywood Association
AS	- Australian Standard
ASCE	- American Society of Civil Engineers
ASTM	- American Society for Testing and Materials
AWS	- American Welding Society
BSI	- British Standards Institution
Caltrans	- California Department of Transportation (United States)
CIRIA	- Construction Industry Research and Information Association (Great Britain)
CSA	- Canadian Standards Association
DIN	- Deutsches Institut fur Normung (German Institute for Standardization)
DOH	- (State) Department of Highways
DOT	- (State) Department of Transportation
FHWA	- Federal Highway Administration (United States)
NAASRA	- National Association of Australian State Road Authorities
NDS	- National Design Specification for Wood Construction (United States)
NFPA	- National Forest Products Association (United States)
NZS	- New Zealand Standards
PCI	- Precast/Prestressed Concrete Institute (United States)
PTI	- Post Tensioning Institute (United States)
RTA	- Roads and Traffic Authority (New South Wales, Australia)
SSFI	- Scaffolding, Shoring, and Forming Institute (United States)
SSRC	- Structural Stability Research Council (United States)
SIA	- Scaffold Industry Association (United States)
UBC	- Uniform Building Code (United States)

CHAPTER 1. INTRODUCTION

OBJECTIVE

Approximately 35,000 State or Federal-aid highway bridges were built in the United States during the past decade. The majority of these bridges were built without incident, which is a credit to the construction industry. During this period, however, there were also several major bridge failures that occurred during construction, and were attributed to construction practices and procedures.[1, 2, 3] Statistically, bridge falsework represents over one-third of the total recorded falsework collapses, and most of these occur during construction of conventionally reinforced concrete beam or box-girder bridges.[4]

Falsework design in the United States, because of its temporary nature, has traditionally been delegated to the contractor or contractor's engineer under the premise that the contractor is responsible for the means and methods of construction. Although there are potential economies in this type of assignment, the design engineer of record for the bridge relinquishes some control of the project which, in turn, increases the probability of construction complications or failures. The possibility of construction problems is compounded by the fact that very few written standards exist for construction of these temporary systems and, in many cases, design assumptions are left to individual engineering judgement.

In 1973, after the Arroyo Seco bridge collapsed during construction, California Department of Transportation (Caltrans) bridge engineers sought to prevent future failures of this type.[5, 6] Perhaps the single most significant finding of the subsequent investigation was that "the serious nature of this (falsework) collapse and its consequence now make it mandatory that controls over this portion of the work be strengthened." The end result was major revisions to existing State specifications, procedural changes with respect to the review of plans and inspection of falsework construction, and the development of a falsework manual.[7] Since that time, California has not had a significant falsework-related failure or loss on any State bridge project.

The Caltrans experience has demonstrated that procedure and control are vital in addressing problems inherent with temporary structures for bridge construction. As a general observation, the lack of adequate control(s) invariably translates to problems on the construction site. In particular, there is a propensity for contractors and engineers alike to cut corners, reduce standards and, in general, exercise less quality control for temporary structures. From a failure analysis (forensic) perspective, errors that contribute to falsework collapses are almost always obvious after the fact, generally result from human error, and could have been avoided.

Following the collapse of the Route 198 bridge over the Baltimore-Washington Parkway in 1989, the Federal Highway Administration (FHWA) determined that there was a need to reassess, on a national level, the specifications currently used to design, construct, and inspect falsework and formwork for highway bridge structures. Towards that end, the FHWA commissioned this synthesis to identify existing information on this subject and present it in one document. This effort has included a survey of United States and Canadian highway departments, and a comprehensive literature search for related publications. The objective of the study has been to identify the current state-of-the-practice in the United States and abroad, based on a review of available standards, specifications, literature, and published research.

Due to the broad nature of this subject, the focus of this study has been limited to conventional falsework, formwork and, to a lesser extent, scaffolding as it specifically relates to highway bridge construction. Other forms of temporary structures, including cofferdams and temporary sheeting, were not considered in this study.

SCOPE

Literature Review

Computer-assisted literature searches were conducted using TRIS, DIALOG, and NEXIS databases. Other information sources were located by examining cumulative indices from the American Concrete Institute (ACI), American National Standards Institute (ANSI), American Society of Civil Engineers (ASCE), National Technical Information Service (NTIS), Portland Cement Association (PCA), Precast/Prestressed Concrete Institute (PCI), and Transportation Research Board (TRB).

Several research libraries were accessed for technical information, including the John Crerar Library at the University of Chicago, and engineering libraries at the University of Illinois at Urbana-Champaign, Northwestern University, and Purdue University. Further information was obtained from the University of California at Berkley. Documents that were difficult to obtain were accessed through various sources, such as the United States Library of Congress, the Engineering Societies Library in New York, Oxford University Library in Great Britain, and the Construction Industry Research Information Association (CIRIA), also in Great Britain.

Foreign standards were generally obtained from one of the institutions noted above. However, to locate additional information, the investigators contacted colleagues in Australia, Canada, Great Britain, Japan, New Zealand, and Switzerland. The literature search was primarily limited to English translated documents, although, several relevant but untranslated publications were also identified and included in the bibliography to this report.

Contact was also made with the Scaffolding, Shoring, and Forming Institute (SSFI) and its member companies to obtain pertinent manufacturer's literature for this study. Additional manufacturers of shoring, forming, and scaffolding systems were solicited for information, as time permitted.

Due to the amount of information obtained during the literature search, it was not possible to reference every document. Therefore, a bibliography of other publications and information sources has been provided.

State Survey

As noted, the study was precipitated by the FHWA's concern over recent incidents of falsework failure during construction of highway bridge structures. In a preliminary survey, the FHWA requested that their regional administrators collect copies of all applicable State documents, including, but not limited to, standard specifications, design specifications, and construction manuals. The FHWA furnished this information to the investigators for review.

To supplement the material provided by the FHWA, the investigators developed a questionnaire that focused on State highway departments' design and review policies for falsework, formwork and scaffolding. Information relating to published or unpublished State research, documentation of reported failures, the level of bridge construction activity in a given State, and other information not originally provided to the FHWA was also requested. The questionnaire was mailed, with a cover letter briefly describing the study objective, to the 50 State bridge engineers and the bridge engineer(s) in Puerto Rico and Washington, D.C. A modified questionnaire was also sent to the chief bridge engineers in the Canadian provinces and territories. The questionnaire is reproduced in appendix A.

Final Synthesis

This report presents the findings of the study. The investigators have accumulated the information, evaluated its relevance, and summarized its content in a brief discussion. This document is intended to be useful to all individuals involved in bridge construction including, but not limited to, bridge engineers, consulting engineers, contractors, suppliers, and inspectors. The subject matter addressed in the report is not all inclusive; the reader is directed to consult the specific reference for more detailed information on a particular subject.

The synthesis is organized into seven chapters, with appendixes. Chapter two briefly highlights all information collected for the study. Chapters three through five summarize information on falsework, formwork, and scaffolding, respectively. Chapter six summarizes policies and procedures for design review and inspection of temporary structures. Conclusions and recommendations are presented in chapter seven, followed by the cited references and a bibliography, which includes related documents found during the literature search.

The synthesis includes three appendixes. Appendix A is the falsework questionnaire sent to United States and Canadian highway departments; appendix B contains a punchlist of review and inspection guidelines. Appendix C contains the addresses where published standards and/or literature can be obtained.

DEFINITIONS

Review of material furnished by the States and other related literature indicated conflicting use of the terms shoring, formwork, and scaffolding. In an attempt to avoid confusion with the terminology in this report, the investigators have adopted the following definitions. These definitions are not intended to be exclusive, but are generally consistent with the common use of these terms.

Falsework - Any temporary construction work used to support the permanent structure until it becomes self-supporting. Falsework would include steel or timber beams, girders, columns, piles and foundations, and any proprietary equipment including modular shoring frames, post shores, and adjustable horizontal shoring.

Formwork - A temporary structure or mold used to retain the plastic or fluid concrete in its designated shape until it hardens. Formwork must have enough strength to resist the fluid pressure exerted by plastic concrete and any additional fluid pressure effects generated by vibration.

Scaffolding - An elevated work platform used to support workmen, materials, and equipment, but not intended to support the structure.

Shoring - This is a component of falsework such as horizontal, vertical, or inclined support members. However, for the purpose of this document this term is used interchangeably with falsework.

Temporary Structures - All temporary means used to support the permanent structure under construction. Temporary structures include falsework, scaffolding, formwork, and shoring.

As further clarification, falsework (shoring) generally supports formwork. Formwork is usually comprised of plywood sheathing backed with a supporting stud, waler, and bracing system, whereas falsework is built with a grid of heavier framing members.

CHAPTER 2. EXISTING STANDARDS AND LITERATURE

UNITED STATES STANDARDS

State Specifications

As part of the questionnaire distributed to the 50 States, the District of Columbia, and Puerto Rico (hereafter considered jointly with the 50 States), State highway officials were asked to provide information on recently built bridges and their construction type. Table 1 presents a summary of this information. As shown, the table establishes the amount of bridge construction performed in each State during the past 2 decades and gives an indication of the principal superstructure type. Construction types include cast-in-place concrete (i.e., conventional slab-beam, box-girder), precast or prestressed concrete (i.e., AASHTO I-girders, box beams, bulb tees, segmental box girders), steel (i.e., rolled shapes, plate girders), timber, and other bridge types that did not fit the preceding categories, for example, concrete arch or box culverts. In a general sense, the information reported in table 1 was accumulated in an attempt to correlate a State's bridge building activity with the level of falsework and formwork requirements contained in State specifications or other manuals.

Table 1 indicates 10 States that list cast-in-place (C.I.P.) concrete as their primary type of bridge construction. Twenty-two States indicated precast concrete as the primary bridge superstructure type. The other major bridge type, structural steel, was predominant in 17 States. Timber and other types of bridges do not account for many recently built structures, except in Colorado. Colorado has gradually been replacing their shorter span bridge structures with concrete culverts.[8] Most are of cast-in-place concrete, but precast alternatives are being accepted in certain situations. The trend toward concrete culvert usage for stream crossings stems from an attempt to reduce bridge deck maintenance.

Each State has basic minimum requirements for falsework and formwork within their standard specifications. This information, which is presented in separate or combined sections of the specifications, usually is located under requirements for concrete construction. As a minimum, the specifications cover general requirements, basic construction practice, and provide some guidelines for acceptable workmanship. Some States expand on these basic requirements by specifying design criteria and addressing serviceability, material requirements, and other special conditions.

Table 2 gives specific information on each State's falsework and formwork requirements. For a majority of States, the information is solely contained within the standard specifications. As shown in the righthand column, 16 States supplement their specifications with information in bridge or construction manuals. In California, a falsework manual is available to supplement the specifications. This document is discussed in subsequent chapters of this report.

Virtually every State listed has general requirements and guidelines for construction and removal of falsework. General requirements encompass such items as the contractor's responsibility, submittal of falsework drawings and calculations, submittal time periods, and review procedures (if any). Falsework construction and removal comprises basic construction techniques, alignment and tolerance requirements, foundation types, use of undamaged material, cure and removal periods, concrete strength requirements, and decentering methods.

In terms of falsework design criteria, approximately half of the States have specific guidelines. The requirements range from minimum loading and maximum deflection criteria to very detailed and comprehensive falsework design guidelines. Minimum specified design live loads are found in the specifications of Delaware, Indiana, Louisiana, Missouri, New Hampshire, New York, Oklahoma, South Carolina, Texas, Washington, and Wisconsin. (See references 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19.) Four of these States - Indiana, Oklahoma, South Carolina and Washington - specify minimum design wind or lateral loads. Delaware, Oklahoma, South Carolina, Washington, Alaska and Ohio provide maximum deflection criteria.[20,21] As a further note, both Indiana and Wisconsin list allowable design stresses for timber falsework.

Arizona, Colorado, Hawaii, Iowa, Kentucky, Maryland, Minnesota and Oregon have more comprehensive design criteria in their standard specifications or construction manuals. (See references 22, 23, 24, 25, 26, 27, 28, 29.) Each of these States has minimum live load and maximum deflection requirements for falsework. All except Maryland and Minnesota have guidelines for wind or lateral loads. Arizona and Maryland also specify minimum total design loads, in addition to dead and live loads.

Aside from loads, these eight States specify allowable stress values for salvaged steel falsework, timber falsework, or both. The contractor is directed to use these design values for both salvaged and new material, unless the contractor can certify a higher stress grade or value. With the exception of Kentucky, these States recommend a national design code for steel, minimum steel grade, and permissible overstresses, if any, allowed for so-called "temporary structures." These same seven States also cite a national code for timber design and analysis. Minimum requirements for the type and grade of wood to use, such as Douglas Fir or Southern Pine No. 2, are occasionally provided.

Although Kentucky does not refer to design codes or standards, its construction manual presents a comprehensive treatment of both steel and timber design. Additionally, Maryland and Minnesota specify allowable stresses for both steel and timber. Of the remaining States, Iowa does not specify allowable steel stresses and Colorado does not specify allowable timber stress. Arizona, Hawaii, and Oregon refer to the existing codes, and do not specify steel or timber allowable stresses.

States with even more comprehensive design criteria include California, Georgia, Idaho, Kansas, and Nevada. (See references 30, 31, 32, 33, 34, 35, 36.) These five States have standard specifications similar to those described above. However, their treatment of falsework design is considerably more detailed. They specify minimum design loads, allowable deflections, applicable design codes and, in most cases, maximum allowable stresses for steel and timber. California and Idaho have wind design criteria based on the height above ground, while Kansas has special lateral load requirements for bridges built with superelevation. Further discussion of these requirements is included in chapters three and four.

Examination of table 2 also shows that four States - Arizona, California, Georgia and Idaho - have more specific design requirements for traffic openings that go beyond clearances and arrangement of concrete protection barriers. In these States, design load criteria is typically more comprehensive at traffic openings and includes minimum section sizes, and connection and bracing requirements.

Table 1. Summary of bridge construction since 1970.

State	No. of Bridges Built			Type of Construction (%)				
	'70-'79	'80-'89	'90	Cast-In-Place Concrete	Precast Concrete	Steel	Timber	Other
Alabama	1113	983	17	40	20	39	<1	<1
Alaska	120	130	12		65	23	12	
Arizona	258	372	79	65	24	11		
Arkansas	874	920	76	53	10	37		
California	3664	1216	16	87	8	2	<1	2
Colorado	601	587	40	21	21	27	<1	31
Connecticut	346	415	25	12	27	44	<1	17
Delaware	NA	NA	15	7	40	40	7	7
Florida	730	920	50	20	65	15		
Georgia[a]	1500	1200	100	50	30	20		
Hawaii	126	38	NA	27	56	16	1	
Idaho	322	304	19	36	48	9		7
Illinois	1123	906	113	22	25	53		
Indiana	NA	426	63		Not Available			
Iowa	NA	NA	40	20	65	15		
Kansas	677	454	44	51	14	32	<1	2
Kentucky	NA	NA	57		93	7		
Louisiana	1627	1188	28	24	51	7	2	16
Maine	169	130	20	15	6	71	<1	8
Maryland	314	241	14	4	3	72	<1	21
Massachusetts	413	177	NA	13	27	59	<1	<1
Michigan	988	332	38	<1	18	79	3	<1
Minnesota	749	629	54	5	39	34	<1	22
Mississippi	687	823	90	1	98	1		
Missouri	1025	787	85	31	27	42		
Montana[b]	Not Available			14	38	16	29	3
Nebraska	402	569	NA	34	33	28	<1	5
Nevada	176	89	4	63	5	32		
New Hampshire[a]	50	75	12	37		58	4	<1
New Jersey	517	157	NA	8	6	86		
New Mexico[a]	250	250	15	15	65	20	<1	
New York	2151	1694	109	7	16	72		5
North Carolina	675	925	100	1	50	49		
North Dakota	526	371	9		67	21	12	
Ohio			Not Available					
Oklahoma	NA	308[c]	96	8	86	6		
Oregon	499	502	23	23	72	4	1	
Pennsylvania[a]	600	1200	200	4	73	22	1	
Puerto Rico			Not Available					
Rhode Island	40	47	1		31	69		
South Carolina	NA	NA	35	26	37	37		
South Dakota	786	466	27	27	47	20	2	4
Tennessee[a]	1100	3700	140	43	43	14		
Texas	2532	2651	329	27	63	2		8

Table 1. Summary of bridge construction since 1970 (continued).

State	No. of Bridges Built '70-'79	'80-'89	'90	Type of Construction (%) Cast-In-Place Concrete	Precast Concrete	Steel	Timber	Other
Utah				Not Available				
Vermont	135	135	15[d]	30	5	65		
Virginia	1250	950	60	15	12	73		<1
Washington	NA	68[c]	30	25	50	16		9
Washington D.C.				Not Available				
West Virginia	1179	1127	151	16	17	65	1	1
Wisconsin	1958	2116	65	37	35	16	6	6
Wyoming	304	219	8	31	6	63		
<u>Canadian Province</u>								
Alberta	1226	1117	54	4	76	13	7	<1
British Columbia	279	281	24	<1	61	35	3	
Manitoba			Not Available					
New Brunswick			Not Available					
Newfoundland	85	90	11	60	30	5	4	1
Northwest Territory			Not Available					
Nova Scotia	176	143	19	4	47	41	6	2
Ontario	731	374	37	45	26	26	3	
Prince Edward Island			Not Available					
Quebec[a]	720	450	50	20	50	30		
Saskatchewan			Not Available					
Yukon	3	9	0	8	58	33		

Notes:
a. Estimated quantities from State or Provincial bridge engineer
b. Montana information based on bridge inventory data
c. Time period representative of 1987-89
d. Based on 12 to 15 bridges/year

Table 2. Summary of State and Provincial specifications.

State	Falsework				Formwork			Other
	General Requirements	Construction Requirements	Design Criteria	Traffic Openings	Construction Requirements	Design Criteria	Reference SP-4	
Alabama		s			s			gn
Alaska	s	s	s		s	s	cm	cm
Arizona	s	s	s	s	s			
Arkansas	s	s			s			
California	s	s	s	s	s	s		fm
Colorado	s	s	s		s	s		
Connecticut	s	s						
Delaware	s	s	s		s	s		
Florida	s	s			s			
Georgia	s	s	s	s				
Hawaii	s	s	s		s	s		
Idaho	s	s	s	s	s	s		
Illinois	s	s			s			cm
Indiana	s	s	s		s			gi
Iowa	s	s	s		s	s		cm
Kansas	s	s	bm		s	bm	bm	bm
Kentucky	s	s	cm		s	cm		cm
Louisiana	s	s	s		s			
Maine	cm	s			s			cm
Maryland	s	s	s		s	s		
Massachusetts	s				s	s		
Michigan	s	s			s			cm, gn
Minnesota	s	s	bcm		s	bcm		bcm
Mississippi	s	s			s			
Missouri	s	s	s		s	s	cm	cm
Montana	s	s			s	s		cm
Nebraska	s	s			s			
Nevada	s	s	s		s	s		cm
New Hampshire	s	s	s		s			
New Jersey	s	s			s			
New Mexico	s	s			s			
New York	s	s	s		s			scm
North Carolina	s	s			s			
North Dakota	s	s			s			cm
Ohio	s	s	s		s			
Oklahoma	s	s	s				s	
Oregon	s	s	s		s			
Pennsylvania	s	s			s	s		
Puerto Rico	s	s			s			
Rhode Island			Not Available					
South Carolina	s	s	sp		s			sp
South Dakota	s							gn
Tennessee	s	s						gn
Texas	s	s	s		s	s		cm

Table 2. Summary of State and Provincial specifications (continued).

	Falsework				Formwork			
State	General Requirements	Construction Requirements	Design Criteria	Traffic Openings	Construction Requirements	Design Criteria	Reference SP-4	Other
Utah	s	s			s	s		
Vermont	s	s			s			
Virginia	s	s			s			
Washington	s	s	s		s	s	s	
Washington, DC	s	s						
West Virginia	s	s			s			
Wisconsin	s	s	s		s	s		cm
Wyoming	gn	s			s			gn
<u>Canadian Province</u>								
Alberta	s	s			s			
British Columbia								CSA only
Manitoba			Not Available					
New Brunswick			Not Available					
Newfoundland	s	s			s			
N.W. Territory			Not Available					
Nova Scotia								CSA only
Ontario	s	s	s		s			
Prince Edward Island			Not Available					
Quebec	s	s	s		s			in French
Saskatchewan								CSA only
Yukon								CSA only

Legend:

- bm - bridge manual
- bcm - bridge construction manual
- cm - construction manual
- fm - falsework manual
- gi - general instructions (Indiana only)
- gn - general drawing notes
- s - standard specification
- scm - steel construction manual
- sp - special provisions
- CSA - Canadian Standards Association

The standard specifications for California, Georgia, Idaho, Kansas, and Nevada also contain more procedural provisions for falsework design, including specific design requirements for falsework, independent review, drawing notes, and inspection. This topic will be discussed in greater detail in chapter six.

Based on a review of design requirements, it is interesting to note that States which are relatively more active in constructing cast-in-place highway bridges generally have more comprehensive specifications and design guidelines. California, Georgia, Kansas, and Nevada indicated that cast-in-place concrete construction is their primary type of bridge superstructure. Idaho listed precast concrete as the primary type, with cast-in-place concrete second. Georgia's current standard specifications apparently evolved from experience on several cast-in-place concrete box girder bridge projects in the 1970's and 1980's.[37]

In general, each State also has a set of minimum construction guidelines for formwork. Most States specifically require that forms be mortar-tight, set true to line, non-bulging, prepared with form release agent prior to concrete placement, and removed after a certain time period or based upon a specified concrete strength. Additional requirements or guidelines include materials for form facing, use of undamaged lumber and plywood, and form tie embedments. The wording differs from specification to specification, but the intent is the same. Each State requires some minimum level of formed concrete quality to insure uniformity throughout their State.

Among the formwork specifications that were reviewed, 20 States had requirements that went beyond form construction and workmanship. Several of these States also had comprehensive falsework design criteria. The design requirements for formwork generally consist of maximum deflection criteria, specified horizontal design loads, and pressures on vertical forms. Fourteen States have maximum formwork deflection criteria. In other instances, separate and more stringent criteria are established. Allowable deflections typically apply to all components of the formwork system, including plywood, studs, joists, and walers.

Eleven of the 20 States identified in table 2 specify design loads for formwork. Most specify that vertical formwork shall be designed for horizontal concrete pressure, based on a given concrete density. Four of the States include formulas for calculating formwork pressures, and another provides a table based on different variables in the specification.

As a final point, table 2 identifies the States that reference either the ACI Committee 347 recommendations or ACI SP- 4 *Formwork for Concrete*.[38, 39] Eight of the States recognize the relevant material contained within these documents, and suggest consultation of these publications for some aspect of falsework and formwork design. Both Minnesota and Missouri refer to concrete pressure formulas from ACI 347 in their construction manuals, whereas Alaska's construction manual uses formwork settlement and recommended tolerances from SP-4.[40] General reference to these ACI documents is found in falsework and formwork specifications from Iowa, Kansas, Oklahoma, and Washington.

National Standards

There are three existing national standards that specifically apply to shoring, scaffolding, and formwork. They are American National Standards Institute (ANSI) A10.9-1983, *American National Standard for Construction and Demolition Operations - Concrete Masonry Work -Safety Requirements*; ANSI A10.8-1988, *American*

National Standard for Construction and Demolition Operations - Scaffolding - Safety Requirement; and ACI 347-88, *Guide to Formwork for Concrete.*[38,41,42] These standards are sufficiently general to apply to building or bridge construction.

ANSI Standard A10.9 was formulated by the ANSI Committee on Safety in Construction and Demolition Operations, and includes requirements for both vertical shoring and formwork. The current version of this standard was based on the ACI 347- 78 guidelines and, therefore, contains similar provisions. The ANSI standard also contains qualitative information on vertical shoring systems and categorizes them as follows: tubular welded frame shoring, tube and coupler tower shoring, and single post shores. Minimum design loads and safety factors are also specified. Further background information and commentary on ANSI 10.9 are provided in reference 43.

ANSI Standard 10.8-1988 covers a broad range of scaffold types, many of which are not applicable to highway bridge structures. However, this standard includes general requirements and provisions for platforms, tube and coupler scaffolds, and fabricated tubular frame scaffolds commonly used to access bridge construction.

ACI 347-88 is the basic source document for many other codes and standards, and has been adopted in its entirety as an ANSI standard. The standard describes various design and construction considerations, and includes special guidelines for bridge construction. ACI Publication SP-4, *Formwork for Concrete* serves as a commentary to ACI 347-88, and includes design aids and illustrative examples and figures.[39] Although ACI 318-89 *Building Code Requirements for Reinforced Concrete* includes some general provisions for design of formwork, and removal of forms and shores, it references ACI 347-88 in the *Commentary.*[44]

In addition to the standards noted above, Occupational Safety and Health Administration (OSHA) Regulation 29CFR, Part 1926, Subpart Q, defines mandatory requirements to protect employees from the hazards of concrete and masonry construction operations.[45] The provisions of ANSI Standard 10.9-1983 are a non-mandatory guideline referenced in an appendix to the OSHA document. Although most States administer their own occupational safety and health programs, they generally adopt the Federal OSHA regulation or similar requirements.

At the present time, both the American Association of State Highway and Transportation Officials (AASHTO) and American Society of Civil Engineers (ASCE) are revising or, in the latter case, developing new standards with respect to temporary works or design loads during construction. The AASHTO revisions were developed from NCHRP 12-34, *Update of AASHTO Standard Specifications for Highway Bridges: Division II - Construction*, and include a new section on temporary works.[46,47] The ASCE effort corresponds to the development of an ANSI/ASCE Standard for Design Loads on Structures During Construction.[48]

FOREIGN STANDARDS

Canada

In 1975, the Canadian Standards Association (CSA) published a national standard entitled *Falsework for Construction Purposes.*[49] As stated in its scope, this standard provides rules and requirements for design, fabrication, erection, inspection, testing, and maintenance of falsework materials and components for buildings and other structures during their construction, alteration, and repair. The falsework standard was prepared by the Technical Committee on Scaffolding for Construction Purposes, which also produced a standard for access scaffolding.[50] The latter document is currently in its second edition. At the present time, CSA has also produced a draft formwork standard.[51] This document is currently being reviewed by the Technical Committee and is scheduled for publication in the near future.

As previously indicated, a questionnaire was distributed to Canadian provincial bridge engineers requesting information similar to that requested from the United States transportation departments. Eight provinces or territories responded and indicated concrete superstructures were their primary bridge type, with precast concrete predominantly used in five provinces and cast-in-place concrete in two provinces. Bridge data from the remaining province was not readily available and, therefore, not furnished.

Based on the responses, most provinces adopt the CSA standards for falsework and formwork. Four of the provinces furnished copies of their applicable specifications, which emphasize or supersede sections of the CSA standard(s). In addition, Ontario indicated that they were in the process of developing their own falsework manual, which may be available by mid-1991.

Great Britain

The Concrete Society and The Institution of Structural Engineers (ISE) jointly prepared a technical report on falsework in 1971.[52] This document generally identified design responsibilities as well as information on timber, steel, and proprietary systems. Following publication of the falsework report, another joint committee was appointed by these organizations to develop a similar report on formwork.[53] This report was prepared "to promote good practice in the design, construction and safe use of formwork, and especially to ensure requisite quality of in-situ or precast concrete in outline and finish." This document serves as a companion to the falsework report.

In 1973, the British Government established a committee to consider safety and other aspects of temporary load bearing falsework and, in particular, bridge falsework. This committee, known as the Bragg Committee, submitted its final report in 1975.[54] Some findings of the Bragg Committee will be discussed in subsequent chapters of this synthesis.

At about the time the Bragg Committee began its investigation, the British Standards Institution initiated the drafting of a code of practice for falsework. The draft British *Code of Practice for Falsework* was published in late 1975, prior to completion of the Bragg report. The draft document was subsequently revised and published as the *Code of Practice for Falsework* in 1982.[55] Related standards and codes of practice are referenced in the Concrete Society/ISE reports, and include *Metal Scaffolding* and *Code of Practice for Access and Working Scaffolds and Special Scaffold Structures in Steel.*[56,57,58]

Australia, New Zealand, and Japan

Australia and New Zealand appear to have modeled their own standards after existing British standards and, in some cases, adopted the same or similar provisions. The Standards Association of Australia recently issued

AS3610, *Formwork for Concrete*, which combines three previous standards in one document.[59] This standard with its commentary, *Supplement 2*, presents design and construction requirements for shoring and formwork of all structure types.[60] In New Zealand, similar requirements are contained in NZS 3109, *Specification for Concrete Construction*.[61]

Temporary structures for Australian bridge projects are further governed by provisions in the *Bridge Design Specifications* as set forth by the National Association of Australian State Road Authorities (NAASRA).[62] Section 12 of this standard, entitled "Design for Construction and Temporary Structures," reviews formwork and falsework design, and is supplemented with appendixes on lateral concrete pressure and testing requirements for components. As in the United States, each Australian State transportation department has provisions that supplement or supersede the national specifications.

Falsework for government bridge projects in New Zealand is regulated by the *Code of Practice for Falsework -Volumes 1 and 2*.[63, 64] Volume 1 contains the code which includes procedural duties, material requirements, loadings, design requirements, and construction guidelines. Volume 2 serves as a commentary.

Japan addresses falsework and formwork design for highway bridges in their *Specifications for Highway Bridges*, published by the Japan Road Association.[65] The provisions in this document are comparable to the AASHTO guidelines on the subject. Further information on temporary support structures is contained in Part 2 of the *Standard Specification for Design and Construction of Concrete Structures*.[66] Both documents have English translations.

Europe

Examination of existing European standards was limited because most of these standards are not English translated. However, several German national (DIN) standards on temporary structures were identified. Included among these documents are DIN standards on lateral concrete pressures, falsework construction, and access scaffolding.[67,68,69] The Swiss have a standard, SIA 162, which includes general information on scaffolding, shoring, and formwork for highway structures.[70] Also, a 1989 draft of the Eurocode incorporates a section on both formwork and falsework.

PUBLISHED LITERATURE AND RESEARCH

The amount of current literature and published research on falsework and formwork, most published since 1970, is fairly extensive. These publications include textbooks, technical journals, conference proceedings, research reports and industry guidelines. Although the textbooks are relatively few in number, there are some notable examples. The United States publications include references 71 and 72. As a result of their efforts to standardize falsework and formwork construction, British engineers have also published several related textbooks. (See references 73, 74, 75, 76.) Some of these authors were directly involved in the committee work that prefaced the British *Code of Practice for Falsework*.

The American Concrete Institute sponsors several industry forums, which have produced some exceptional papers on shoring, formwork, concrete pressures, construction loads, and safety.[77,78,79] The joint ACI-ASCE

Committee report on Concrete Bridge Design (ACI 343-88) contains discussion and recommendations related to construction considerations.[80] In recent years, there also have been dozens of related articles published in ACI journals. Proceedings from conferences held by the Institution of Civil Engineers have also produced some insightful commentary with regards to the British standardization process. In addition to the American and British publications, there have been several articles by engineers in Australia and New Zealand that are particularly noteworthy. References in these articles indicate a considerable amount of technical exchange between engineers in these respective countries.

In the United States, several State highway departments have sponsored in-house or contract research on the subject matter. This research includes studies by Hawaii, South Dakota, and California. (See references 81, 82, 83, 84, 85, 86, 87.) The in-house research work performed by Caltrans was the basis of some of the provisions in their *Falsework Manual*.[88] An extensive amount of research has also been commissioned by the Construction Industry Research and Information Association (CIRIA) in Britain, which resulted in a series of technical reports on formwork pressures and load capacities of adjustable steel props.[89, 90, 91] Further work on these subjects has been conducted in New Zealand.[92, 93]

In Germany, related articles on construction methods can be found in *Beton-Kalender*, which is an annual concrete digest. Several of these articles are identified in the bibliography. Another noteworthy European reference on timber falsework construction for bridges was identified from Yugoslavia.[94]

The Scaffolding, Shoring and Forming Institute (SSFI), a manufacturer's trade association in the United States, has conducted its own testing on steel frame assemblies. *Recommended Procedures for Compressive Testing of Welded Frame Scaffolds and Shoring Equipment* is referenced in ANSI A10.9.[95] SSFI also publishes safety guidelines for shoring concrete formwork, vertical concrete formwork, steel frame shoring, single post shores and scaffolding. (See references 96, 97, 98, 99, 100.) The Scaffold Industry Association, which is an organization representing suppliers and contractors, publishes similar guidelines.[101]

CHAPTER 3. FALSEWORK

DESIGN CONSIDERATIONS

Loads

The design load for falsework or shoring, is generally specified as the sum of dead and live vertical loads, and an assumed horizontal load corresponding to wind, an induced lateral load, or combination of both. A schematic diagram of many of the potential load conditions is shown in figure 1. ANSI 10.9, the AASHTO *1991 Interim Specifications* and many State specifications are relatively consistent with respect to minimum uniform load requirements.[102] A summary of these requirements is outlined in the following paragraphs.

Dead loads include the weight of concrete, reinforcing steel, formwork, and falsework. The weight of concrete, reinforcing steel, and formwork is generally specified to be 160 pounds per cubic foot (lb/ft^3) (2550 kg/m^3) for normal weight concrete or 130 lb/ft^3 (2100 kg/m^3) for lightweight concrete. Some States also specify a minimum vertical load requirement of 100 pounds per sq ft (lb/ft^2) (4.8 kN/m^2).

Live loads typically consist of equipment weights applied as concentrated loads and a uniform load not less than 20 lb/ft^2 (0.96 kN/m^2), plus 75 pounds per lin ft (lb/ft) (1.1 kN/m) applied at the outside edge of the deck overhangs. In California, the latter requirement applies only to overhang falsework and is not applicable to falsework components below the deck overhang system. In order to avoid being overly conservative, the 75-lb/ft (1.1 kN/m) loading is generally distributed over a length of 20 ft (6.1 m) when designing the falsework components below the level of the bridge soffit.

The horizontal load used to design the falsework bracing system includes the sum of lateral loads due to wind, construction sequence, including unbalanced hydrostatic forces from fluid concrete, and stream flow, where applicable. Superelevation, inclined supports, out-of-plumbness, thermal effects, post-tensioning, and less predictable occurrences, such as impact of concrete during placement, stopping and starting of equipment, and accidental impact of construction equipment, can also introduce horizontal loads into the falsework system. In general, AASHTO and many State specifications require that the horizontal design load correspond to the actual sum of potential lateral loads, but not less than 2 percent of total dead load. Some exceptions include Georgia where "the assumed horizontal load shall be the sum of the actual horizontal loads due to equipment, construction sequence or other causes, and a wind load of 50 lb/ft^2 (2.4 kN/m^2), plus 1 percent of the vertical load to allow for unexpected forces, but in no case shall the assumed horizontal load to be resisted in any direction be less than 3 percent of the total dead load," and Kansas, which requires "a minimum 2 percent of total dead load.[31,32] Falsework supporting bridge roadways over 0.04 ft/ft superelevation shall use a minimum lateral load equal to 4 percent of the total dead load."[34]

It is significant to note that accidental impact loads are not specifically quantified. This type of loading is generally addressed, however, by ANSI which requires an additional 25-lb/ft^2 (1.2 kN/m^2) live load where motorized carts are used. Further information on this subject is discussed in reference 71.

Many State bridge specifications do not prescribe wind loads in their falsework and formwork provisions, and there are inconsistencies between States that have established values. California and States with similar

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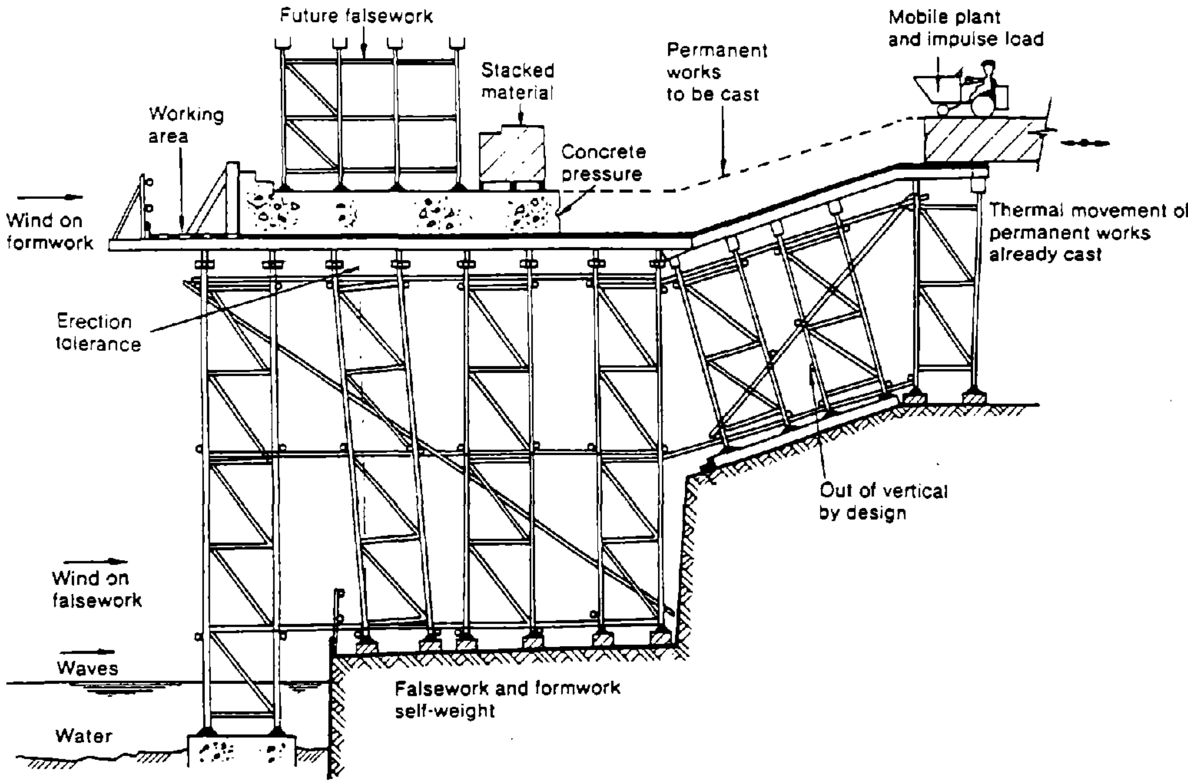


Figure 1. Typical load conditions.[58]

specifications adopt a slightly modified version of the *Uniform Building Code* provisions for open-frame towers, as follows:[103]

The minimum wind load on heavy-duty shoring towers having a vertical load carrying capacity exceeding 30 kips (133 kN) per leg shall be the sum of the products of the wind impact area, shape factor and the applicable wind pressure for each height zone. The wind impact area is the total projected area of all elements in the tower face normal to the applied wind. The shape factor for heavy-duty shoring shall be taken as 2.2. Wind pressure values shall be determined from the following table:

Height Zone (Feet Above Ground)		Wind Pressure Value: Shores Adjacent to Traffic	Wind Pressure Value: At Other Locations
0 to 30	(0 to 9.1 m)	20 psf (0.96 kN/m^2)	15 psf (0.72 kN/m^2)
30 to 50	(9.1 m to 15.2 m)	25 psf (1.2 kN/m^2)	20 psf (0.96 kN/m^2)
50 to 100	(15. 2m to 30.5 m)	30 psf (1.5 kN/m^2)	25 psf (1.2 kN/m^2)
Over 100	(over 30.5 m)	35 psf (1.7 kN/m^2)	30 psf (1.4 kN/m^2)

The minimum horizontal load on all other types of falsework shall be the sum of the products of the wind impact area and the applicable wind pressure value for each height zone. The wind impact area is the gross projected area of the falsework and any unrestrained portion of the permanent structure, excluding the areas between falsework posts or towers where diagonal bracing is not used. Wind pressure values shall be determined from the following table:

Height Zone (Feet Above Ground)		Wind Pressure Value: For Members Over and Bents Adjacent to Traffic Openings	Wind Pressure Value: At Other Locations
0 to 30	(0 to 9.1 m)	2.0 Q psf	1.5 Q psf
30 to 50	(9.1 m to 15.2 m)	2.5 Q psf	2.0 Q psf
50 to 100	(15.2 m to 30.5 m)	3.0 Q psf	2.5 Q psf
Over 100	(over 30.5 m)	3.5 Q psf	3.0 Q psf

where $Q = 1 + 0.2W$; but not greater than 10, and W = width of the falsework system, in feet.

In Britain, the *Code of Practice for Falsework* distinguishes between maximum wind force during the life of the falsework, which represents an extreme condition, and a maximum working wind force during operations.[55] Forces from both of these conditions are used to check the stability of the falsework at appropriate stages of construction. The British Code also has relatively complete guidelines for ice, stream and wave loadings, similar to the provisions for permanent structures in AASHTO.[104]

One of the many recommendations of the Bragg Committee was the so-called 3-percent horizontal rule, "where all falsework structures should be designed to accommodate all identifiable horizontal forces plus an additional allowance of 1 percent of the vertical load in any horizontal direction to allow for the unknown. But in no case should the allowance for horizontal loads be less than 3 percent of the vertical."[54] The committee recognized that certain horizontal forces are identifiable and can be calculated, whereas there are many other forces that are unforseen and not as readily quantified. The *Code of Practice for Falsework* ultimately adopted a 2.5-percent minimum requirement.

The New Zealand *Code of Practice for Falsework, Volume 1* includes specific provisions for lateral loads generated by non-vertical support members, a minimum lateral load equal to 2 percent of the dead load, and a horizontal seismic force.[63] The latter force is obtained from a basic seismic coefficient multiplied by factors representing the risk associated with the falsework exposure period and the consequences of failure.

For post-tensioned construction, it is generally recognized that redistribution of gravity load occurs after the superstructure is stressed. The distribution of load in the falsework after post-tensioning is dependent on factors such as spacing and stiffness of falsework supports, foundation stiffness, superstructure stiffness, and tendon profile and loads. The amount of load redistribution can be significant and may be a governing factor in the falsework design. The AASHTO *1991 Interim Specifications* and some State specifications recognize this potential, but do not offer specific design guidelines. Some research has been conducted on this subject, and is discussed in references 81, 105, 106.

Similar problems have been identified with respect to the redistribution of vertical load due to deck shrinkage. This problem has been researched by Caltrans and is indirectly addressed in their specification.[30,84] Caltrans found that, depending on the falsework configuration, type of construction, and construction sequence, the maximum load imposed on the falsework developed within 4 to 7 days after the concrete was placed, and varied between 110 to 200 percent of the measured load at 24 hours.

Stresses

Twenty-two of the 50 States surveyed specify design criteria for falsework that includes allowable stresses for steel and/or timber construction. A majority of the States with established design criteria adopt the AASHTO provisions for structural steel, with the remainder adopting the AISC allowable stress provisions.[107] Because AASHTO adopts the *National Design Specification for Wood Construction (NDS)*, only the distinctions between this and other specifications will be discussed.[108, 109]

Table 3 summarizes the allowable stresses for structural steel prescribed by AISC, AASHTO, and several States with variations of these provisions. For the latter States, provisions for axial tension, tension in flexure, and shear provisions are generally consistent with either AISC or AASHTO, whereas allowable axial compression and compression in flexure tends to vary. Despite the difference in the constants used in these expressions, most of the equations have the same form and predate the 1963 specifications (6th edition of AISC), when the Structural Stability Research Council formula (AISC eqn. E2-1) was adopted.[110]

Some States also specify allowable stresses for unidentified, or salvaged, steel grades, as shown in table 4. For California, Georgia, Idaho, and Nevada, the allowable flexural and axial compressive stresses are the same as

Table 3. Allowable stresses for structural steel.
(pounds per square inch)

Specification	Axial Tension "F_t"	Flexure, "F_b" Tension	Compression	Axial Compression "F_a"	Shear "F_v"
AISC[a]	0.6 F_y	0.60 F_y	0.60 F_y[b]	Eqn E2-1[c]	0.4 F_y
AASHTO[d]	0.55 F_y	0.55 F_y	20,000 - 7.5 $(L/b)^{(2)}$ [e]	16,980 - 0.53 $(KL/r)^2$ [e]	0.33 F_y
Iowa[f] (F_y = 30 kip/in^2)	0.55 F_y	0.55 F_y	16,500 - 5.2 $(L/b)^2$	14,150 - 0.37 $(KL/r)^2$	0.33 F_y
Kansas[g]	-	18,000	$\frac{12{,}000{,}000}{Ld/bt} \leq 18{,}000$	16,000 - 0.38 $(L/r)^2$	11,000
Kentucky[h]	-	0.55 F_y	-	AISC Eqn E2-1	0.4 F_y
Maryland[i]	24,000	0.55 F_y	20,000 - 7.5 $(L/b)^2$	16,980 - 0.53 $(KL/r)^2$	0.33 F_y
Minnesota[j]	0.55 F_y	0.55 F_y	20,000 - 7.5 $(L/b)^{(2)}$ [e]	16,980 - 0.53 $(KL/r)^2$ [e]	0.33 F_y

1 lb/in^2 = 6895 Pa, 1 kip/in^2 = 6.895 MPa, 1 ft = 0.305 m, 1 in = 25.4 mm

Notes:

a. California, Colorado, Georgia, Idaho, and Nevada adopt AISC allowable stresses for identifiable grades of steel. Louisiana, Maryland and South Dakota permit AISC, subject to approval.
b. Refer to AISC Manual of Steel Construction - Allowable Stress Design for compact sections or compact and non-compact sections with unbraced length greater than L_c.
c. AISC Eqn E2-1:

$$F_a = \frac{F_y}{F.S.}\left[1 - \frac{(KL/r)^2 F_y}{4\pi^2 E}\right] \quad when\ KL/r < C_c$$

$$F_a = \frac{\pi^2 E}{F.S.(KL/r)^2} \quad when\ KL/r > C_c$$

d. States not identified in table or footnote a. adopt AASHTO provisions.
e. Corresponds to A36 steel.
f. Iowa adopts AASHTO provisions, but specifies F_y = 30 kip/in^2.
g. Allowable stresses discussed in Bridge Manual, but not specified in Standard Specifications.
h. Allowable stresses discussed in Construction Manual, but not specified in Standard Specifications.
i. Maryland specifies allowable axial tension and adopts AASHTO for remaining stresses.
j. AASHTO basic unit stress may not be increased by more than one-third for any combination of loads.

Table 4. Allowable stresses for salvaged steel.
(pounds per square inch)

Specification	Axial Tension "F_t"	Flexure, "F_b" Tension	Flexure, "F_b" Compression	Axial Compression "F_a"	Shear "F_v"
California, Georgia, Idaho, Nevada	0.6 F_y	0.6 F_y	$\frac{12{,}000{,}000}{Ld/bt} \leq 22{,}000$	$16{,}000 - 0.38\,(L/r)^2$	0.4 F_y
Colorado	18,000	18,000	$\frac{20{,}000}{1 + \frac{L^2}{2{,}000\,b_f^2}}$ [a]	$\frac{18{,}000}{1 + \frac{L^2}{18{,}000\,r^2}} \leq 15{,}000$ [b]	12,000

1 lb/in^2 = 6895 Pa, 1 kip/in^2 = 6.895 MPa, 1 ft = 0.305 m, 1 in = 25.4 mm

Notes:
a. 18,000 for $L < 15b_f$
b. 18,000 for $L/r < 25$

those specified by Kansas. The allowable compression formulas for Colorado correspond to the Gordon-Rankine format of an early AISC formula.[111,112] For salvaged steel, the States tend to subscribe to older and more conservative allowable stress criteria, as opposed to using more current criteria with a reduced yield stress. The exception is Iowa, which appears to acknowledge the likelihood of salvaged steel being used in falsework construction by limiting the maximum design yield strength to 30 kips per square inch (kip/in^2) (207 MPa), roughly corresponding to the A7 steel common in older bridge construction.

Web crippling is an important consideration when designing the steel beam grillage common to falsework construction; several State specifications contain web crippling provisions. The current AISC specifications have been extensively modified to distinguish between local web yielding, web crippling, and sidesway web buckling. The current web yielding criterion correspond to the original web crippling equations, and are an indication of the load level required to yield the web steel below the top flange. The new web crippling provisions limit concentrated loads to prevent column-type buckling of the web, and the sidesway web buckling provision also limits magnitudes of concentrated load to prevent the tendency for the tension flange to "kick-out" under heavy compression loads.

The AASHTO *Standard Specifications for Highway Bridges* do not specifically require a web crippling analysis. However, AASHTO limits web shear stress to 0.33 F_y and requires bearing stiffeners when web shear stress exceeds 75 percent of this value. Thus, if a steel member is designed in accordance with AASHTO provisions, web crippling or buckling is indirectly accounted for with this design method.

With respect to timber falsework, 16 States reference AASHTO or NDS in their standard specifications. The current AASHTO specification is based on the 1982 edition of NDS and for the purpose of this discussion is considered the same. In addition to referencing AASHTO or NDS, several States specify allowable unit stress values and, in some cases, note exceptions to the national standards. These States and their prescribed stresses are listed in table 5. In general, the tabulated values are unit stresses and subject to modification due to slenderness, moisture content, and other factors. However, contrary to NDS, California and States with similar specifications do not require an allowable stress reduction for wood with a moisture content greater than 19 percent. (See references 30, 31, 32, 33, 36.) California also allows a 50-percent increase in design values for bolts in single shear connections, which is based on in-house research.[83] The allowable stresses specified by Wisconsin and Minnesota include a 25-percent increase to account for short-term load duration.[19, 28]

Stability

Many of the falsework failures identified in this report and investigated by the authors have been attributed to lack of lateral stability. In general, the term "stability" refers to the ability of a component or a system of interconnected elements to resist overturning or collapse. In falsework construction, overall stability is a function of both internal (local) and external (global) conditions. Internally, falsework can be subject to a wide variety of local horizontal forces produced by out-of-plumb members, hydrostatic pressures on formwork, superelevation, differential settlement, and so forth. Therefore, it is necessary for the falsework assembly to be adequately

Table 5. Allowable unit stresses for structural lumber.
(pounds per square inch)

Specification	Extreme fiber in bending "F_b"	Tension parallel to grain "F_t"	Horizontal shear "F_v"	Compression perpendicular to grain "$F_{c\perp}$"	Compression parallel to grain "F_c"	Modulus of elasticity "E"
AASHTO[a]	1450[b]	850	95	625	1000	1,700,000
California[c]	1500-1800	1200	140	450	$\frac{480{,}000}{(L/L_d)^2} \leq 1600$	1,600,000
Indiana[d]	1800	-	185	-	$1800\left(1-\frac{L}{60d}\right)$[e]	1,600,000
Iowa[f]	1200	1000	120	390	1000	1,600,000
Kansas[g]	1200	-	120	250	850[h]	1,500,000
Kentucky[i]	1600	-	125	405	1000	1,600,000
Maryland[j]	1.3(AASHTO) $\leq$ 1800		150-200	1.25(AASHTO)	1.25(AASHTO)	Ref. AASHTO
Minnesota[k]	1875	-	120	480	1560	1,800,000
Wisconsin[l]	1875	-	150	500	1500	-

1 lb/in^2 = 6895 Pa, 1 kip/in^2 = 6.895 MPa, 1 ft = 0.305 m, 1 in = 25.4 mm

Notes:

a. The current AASHTO Specifications (14th Edition) are based on the National Design Specification for Wood Construction (NDS), 1982 Edition. The allowable unit stresses in this table correspond to No. 2 Douglas Fir - Larch used at 19-percent maximum moisture content.
b. Allowable stress corresponds to single member use.
c. Georgia, Idaho and Nevada have similar specifications.
d. The tabulated values correspond to Douglas-Fir.
e. L = length of column, d = least dimension.
f. Allowable stresses correspond to lumber 5 in thick or greater.
g. Allowable stresses discussed in Bridge Manual, but not specified in Standard Specifications.
h. Refers to NDS Section 3.7 for intermediate and long columns.
i. Allowable stresses discussed in Construction Manual, but not specified in Standard Specifications.
j. Maryland references AASHTO and prescribes allowable increases.
k. MnDOT adapts AASHTO. Tabular values correspond to No. 1 Douglas Fir - Larch and include 25-percent increase for short-term load duration.
l. Allowable stresses correspond to No. 1 Douglas Fir and includes 25-percent increase for short term load duration.

connected to resist these forces. In practice, however, the inherent temporary nature of falsework construction does not always translate to a well-connected assembly. The construction shown in figure 2 is generally more representative of as-built conditions.

As noted in the previous section, the stability of beam grillages is an important consideration when designing falsework. This is illustrated in figure 3 where the concentrated reaction from the longitudinal beam(s) is transferred to a transverse ledger beam at a falsework bent. In this case, the transverse ledger beam should be analyzed for web crippling due to the concentrated reactions and overturning. Although it may not be readily apparent from the figure, the longitudinal beam introduces a lateral force component at the top of the transverse ledger beam because of a 3.5-percent grade in the bridge (supported) superstructure.

In conventional shoring systems, individual frames or bents are stabilized by diagonal bracing. In order to simplify the analysis of these structures, California adopts a method of analysis for single tier and multitier frame bents referred to as the "resisting-capacity" procedure. This procedure is similar to the "portal method" and assumes that the horizontal design load is resisted by the sum of horizontal components of the load-carrying diagonals. The adequacy of the bracing is checked by comparing the force associated with the most severe load case with the corresponding allowable member and connection capacities. For multitier bents, the bracing capacity of each tier is evaluated independently of the other tiers. Example problems are provided in the *Falsework Manual*.[88]

External stability and overturning due to lateral or longitudinal loads are generally considered synonymous. If a falsework frame or tower is theoretically stable, external bracing is not necessarily required. However, if the resisting moment is less than the overturning moment, the difference must be resisted by bracing, cable guys, or other means of external support. Depending on the applicable standard, the minimum factor of safety against overturning can vary anywhere between 1.0 and 1.5.[55,63,88] Many States also include a provision requiring the falsework system to be sufficiently stable to resist overturning prior to placement of the concrete.

In order to ensure longitudinal stability, it is necessary to provide a system of restraint to prevent the falsework bents from overturning when the horizontal design load is applied in the longitudinal direction. This type of restraint can be furnished by diagonal bracing between pairs of adjacent bents, or by direct transfer of horizontal load into the permanent piers, as shown in figure 4. Although friction oftentimes provides means of load transfer, so-called "positive connections" eliminate or at least reduce the probability of underestimating the necessary restraint. The need for positive load transfer is particularly apparent when superelevation exists or the soffit is inclined.

The subject of stability and load combinations are generally interrelated. Critical load combinations are identified in reference 113 and illustrated in figure 5. Load case 1 corresponds to the falsework after erection but prior to concrete placement. At this stage, the designer should anticipate the maximum wind load without the stabilizing influence of the poured-in-place concrete. Overturning due to wind and any induced horizontal loads is resisted by the self-weight of the temporary construction and a nominal live load. Load case 2 corresponds to the condition during placement of the concrete. During this stage of work, it is reasonable to assume a moderate wind loading, but is also more likely that the induced horizontal loads due to form pressures, impact,

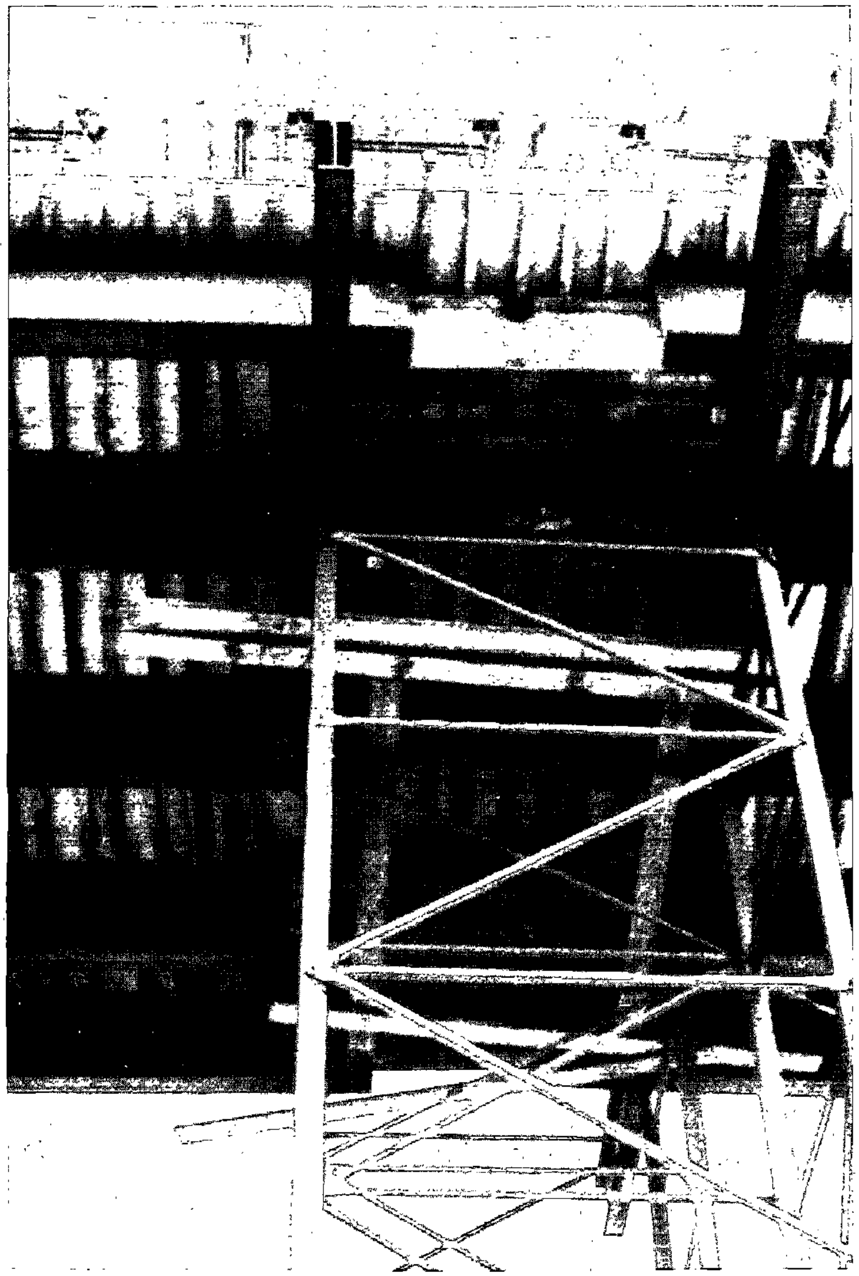


Figure 2. Formwork and beam grillage supported by heavy-duty shoring towers.

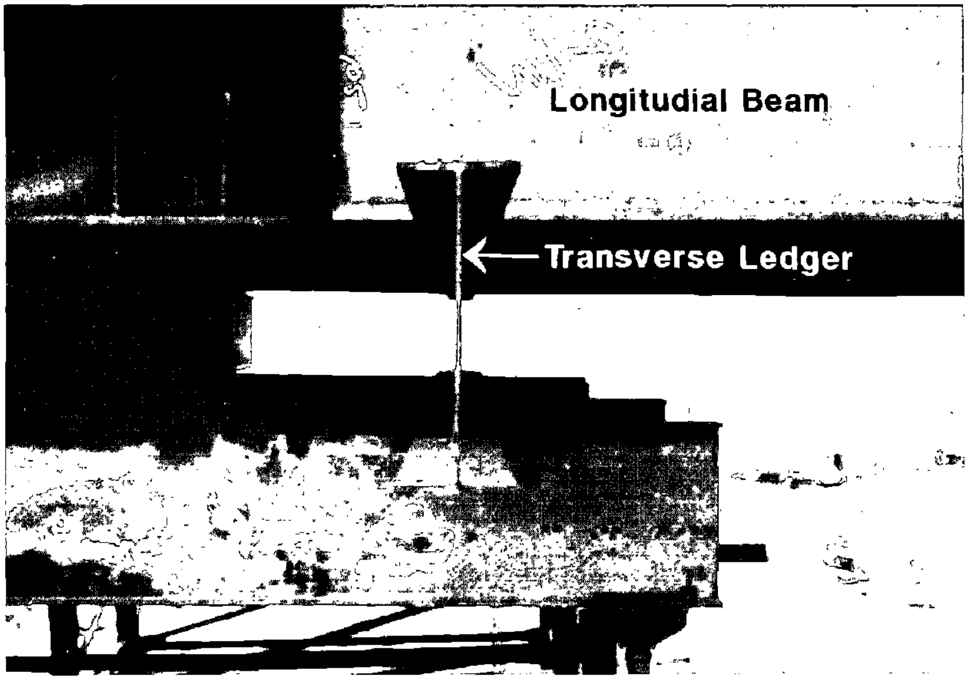


Figure 3. Beam grillage below form soffit.

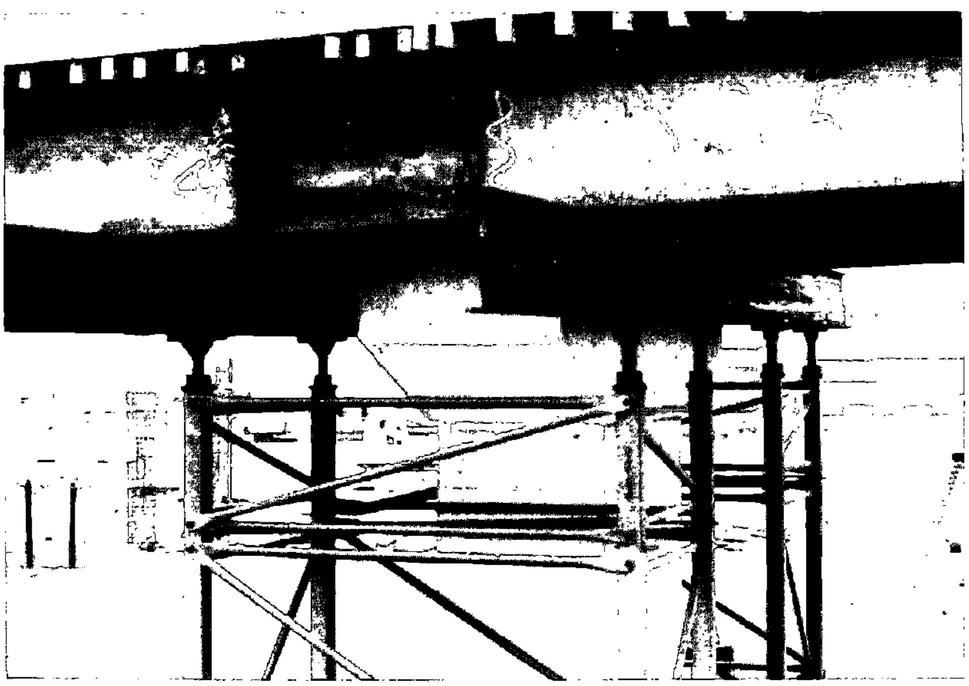
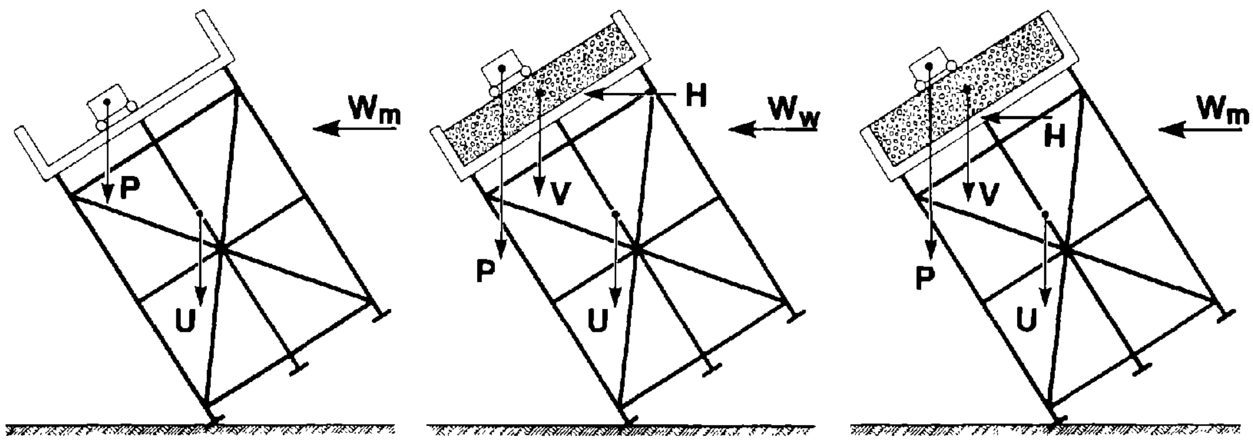


Figure 4. Falsework adjacent to permanent pier.



(i) Falsework just erected

(ii) Falsework during concreting

(iii) Concreting just completed

U = *Formwork and falsework* self-weights.

V = *Dead weight* of concrete being poured.

P = Loading effect of *plant and men* working on the structure.

H = Random *horizontal forces* due to impact, sloping forms, erection tolerances, etc.

W_w = Force exerted by maximum *wind* allowable during *working* conditions.

W_m = Force exerted by *maximum wind* expected during life of scaffold.

Figure 5. Critical load combinations.[113]

or finishing equipment will increase. The maximum and average wind loads correspond to provisions in the British Code.[55] The overturning moment due to lateral loads is resisted by the same vertical loads in load case 1 plus the weight of the freshly placed concrete. Load case 3 corresponds to the same condition as load case 2, but subject to an increased wind load sometime after the concrete is placed.

Deflection and Camber

Many specifications, including the AASHTO *1991 Interim Specifications*, prescribe a maximum allowable deflection for falsework flexural members corresponding to 1/240 of their span. Idaho specifies 1/500 of the span. The intent of this type of limitation is to ensure a reasonable degree of rigidity in the falsework, such that distortion of the forms is minimized. The *California Falsework Manual* states that this deflection is generally based on the assumption that all the concrete in the bridge superstructure was placed in a single pour.[88] However, most specifications are not specific as to how this deflection should be determined. The actual deflection will depend on the sequence of construction when two or more pours are required for a given span.

Uplift can occur when falsework beams are continuous over a long span, coupled with a relatively short adjacent span. Two common examples of this condition are longitudinal beams with short end spans and a transverse beam with a relatively long overhang. In the longitudinal example, uplift can occur at the end support. For the latter case, shown in figure 6, uplift can occur at the first interior post (support). Both of these conditions can contribute to instability and therefore should be carefully analyzed or avoided.

Caltrans has conducted research on curing effects and concrete support periods on dead load deflections of reinforced concrete slab bridges. Their findings indicated that variation in curing time from 7 to 21 days did not significantly affect deflections. However, the difference between 7- and 10-day support periods and 10- and 21-day support periods was significant. The end result was a revision to the "effective modulus" used to calculate ultimate deflections.[86]

As described in reference 88, camber adjustments are made to the profile of a load-supporting beam so the completed structure will have the lines and grades shown on the contract plans. The most common method of camber adjustment is to attach camber strips or lengths of wood to the top of the falsework beam to obtain the desired profile. In general, this adjustment is made to account for anticipated deflection of the falsework beam, vertical curve compensation, superstructure deflection, and any residual camber that may be required. In theory, when falsework spans are relatively short, the adjustment for vertical curve, superstructure deflection, and residual camber may be neglected. However, as falsework spans increase, these factors become increasingly more significant.

Traffic Openings

Traffic openings in falsework are relatively common, particularly for bridge construction over public roads. Several State specifications contain special provisions for traffic openings, including clearance requirements and special load conditions. Clearance requirements are also identified in the ACI Committee 343 report. California devotes an entire chapter of the *Falsework Manual* to this subject and has some of the most comprehensive

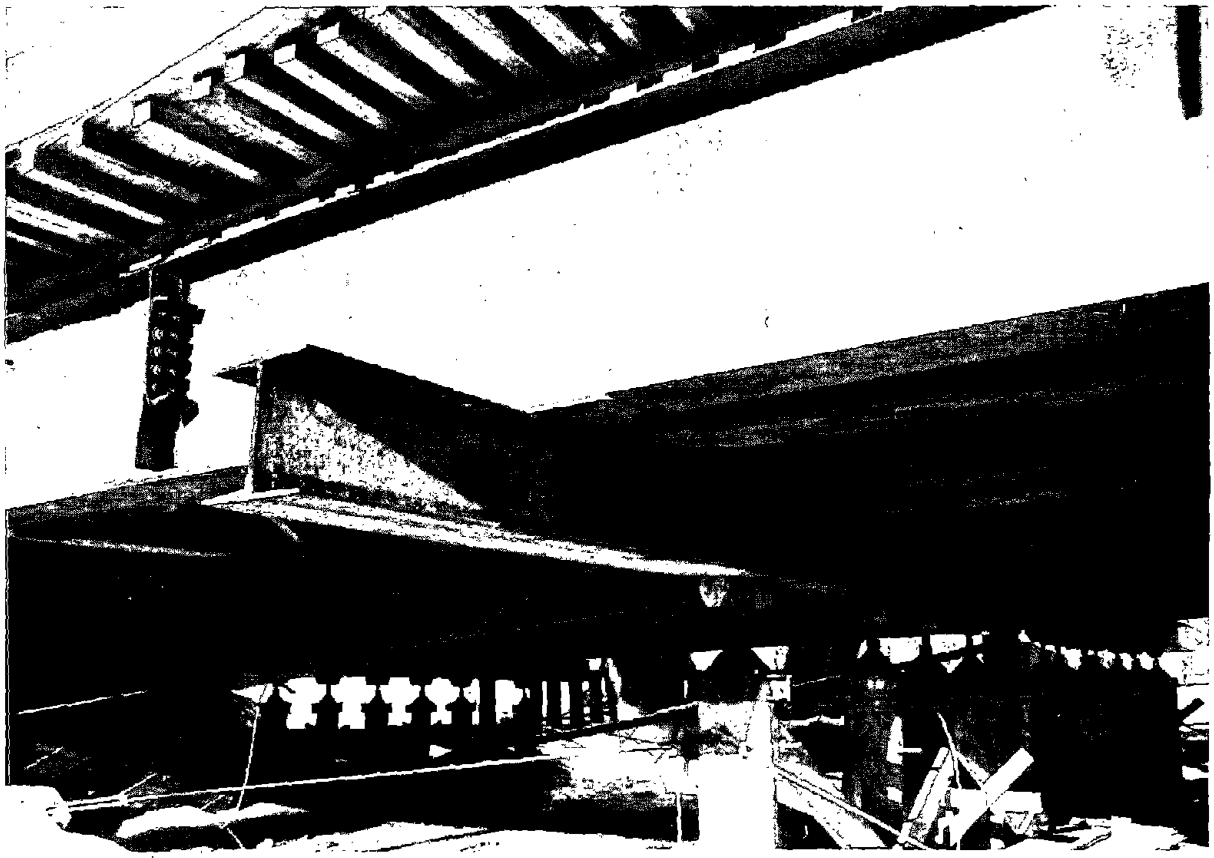


Figure 6. Cantilevered ledger beam at temporary pile bent.

specifications. Falsework over or adjacent to roadways or railroads, which are open to traffic, are required to be designed and constructed so that the falsework remains stable if subjected to accidental impact. The Federal Lands Highway Office (FLHO) of the FHWA has adopted similar requirements, which include:[114]

> The vertical loads used for the design of falsework columns and towers, but not footings, which support the portion of the falsework over or immediately adjacent to open public roads, shall be increased to not less than 150 percent of the design loads which would otherwise be calculated in accordance with these provisions.
>
> Each column or tower frame supporting falsework over or immediately adjacent to an open public road, shall be mechanically connected to its supporting footing at its base, or otherwise be laterally restrained, so as to withstand a force of not less than 2,000 pounds (lb) (8.9 kN) applied to the base in any direction. Such columns or frames shall also be mechanically connected to the falsework cap or stringer so as to be capable of withstanding a horizontal force of not less than 1000 lb (4.4 kN) in any direction.
>
> When timber members are used to brace falsework bents which are located adjacent to openings for public traffic, all connections for such bracing shall be bolted using 5/8 in (15.9 mm) or larger bolts.
>
> When falsework towers or columns are located adjacent to an open public roadway, the falsework shall be protected from the traffic at all times by temporary concrete barrier system configured in accordance with the Traffic Control Plan. The falsework shall be located so that falsework footings or pile caps are located at least 3 in (76 mm) clear of concrete traffic barriers, and all other falsework members are at least 1 ft (0.31 m) clear of concrete traffic barriers.

STEEL SHORING SYSTEMS

The term "steel shoring" can describe a wide range of vertical and horizontal shoring systems. The discussion in this section, however, is limited to vertical shoring systems, which include tubular welded frames, tube and coupler towers, and single post shores. In the United States, modular systems began to develop in the 1940's and were widely used in concrete construction by 1950.[115] The modular systems were preceded by tube and coupler shoring, which is still very common in Great Britain.

ANSI Standard 10.9 requires that allowable loads for vertical shoring be based upon the *Recommended Procedures for Compression Testing of Welded Frame Scaffolds and Shoring Equipment* developed by SSFI.[95] These procedures include test methods for four-legged frames, screw jacks, and post shores. CSA 269.1 *Falsework for Construction Purposes* contains a similar procedure. ANSI requires shoring design and specifications to be based on working loads using this procedure, with a factor of safety of at least 2.5.[41] Alternative test methods have been developed by others.[116,117,118]

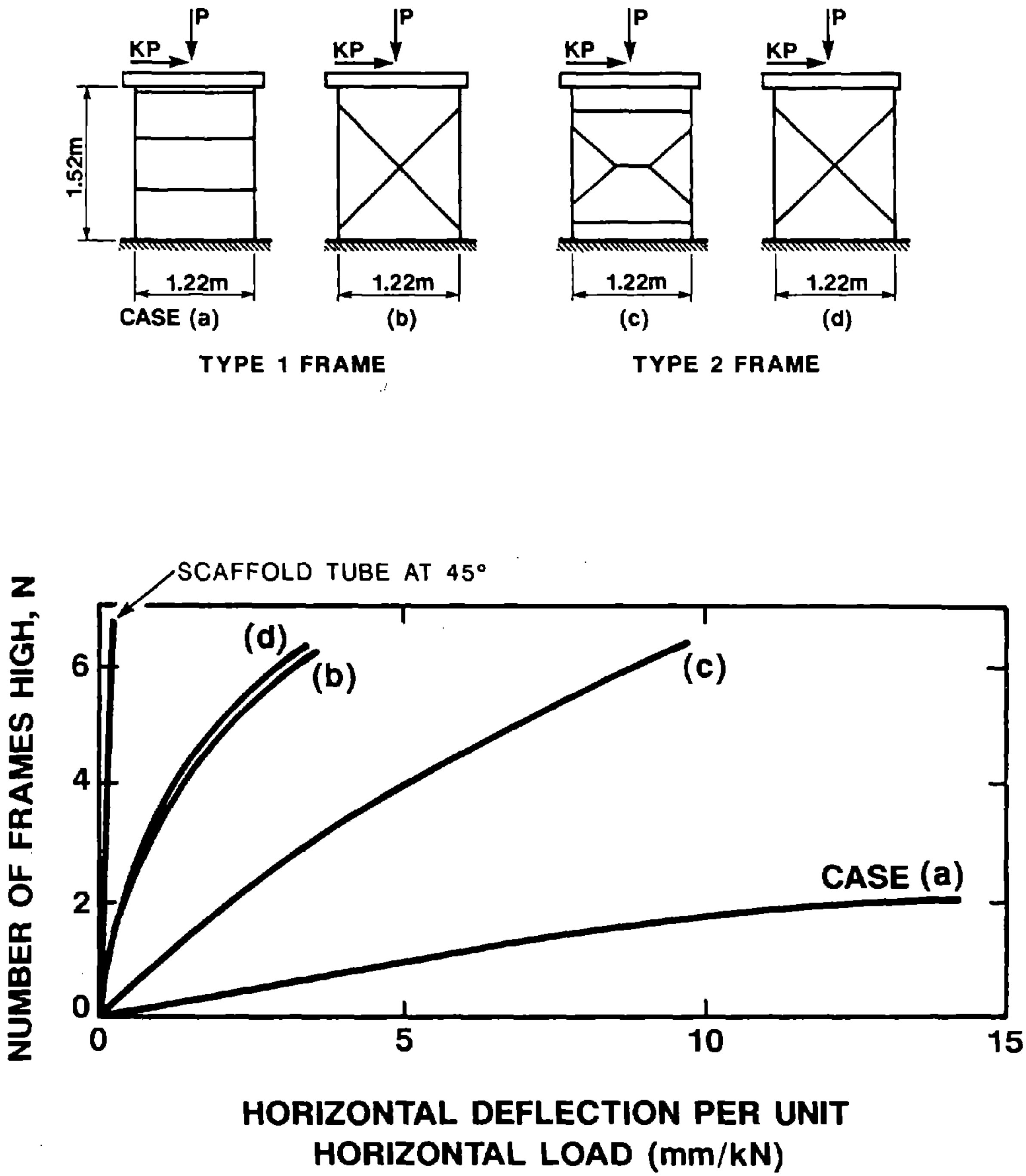
In the *Falsework Manual*, Caltrans classifies steel shoring systems by load-carrying capacity.[88] The so-called "pipe-frame" systems consist of ladder or cross-braced frames with maximum allowable leg loads from 10,000 to 11,000 lb (44.5 to 48.9 kN). When externally unbraced, pipe-frame assemblies are generally limited to 20-ft (6.1-m) heights. Intermediate frames are described as cross-braced frames with an allowable load-carrying capacity of up to 25,000 lb (111 kN) per leg. Heavy-duty shoring systems have allowable leg loads of 100,000 lb (445 kN). Despite these distinctions, the California specifications define steel shoring with allowable leg loads greater than 30,000 lb (133 kN) as heavy-duty. The latter definition is probably more common within the industry.

In the United States, there are several manufacturers of proprietary shoring systems. However, there are no industry standards for the various components of these structures and, as a general rule, towers or components produced by different manufacturers should not be intermixed. Some other limitations or general characteristics of modular systems are as follows:

- Allowable leg capacities are generally reduced when the screw jacks, or extension legs are fully extended.
- Multitiered towers stacked in excess of two frames high have lower allowable leg capacities than single- or double-tier towers.
- Some manufacturers allow a 4 to 1 differential leg loading between two legs of a frame, or two frames in a tower. Significant differential leg loads are generally discouraged, however, unless substantiating data can be furnished by the manufacturer that indicate that the differential loading will not overstress the tower components.
- As shown in figure 7, the drift characteristics of proprietary systems can vary considerably depending upon their bracing configurations. The ladder frames exhibit the least lateral stiffness and very little benefit is derived from horizontal braces.

In comparison with the United States proprietary systems, the tube and coupler scaffolding in Britain tends to be more standardized. In addition to the *Code of Practice for Falsework*, the British Standards Institute publishes CP97 *Code of Practice for Access and Working Scaffolds and Special Scaffold Structures in Steel* and BS1139 *Metal Scaffolding*.[56, 57, 58] Although the latter standards are primarily descriptive in terms of materials and tolerances, they also provide guidance on bracing arrangements, effective lengths, joint eccentricity, and allowable loads for couplers and fittings.

The British have also conducted a considerable amount of research on the behavior of adjustable steel props, or post shores. In the mid to late 1970's, the CIRIA commissioned three separate studies on this subject. The first concerned the influence of site factors on prop strengths and identified significant discrepancies between the test methods of BS4074 *Specification for Metal Props and Struts* and conditions found on-site.[90] General guidelines were recommended with respect to erection, maintenance and safe working loads. The report recommended that corrections should be made to the capacity of any prop which exceeds 1 1/2-degrees out-of-plumb and that maximum eccentricities be limited to 1 1/2 in (38.1 mm). Safe working loads were established



(1 in = 25.4 mm, 1 ft = 0.305 m, 1 kip = 4.45 kN)

Figure 7. Load-deflection characteristics of proprietary frames.[106]

by applying a factor of safety of two to the measured collapse loads. This information is included in the British Code and reproduced in figure 8. The second study was a follow-up to the original investigation and proposed improvements in the method of testing props so the results of tests on different manufacturer's components could be directly compared.[91] It is interesting to note that test results on used and repaired props were similar to those results obtained with new props. The third study was on the distribution of loading on props to soffit formwork due to transitory loads and impact forces during concrete placement.[119]

ERECTION AND BRACING

Many existing standards, including the AISC *Manual for Steel Construction* and the AITC *Timber Construction Manual*, contain general requirements with respect to erection tolerances and alignment. Although these standards were developed for permanent construction, they can also serve as a useful guide(s) for temporary structures. Recommendations for erection of steel frame shoring, tube and coupler shoring, and post shores are published by SSFI, and commonly appear on plans prepared by SSFI member companies. Similar guidelines are published by SIA.[101]

As noted earlier, the British *Code of Practice for Falsework* (BS 5975) adopts the CIRIA erection tolerances for adjustable steel props. For tube and coupler falsework, the following requirements are specified:

- Vertical members should be placed centrally under the members to be supported and over the member supporting them with no eccentricity exceeding 1 in (25.4 mm).

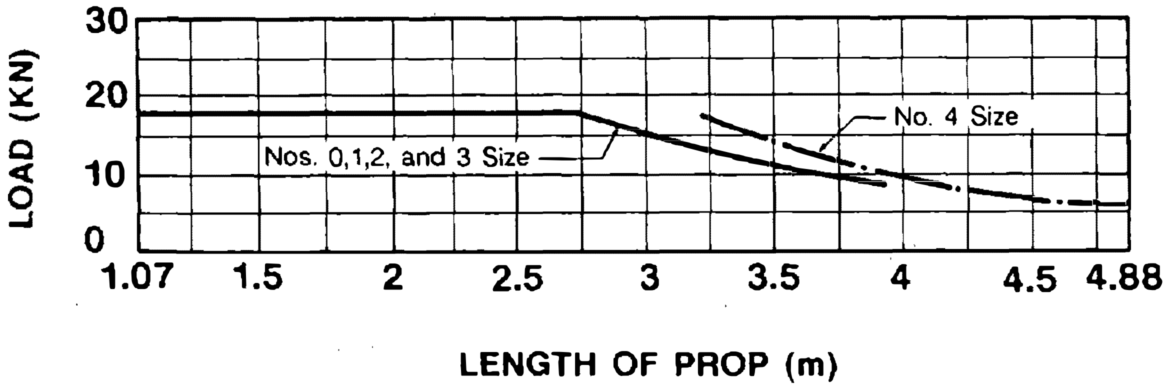
- Adjustable forkheads and baseplates should be adequately laced or braced where their extension exceeds 12 in (305 mm), unless an alternative figure is specified. The bracing tubes should be attached close to the fork or baseplate and to an adjacent vertical member, close to the lacing.

- Verticals should be plumb within 0.60 in (15 mm) over 6.56 ft (2 m) of height, subject to a maximum displacement from the vertical of 1 in (25.4 mm).

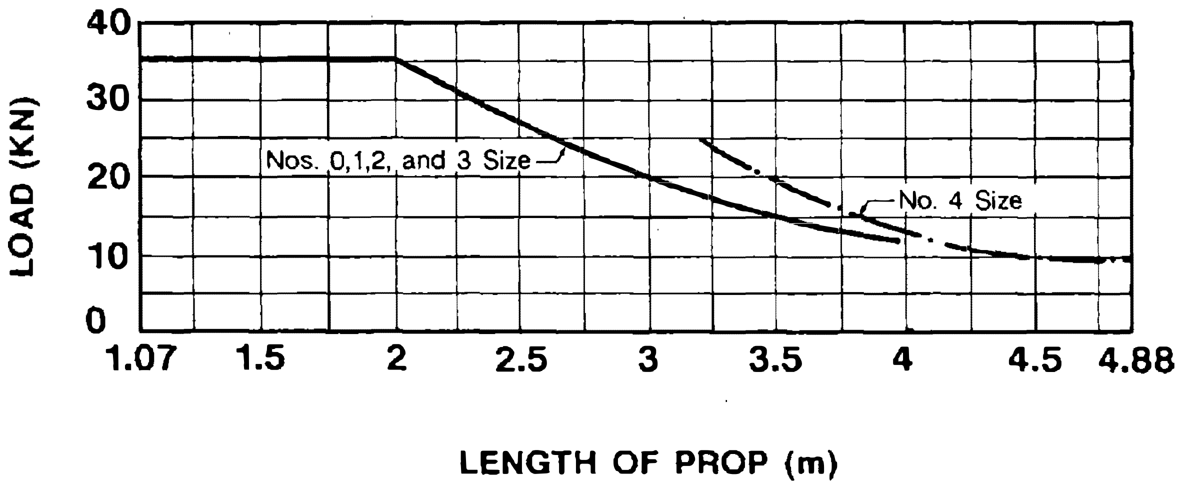
- The centerlines of tubes at a node point should be as close together as possible, and never more than 6 in (152 mm) apart (see figure 9).

- Sole plates used to distribute falsework loads on to foundation soils should normally be set horizontally within a tolerance not exceeding 1 in (25.4 mm) in a length of 3.28 ft (1 m).

Although the British Code allows a 1-in (25.4-mm) eccentricity in vertical load, eccentric loads on shore heads should generally be avoided. The shim and blocking details shown in figure 10 are recommended to minimize this type of eccentricity.



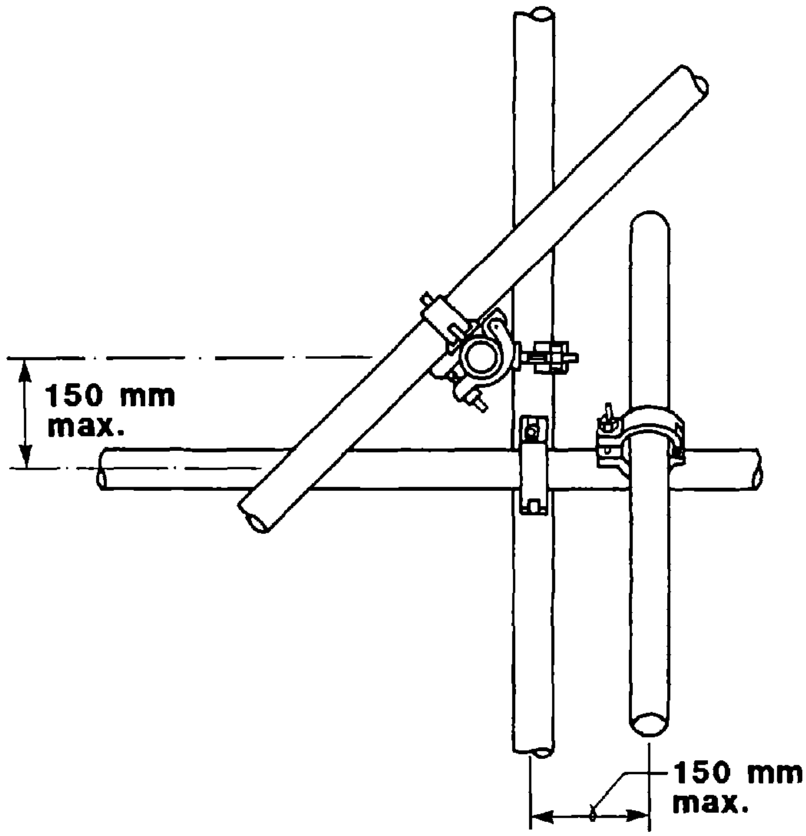
(a) 1.5° maximum out-of-plumb and 25-mm maximum eccentricity.



(b) 1.5° maximum out-of-plumb with concentric load.

(1 ft = 0.305 m, 1 kip = 4.45 kN)

Figure 8. Safe working loads for props.[55]



(150 mm = 5.9 in)

Figure 9. Maximum deviation of load path.[55]

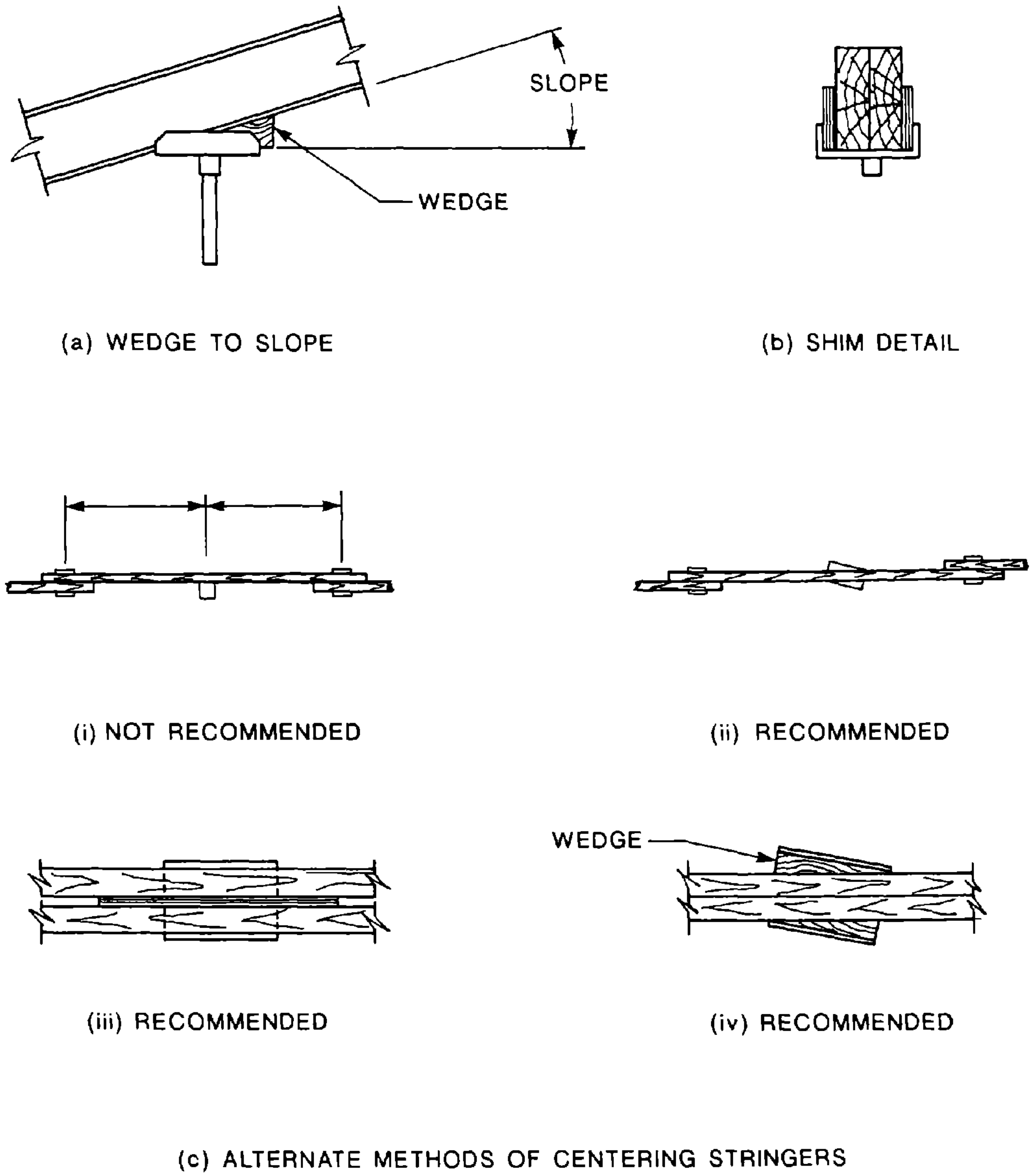


Figure 10. Recommended details for beams in forkheads.[120]

As a general rule, manufacturers of modular frames recommend external bracing when the height exceeds four times the least base dimension. Therefore, it is common practice to connect rows of towers to each other with tube and coupler horizontal lacing members or, where practical, with additional cross-bracing so rows of frames are continuously cross-braced in one plane.

Bracing and lacing bridge falsework in the transverse and longitudinal direction is particularly common for tube and coupler scaffolding, and a considerable amount of published literature can be found with respect to these bracing arrangements.[63,106,121] Many guidelines in this literature also apply to modular frame construction. In general, braces should be connected as near as possible to nodes and, where continuous diagonal bracing tubes are used, connections at the node points or intermittent node points are recommended. The effect of alternative coupler positions are shown in figure 11. The buckled shapes in figure 11(a) and (b) illustrate that the buckling load required to produce failure is much less than in figure 11(c) because the unbraced lengths are longer.

Other common bracing schemes are identified in figure 12. An arrangement of steeply inclined braces may be more effective than a brace at a flatter angle, because of a reduction in the unsupported length. The use of cross bracing provides a redundant system, however, and when subject to lateral load will insure that at least one brace remains in tension. In lieu of cross bracing, alternate bents generally have opposite diagonals. As shown, braces cease to be effective if connected at locations where the vertical load is removed and lift-off can occur due to the vertical component of the brace reaction.

Sufficient plan (horizontal) bracing is also required to transmit lateral loads to the resisting bents. For tube and coupler scaffolding, reference 121 recommends that plan bracing should occur at the top and bottom lifts (tiers) and at least every third intermediate lift. In general, plan bracing at the top tier can be omitted when the grillage used to support the permanent structure is capable of acting as a diaphragm. When shoring a sloped surface, however, tube bracing coupled to each leg and in both directions is recommended. This detail is illustrated in figure 13.

In the United States, external cable bracing is commonly used to resist overturning of tall and slender falsework. As outlined in the *California Falsework Manual*, the safe working load of the cable is based on the breaking strength multiplied by the efficiency of the cable connector(s) and divided by a factor of safety of 2 or, in lieu of better information, the safe load prescribed in table 6 divided by a safety factor of 2. Cable connectors are, in turn, designed in accordance with the criteria in tables 7 and 8. Because external cable bracing does not prevent horizontal deflection of the top of a multitiered frame, a reduction in horizontal design load is not allowed when investigating the adequacy of tower components under combined vertical and horizontal forces.

FOUNDATIONS

In general, the responsibility for designing temporary foundations is almost always assigned to the contractor. Beyond this type of assignment, however, many State specifications are vague with respect to foundation requirements. Some of the more explicit specifications are as follows:[30]

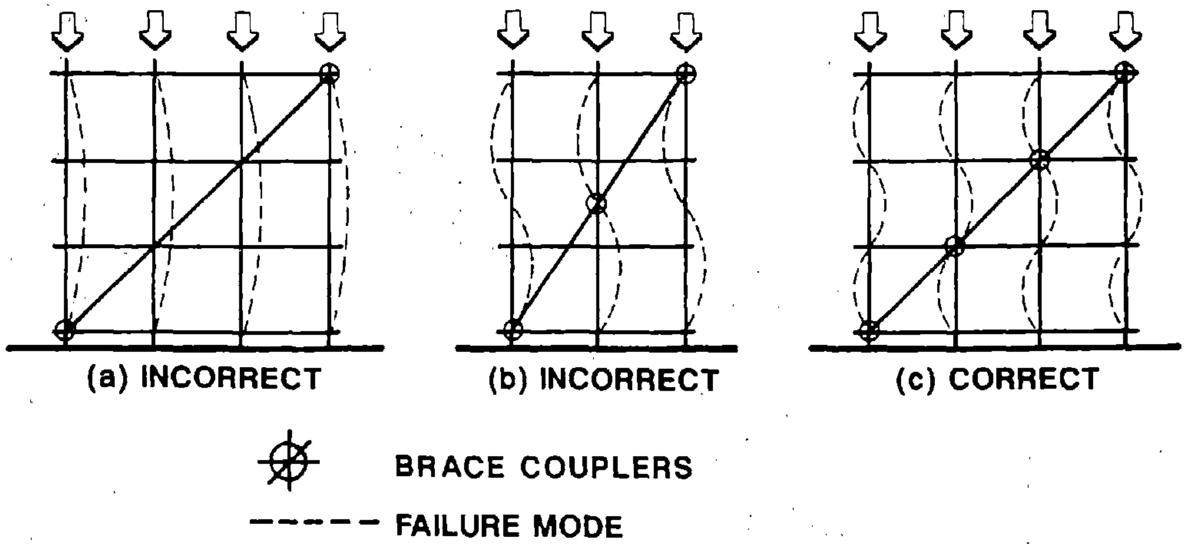


Figure 11. Brace coupler positions.[121]

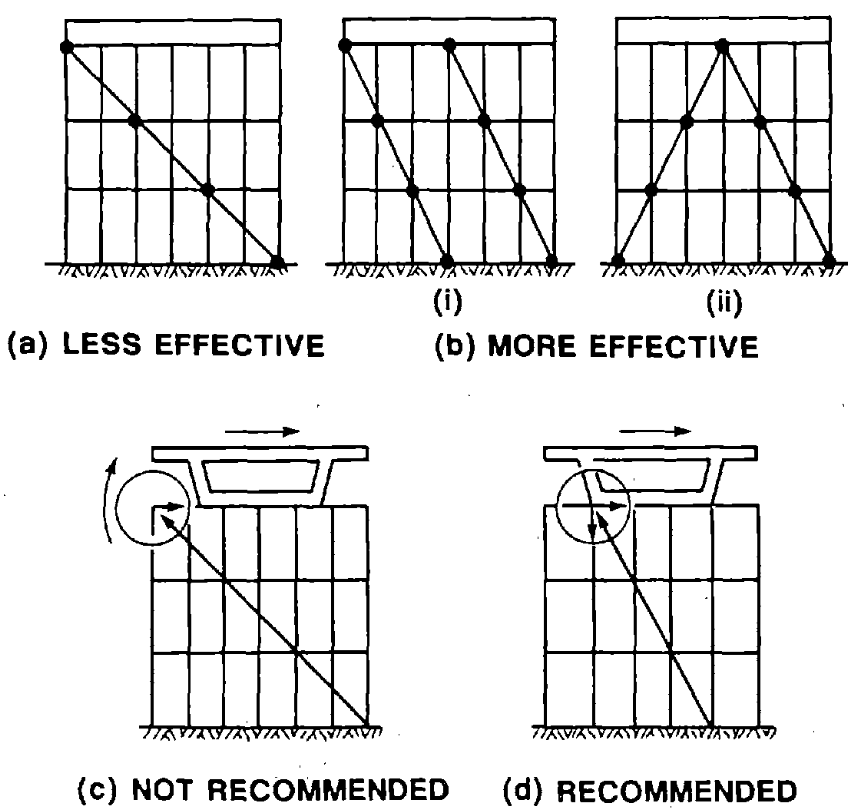


Figure 12. Scaffold tube falsework details.[106]

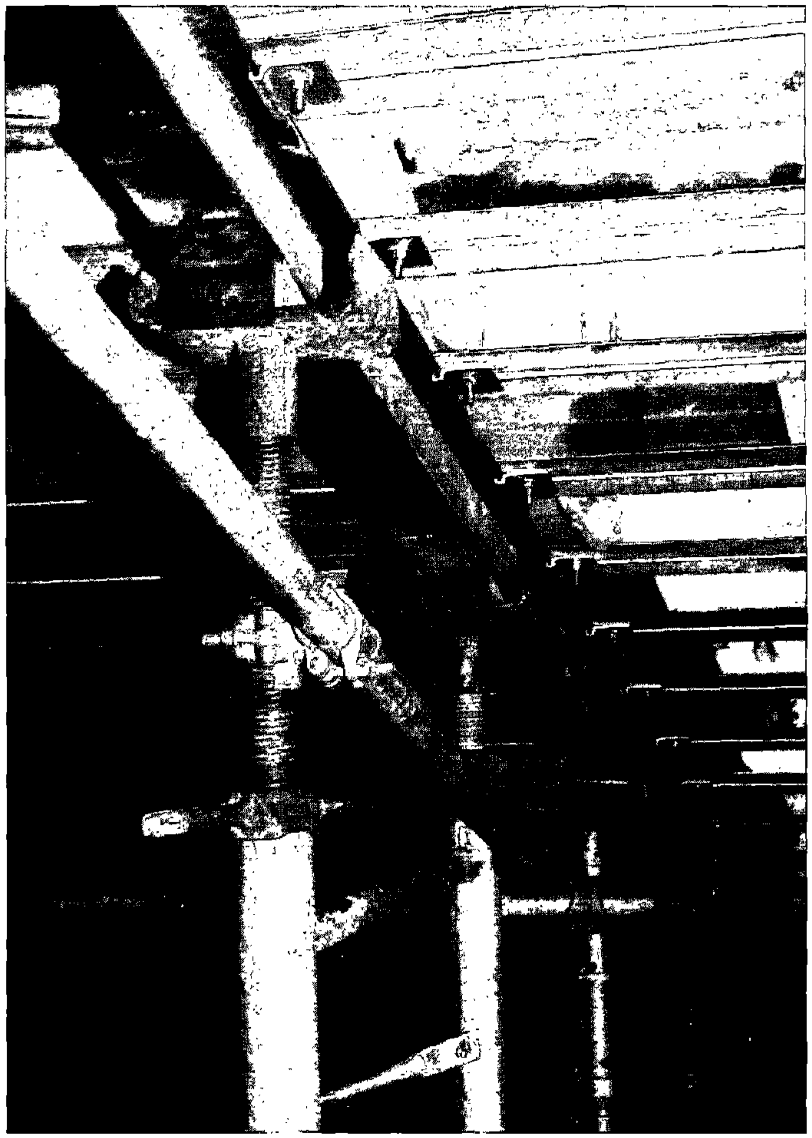


Figure 13. Bracing detail for screw leg supporting a sloped soffit.

Table 6. Wire rope capacities.[88]

Safe load in pounds for new improved plow steel hoisting rope
6 strands of 19 wires, hemp center
(Safety Factor of 6)

Diameter (inches)	Weight (lbs/ft)	Safe Load (lbs)	Diameter (inches)	Weight (lbs/ft)	Safe Load (lbs)
1/4	.10	1,050	1	1.60	15,000
5/16	.16	1,500	1-1/8	2.03	18,600
3/8	.23	2,250	1-1/4	2.50	23,000
7/16	.31	3,070	1-3/8	3.03	25,900
1/2	.40	4,030	1-1/2	3.60	30,700
9/16	.51	4,840	1-5/8	4.23	35,700
5/8	.63	6,330	1-3/4	4.90	41,300

1 in = 25.4 mm, 1 lbs = 4.45 N, 1 lb/ft = 14.59 N/m

Table 7. Wire rope connections.[88]

(As compared to Safe Loads on Wire Rope)

Type of Connection	Efficiency
Wire Rope	100%
Sockets-Zinc Type	100%
Wedge Sockets	70%
Clips-Crosby Type	80%
Knot and Clip (Contractors Knot)	50%
Plate Clamp-Three Bolt Type	80%
Spliced Eye and Thimble:	
1/4" and smaller	100%
3/8" to 3/4"	95%
7/8" to 1"	88%
1-1/8" to 1-1/2"	82%
1-5/8" to 2"	75%
2-1/8" and larger	70%

1 in = 25.4 mm

Table 8. Number of clips and spacing for safe application.[88]

Improved Plow Steel Rope Diameter (inches	Number of Clips Drop Forged	Number of Clips Other Material	Min. Spacing (inches)
1/3	3	4	3
2/3	3	4	3-3/4
3/4	4	5	4-1/2
7/8	4	5	5-1/4
1	5	6	6
1-1/8	6	6	6-3/4
1-1/4	6	7	7-1/2
1-3/8	7	7	8-1/4
1-1/2	7	8	9

1 in = 25.4 mm

> Falsework footings shall be designed to carry the load imposed upon them without exceeding the estimated soil bearing values and anticipated settlements.
>
> Anticipated total settlements of falsework and forms shall be shown on the falsework drawings. These should include falsework footing settlement and joint take-up. Anticipated settlements shall not exceed one inch. Falsework supporting deck slabs and overhangs on girder bridges shall be designed so that there will be no differential settlement between the girders and the deck forms during placement of deck concrete.
>
> Foundations for individual steel towers where the maximum leg load exceeds 30 kips shall be designed and constructed to provide uniform settlement under all legs of each tower under all loading conditions.
>
> When footing type foundations are to be used, the Contractor shall determine the bearing value of the soil and shall show the values assumed in the design of the falsework on the falsework drawings.
>
> Falsework shall be founded on a solid footing safe against undermining, protected from softening, and capable of supporting the loads imposed on it. When requested by the Engineer, the Contractor shall demonstrate by suitable load tests that the soil bearing values assumed for the design of the falsework do not exceed the supporting capacity of the soil.

With respect to the latter provisions, California is the only State that prescribes specific load test procedures, and allowable bearing stress for sand and clay soils.

As with permanent structures, the type of foundation(s) required for temporary works is a function of soil conditions and design loads. Depending on the falsework system, foundation loads can be distributed over the entire length of a supported span or concentrated at temporary bents. In either case, timber foundation pads, or mud sills, may be adequate to support the falsework and construction loads.

With an increase in leg load, the method of foundation support on intermediate and heavy-duty shoring towers becomes more significant. As noted above, some States require that foundations be designed for uniform settlement under all legs of the tower and under all loading conditions. For heavy-duty shoring, this necessitates the use of concrete mats or pile foundations, as opposed to timber cribbing. Pile foundations are required when site conditions preclude timber cribbing or concrete pads, and are generally specified to support falsework for bridge structures over water or where conventional pad foundations are not feasible due to poor soil conditions. In some cases, temporary construction loads are supported by brackets off the permanent piers and abutments, shown in figure 14. However, several States do not permit this practice.

The AASHTO *Standard Specifications for Highway Bridges* contain several sections which relate to foundations.[103] Many of these provisions, however, apply to permanent pier construction and sections applicable to falsework construction, for example, pile and framed bents, and timber cribbing, are generally more qualitative. For the most part, basic design information for both permanent and temporary construction is limited to pile

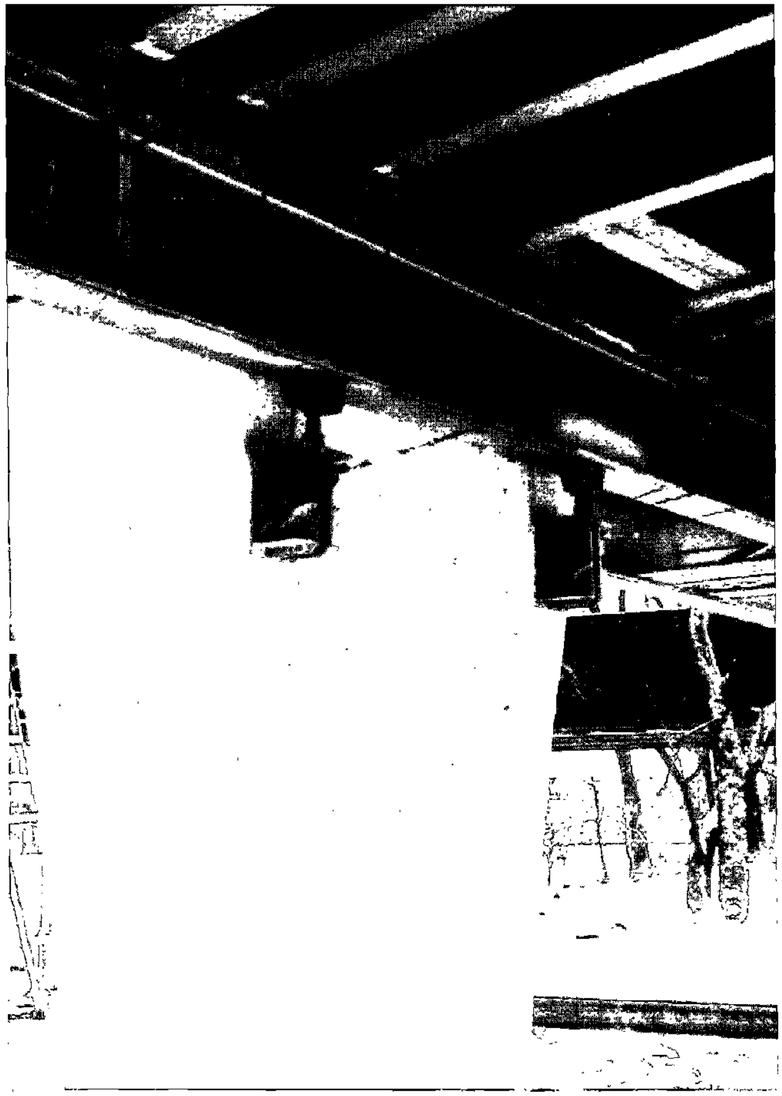


Figure 14. Temporary support brackets.

design criteria, and forces due to stream current and ice loads. The AASHTO Division II *1991 Interim Specifications* for temporary works do not contain specific guidelines for foundation design.

In the *Falsework Manual*, Caltrans addresses several aspects of foundation design unique to temporary construction. Caltrans outlines specific design procedures for timber sills based on an effective length over which the applied post loads are assumed to be uniformly distributed. The effective length depends on whether the pad is symmetrically or asymmetrically loaded, and general formulas are provided. The *Falsework Manual* also includes some specific guidelines and design procedures for pile foundations. The majority of the discussion relates to timber pile bents and an empirical method of analysis based on a modified combined stress equation. The derivation of the equation is described in detail, and is based upon field testing and analytical studies.[87] General guidelines with respect to required penetration, point-of-fixity, and soil relaxation are also discussed.

The procedures developed by Caltrans for timber pile bents are not applicable to steel pile bents. In general, the subsurface conditions which require the use of steel pile bents are not conducive to the development of a true point of fixity in the pile. Therefore, piles used in steel pile bents are assumed to be columns pinned at the pile tip. Steel pile bents must be stable against overturning and, as a result, the method of analysis is similar to the "resisting-capacity" previously discussed.

Design of concrete footings is addressed in a number of textbooks and, therefore, not specifically discussed in this section.[122] However, as shown in figure 15, plain concrete (unreinforced) when overloaded may fail in a brittle mode, which can result in significant vertical displacement and redistribution of vertical shoring loads. Therefore, although permitted by ACI and AASHTO, the use of a plain concrete pad as flexural element to support heavy-duty shoring loads is not always desirable.

With the exception of piles, the British *Code of Practice for Falsework* (BS 5975) is relatively complete with respect to foundations and ground conditions for temporary works. Pile foundations are addressed in a separate British standard on foundations. BS 5975 includes allowable bearing pressures for a wide range of rock and soil types and an identification table similar to Unified System of Classification (ASTM D-2487).[123] New Zealand adopts a similar standard, which includes a fairly comprehensive review of soil properties and foundation design.[63, 64]

As a further note, the British Code includes modification factors which, depending upon the reliability of site information, magnitude of anticipated settlement, and fluctuations in ground water level, are applied to the prescribed bearing pressure. The Code also contains some specific guidelines for the protection of foundation areas, including:

- No distribution members should be set or bedded on to frozen ground.
- Edges subject to erosion, for example, the edges of slopes and terraces, should be protected against eroding forces. An example of this type of erosion is shown in figure 16.
- Groundwater flows affecting the ground strata or ground surface should be reported to the falsework designer.

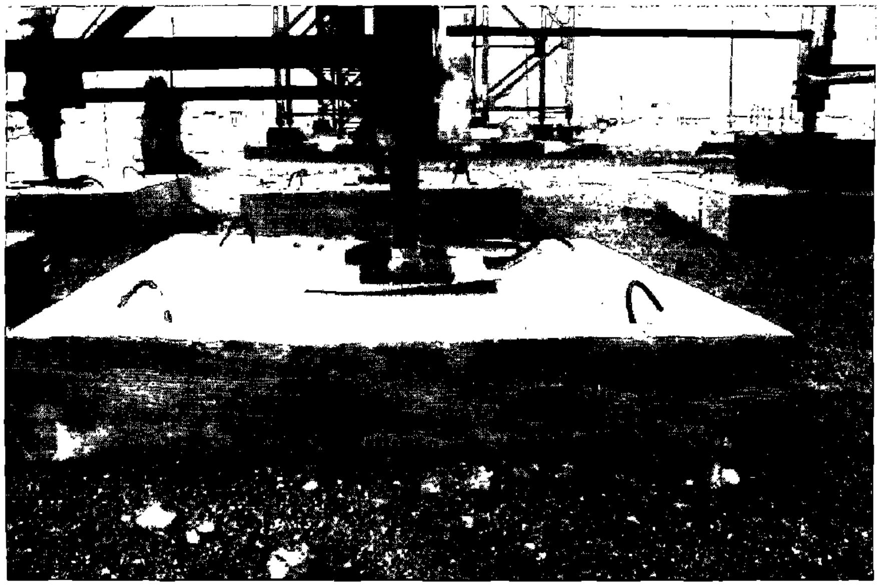


Figure 15. Plain (unreinforced) concrete footing.

Figure 16. Washout under sill support.

- Any rock outcrops, buried rocks, or obstructions that are uncovered and not indicated on the drawings should be compared with the design assumptions as they can result in differential settlements.
- Where the requirements are such that foundation members need to be set other than level, appropriately shaped packs should be used at the base of the vertical, and the foundation member should be effectively prevented from moving down the slope. (See figure 17 below).

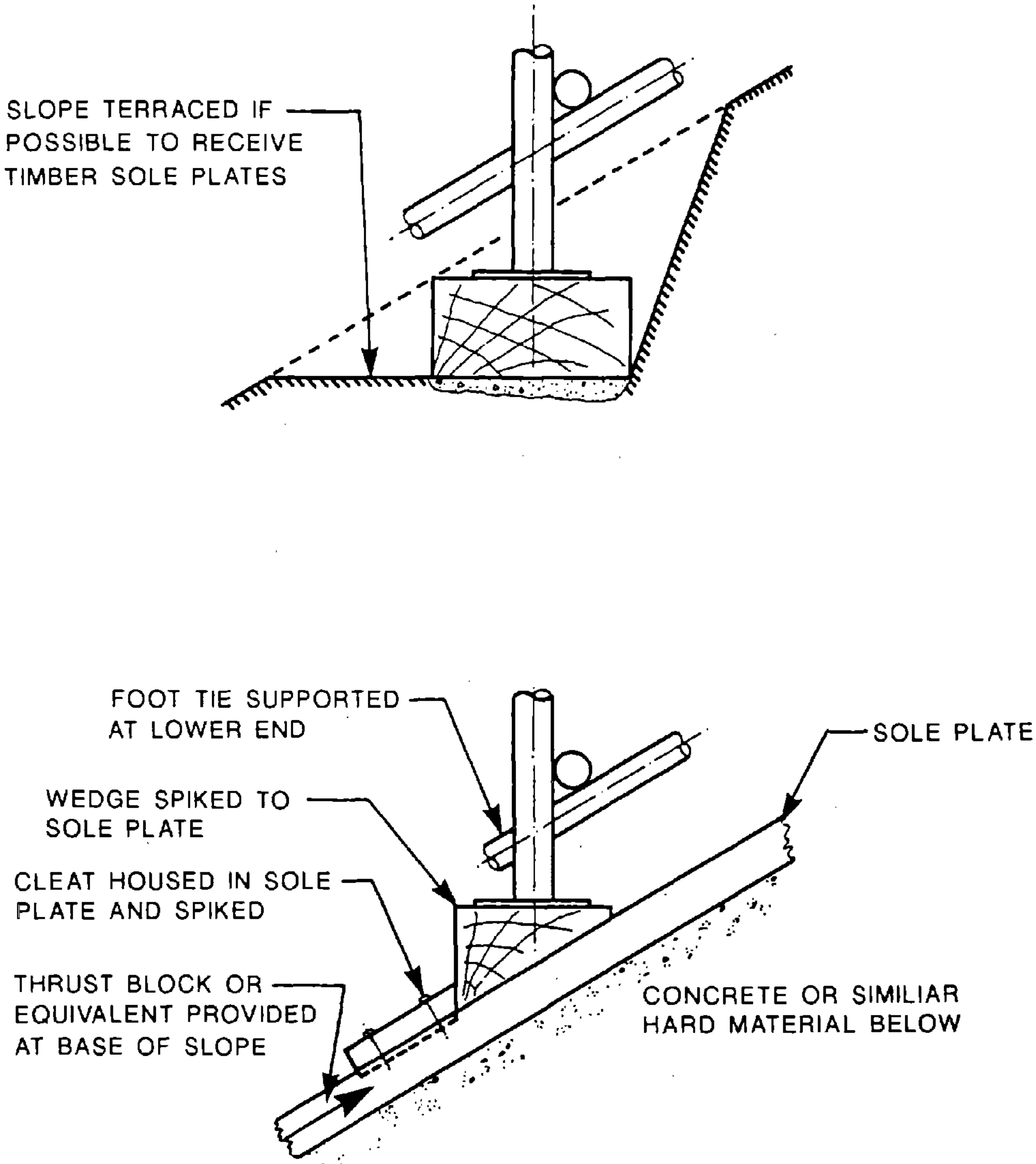


Figure 17. Base details on slopes.[52]

CHAPTER 4. FORMWORK

DESIGN CRITERIA

Concrete formwork must support all loads applied to the structure being formed until these loads are carried by the structure itself. Loads acting on formwork include the weight of formwork, weight of reinforcing steel, concrete self-weight, horizontal pressures exerted by the plastic concrete, and various live and environmental loads imposed during construction and curing. Construction live loads include impact from concrete dumping into the forms, concrete pumping forces, movement of workmen and construction equipment on or near the forms, and internal or external vibration of the forms. Environmental loads include snow, wind, rain and thermal fluctuations. Fresh concrete has material properties lying somewhere between a liquid and a solid substance, and thus is generally described as a plastic material. After time, it loses its plasticity and becomes a solid. The rate at which it changes from a plastic to a solid state has considerable effect on the lateral pressure exerted on the formwork.

The weight of concrete depends primarily on the density of the aggregates used. For bridge construction, the majority of all formwork constructed involves hardened concrete weighing 140 to 145 lb/ft^3 (2240 to 2340 kg/m^3). Most States require a design concrete density for normal weight concrete which includes the weight of reinforcement ranging from 150 to 160 lb/ft^3 (2400 to 2550 kg/m^3). A few States list 120 or 130 lb/ft^3 (1920 or 2100 kg/m^3) as the design density for lightweight concrete. For normal weight concrete, a design density of 160 lb/ft^3 (2550 kg/m^3) may be more reflective of the actual plastic concrete density, which is approximately 5-percent higher than hardened concrete.[124] Formwork, depending on the construction material, generally weighs from 3 to 15 lb/ft^2 (145 to 720 N/m^2) of surface area.

ACI Committee 347 recommends that both vertical supports and horizontal framing components of formwork be designed for a 50-lb/ft^2 (2.4 kN/m^2) minimum live load of horizontal projection. This load accounts for the weight of workmen, runways, screeds and other equipment. When motorized carts are used, the minimum should be 75 lb/ft^2 (3.6 kN/m^2). Regardless of slab thickness, the minimum design value from combined dead and live loads should be 100 or 125 lb/ft^2 (4.8 or 6.0 kN/m^2) when motorized carts are used. Additionally, some States specify a 75-lb/ft (1.1 kN/m) live load applied to cantilever bracket overhangs.

Lateral loads imposed by fresh concrete against wall or column forms differ from gravity loads on a horizontal slab form. This subject has been extensively researched and is generally a function of:

- Weight or density of concrete.
- Vibration and revibration to consolidate the concrete.
- Initial concrete temperature.
- Size of the element being cast.
- Rate of placing concrete in the forms.
- Concrete slump.
- Retarding admixtures and superplasticizers.

Other factors may affect the magnitude of lateral concrete pressure on formwork, but their influence is small compared to the factors listed above. Therefore, they are often neglected in form design. (See references 89, 125, 126, 127, 128, 129.)

Figure 18 illustrates the actual and assumed pressures applied to vertical formwork. As shown, the design pressure distribution varies with depth to a maximum value and remains constant below this depth. The variable pressure near the top is a hydrostatic, triangular distribution conforming to traditional fluid mechanics, whereby pressure equals the density multiplied by depth.

The design pressure envelope is a function of concrete placement depth and the effects of concrete vibration. Concrete near the top surface is generally vibrated to depths of 3 to 4 ft (0.9 to 1.2 m), which fluidizes the top level of concrete, and exerts the full hydrostatic pressure on the forms. As the placement depth increases, the effects of vibration at the bottom of the form is reduced and, in turn, the concrete exerts less pressure on the formwork due to internal friction and other effects. The reduction in lateral pressure is primarily a function of time and temperature, but several of the factors listed above can also have some influence.(127)

ACI Committee 347 prescribes two wall equations and one column equation that predicts maximum lateral pressure as a function of placement rate and temperature.(38) Each wall formula governs for different rates of placement, but the column equation has no set placement limit. A plot of the ACI equations with different placement rates and temperature levels is shown in figure 19.

The ACI pressure formulas are applicable to internally vibrated concrete made with Type I cement, containing no pozzolans or admixtures, and having a slump of not more than 4 in (102 mm). For concrete weighing other than 150 lb/ft^3 (2400 kg/m^3), the resulting pressure from the equations is multiplied by the ratio of actual unit weight to 150 lb/ft^3 (2400 kg/m^3). When a retarding admixture or fly ash or other pozzolan replacement of cement is used in hot weather, an effective temperature less than that of the concrete in the form should be used. These limitations are important because the empirical equations were based on data and conditions that have changed over the years, particularly admixture usage and placement rates. These same limitations were also relevant to formulas used in Great Britain before 1985. However, the British formulas have been modified in recent years to more accurately reflect these modern day concrete parameters.

The current British practice for determining lateral concrete pressure in wall and column forms is based on *CIRIA Report 108*, which presents two equations to predict maximum concrete pressure.(89) One equation is the traditional fluid pressure equation that is dependent on concrete density and vertical pour height. The other is more complex, and its variables include concrete density, form height, concrete placement rate, initial concrete temperature, and three coefficients. Two coefficients are based on temperature, and formwork size and shape. A third coefficient is dependent on the constituent materials of the concrete, such as portland cement, fly ash additive, blast furnace slag use, rapid hardening cement (Type III) use, or admixture use.

The CIRIA equations have also been adopted by Australia and New Zealand. New Zealand has conducted some independent research on the applicability of these equations to certain local conditions.(92) This study corroborated the CIRIA work, but also showed that heavy concentrations of vertical reinforcement can reduce horizontal formwork pressures under normal internal vibration. This finding is significant to New Zealand

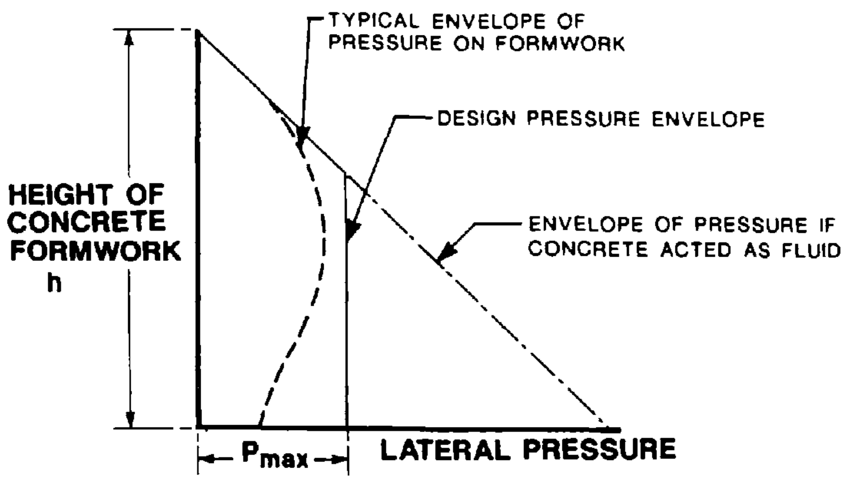
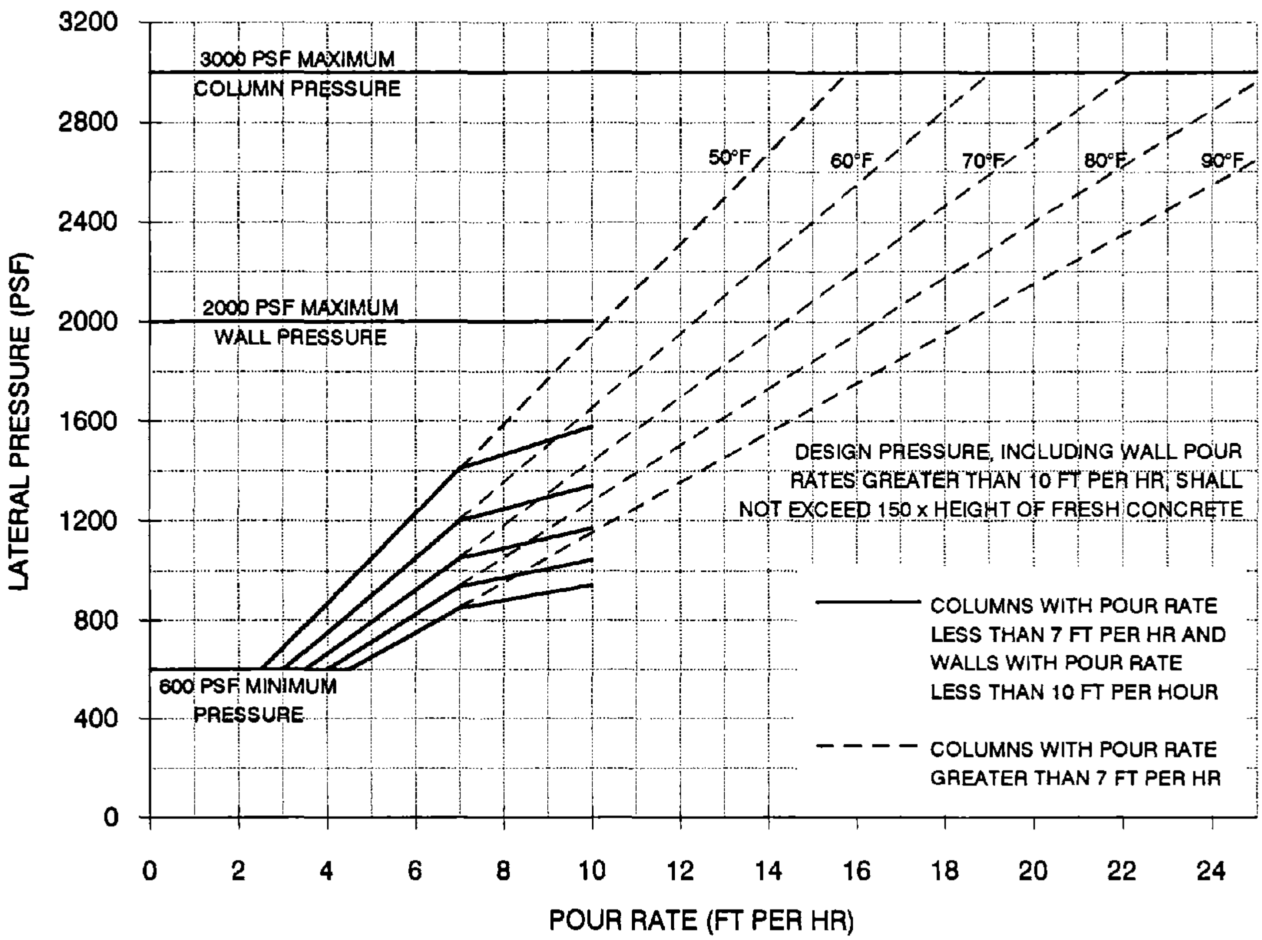


Figure 18. Distribution of concrete pressure with form height.(89)



(1 ft = 0.305 m, 1 lb/ft^2 = 0.048 kN/m^2)

Figure 19. Lateral pressure of concrete on formwork. (Adapted from reference 38.)

because of seismic design considerations, and could possibly be extrapolated to conditions in the Western United States.

References 126, 127 and 128 present extensive research findings on the subject of lateral concrete pressure. An empirical equation for maximum concrete pressure in walls presented in the references is contained in the Canadian draft formwork standard, CSA 269.3-M.[51] This equation contains some variables not contained in the ACI or CIRIA equations, including immersion depth of the vibrator, a minimum dimension of the form, slump, and percentage of fly ash or slag inclusion. This proposed standard also includes the traditional fluid pressure equation concrete density multiplied by concrete height. For walls, the proposed standard indicates maximum pressure is the lesser of these two equations. Column pressure is a function of the fluid pressure equation only.

Other factors should be considered in the design of formwork. For example, when concrete is pumped into the bottom of forms, the form pressure is equal to the full liquid head plus any additional pump pressure required to overcome frictional flow resistance. This extra pressure is dependent upon the concrete mix, pump type, and flow restrictions. High pump speeds can overpressure forms locally, and even at ideal conditions, it is recommended that the calculated design pressures be increased by 25 percent. Where significant restrictions to the flow of concrete exist, such as precast elements inside the forms or large anchorage/embedments, it is recommended that the extra pressure should be 100-percent more than the full liquid head of fresh concrete.[130]

Pressure induced by fresh concrete acts perpendicular to the form surfaces and, consequently, battered (inclined) wall forms will tend to uplift as concrete is placed. Therefore, these form elements require positive anchorage or bracing. Another point to consider is the concrete placing sequence. As the concrete is initially placed, lateral pressure tends to spread the form at the bottom and constrict it at the top thereby redistributing the lateral pressure. Also during the pouring process, if fresh concrete is significantly higher along one side of tied forms than the opposite side, an imbalance in horizontal thrust is created that can cause dislocation and sliding of the entire unit if it is not adequately anchored. These conditions are generally covered by the factor of safety, but have contributed to form failures.[130]

FORM MATERIALS

Formwork construction materials include lumber, plywood, hardboard, plastics, fiber forms, corrugated boxes, steel and aluminum. Materials used for joining the forms are nails, bolts, screws, form ties, anchors, and other accessories which are specific to a particular type of form. Form materials, accessories, and related reference data are provided in table 9.

Dimensional Lumber - Almost all formwork jobs, regardless of the different types of primary materials used, usually require some lumber. Lumber species, grades, sizes and lengths vary geographically and, therefore, local suppliers will be the primary source of advise for specific materials and sizes that are available.

Lumber that is straight and free from defects may be used for formwork, although softwoods are generally most economical for all types of formwork. Partially seasoned stock is usually preferred for formwork because dried lumber can swell excessively when wet, and green lumber tends to dry out and warp during hot weather,

Table 9. Form materials with references for design and specification. (adapted from reference 38)

Item	Principal use	Reference data
Lumber	Form framing, sheathing, and shoring	National Design Specification for Wood Construction (NDS) Reference 108, 109. *Wood Handbook: Wood as an Engineering Material*, Reference 131. *Wood Engineering*, Reference 132. *Timber Construction Manual*, Reference 133.
Plywood	Form sheathing and panels	*Construction and Industrial Plywood*, Reference 134. *Concrete Forming*, Reference 135. *Plywood Design Specifications*, Reference 136.
Steel	Panel framing and bracing Heavy forms and falsework	*Manual of Steel Construction*, Reference 107. *Cold-Formed Steel Design Manual*, Reference 137.
Aluminum	Lightweight panels and framing; bracing and horizontal shoring	*Aluminum Construction Manual*, Reference 138.
Fiber or laminated paper pressed tubes or forms	Column and beam forms; void forms for slabs, beams, girders, and precast piles	
Concrete	Footings, stay-in-place forms, molds for precast units	ACI 318, Reference 44. ACI 347.R, Reference 38.
Form ties, anchors and hangers	For securing formwork against placing loads and pressures	See table 10 for recommended safety factors
Steel joists	Formwork support	*Standard Specifications, Load Tables, and Weight Tables for Steel Joists and Joist Girders*, Reference 139.
Steel frame shoring	Formwork support	*Guide to Horizontal Shoring Beam Erection Procedure for Stationary Systems*, Reference 99. *Guidelines for Safety Requirements for Shoring Concrete Formwork*, Reference 96. *Design Manual for Structural Tubing*, Reference 140.
Form insulation	Cold weather protection of concrete	ACI 306-R, Reference 141.

thus causing problems in form alignment. As a general rule, old and new lumber should not be used interchangeably in the same panel when uniform finish is important.[39]

Plywood - Plywood is extensively used as sheathing, decking, and form lining for a variety of reasons. It comes in large panels [typically 4 ft by 8 ft (1.2 m by 2.4 m)] for economic erection and removal, and is available in numerous strengths and thicknesses. Its physical properties are constant and dependable, and its inherent smooth surface provides desirable concrete surfaces. Plywood can also be used for special forming requirements because it has the ability to conform to curved surface profiles.

Any exterior grade plywood can generally be used for concrete formwork. The plywood manufacturing industry, however, produces a plywood specifically for concrete forming known as Plyform. Plyform differs from conventional exterior plywood grades in that wood species and veneers are more selective, and exterior face panels are sanded smooth and factory oiled. Several classes of Plyform are commercially available for specific applications. These classes, along with design and construction information, are addressed in manufacturer's literature and an American Plywood Association (APA) publication on this subject.[135] Furthermore, an ASTM standard exists for plywood composition and properties.[142]

Several proprietary plywood form panels are also available. Some panels are similar to Plyform except special polymer resins or liquid plastics are used to impregnate the wood face instead of oil. Other plywood panel types are completely overlaid with a high-density plastic sheet having thicknesses up to 1/8 in (3.2 mm). These materials have to be handled differently than conventional plywood, such as field cutting with circular saws. Consultation of manufacturer's literature is recommended in fabricating forms with proprietary plywood panels.

Hardboard - Tempered hardboard, sometimes used to line inside form surfaces, is manufactured from wood particles impregnated with a tempering liquid and then polymerized by baking. This material is available in large sheets 4-ft (1.2-m) wide by 6-, 8-, 12-, and 16-ft (1.8-, 2.4-, 3.7-, and 4.9-m) long, and its hard smooth surface produces concrete surfaces relatively free of blemishes and joint marks. The thin sheets can be bent to small radii for constructing forms for curved surfaces.

Fiber Form Tubes - Forms frequently used for round concrete columns are made of a specialty cardboard type material. These fiber forms are available in sizes up to 48-in (1.2-m) inside diameter, and in lengths up to 50 ft (15.2 m). Two types of waterproof coatings are used. One is a plastic-type treatment for use when forms are to be re-used and a clean finish is specified; the other is a wax treatment where the forms will not be reused or where the condition of the exposed concrete surface is not important.

The forms are manufactured by wrapping successive layers of fiber sheets spirally and gluing them together to produce the desired wall thickness. When removed from columns, a spiral effect is left on the concrete surface. Seamless tubes which do not leave a spiral effect when removed are also available.

Steel Forms - Steel forms come in two types: manufactured forms prefabricated into standard panel sizes and shapes, and forms fabricated for special uses. For certain applications, steel forms have advantages over forms made of other materials. They provide adequate rigidity and strength, and can be erected, disassembled, moved and re-erected rapidly. They also provide a smooth concrete surface that is often desirable.

Unless steel forms are reused several times, they are expensive. Contractors may rent them for smaller projects to avoid the investment. Special precautions also need to be taken, as steel forms provide no insulation protection to concrete placed during cold weather.

Aluminum Forms - Aluminum forms are in many respects similar to steel forms, but lighter and thus easier to handle. Thicker sections or larger members are required, however, because aluminum is less rigid than steel.

Aluminum corrodes when it is exposed to moist concrete under continuous or repeated use, and corrosion by-products can result in staining of exposed concrete surfaces. Therefore, aluminum should only be used if suitably coated or as structural support for a separate form facing material. Some States prohibit aluminum form usage and review of the particular State specification is recommended before contemplating this form type.

Proprietary Wall Form Panels - These form panels are mass produced, brand-name form sections constructed either of steel, or steel and wood. They are produced in small segments, so they are adaptable to a variety of concrete shapes and construction types. Design information for proprietary form panel systems is generally furnished by the manufacturer.

Based on information found in their *Bridge Construction Manual*, Minnesota has had mixed experience with some of these panel systems and does not recommend their use in concrete exposed to view for the following reasons: (28)

- Objectionable offsets existed at abutting panel edges.
- There were an excessive number of joints. (The frequency of panel joints should generally be no greater than in conventional plywood-form construction).
- After being reused a number of times, permanent set (permanent deflection) in the panels became excessive.
- Adequate provisions were not made for overall alignment of the form work, nor for providing mortar-tight joints.

Aesthetic requirements should be carefully considered before these panels are specified.

Hardware - Forming hardware generally associated with highway bridge construction includes proprietary form ties, form hangers, and cantilever overhang brackets. Table 10 provides minimum safety factors for formwork accessories as recommended by ACI. In selecting form hardware, the engineer should verify materials furnished for the job meet these minimum ultimate strength requirements.

A form tie typically consists of an inside tensile member and an external device used to hold concrete forms against the active pressure of freshly placed plastic concrete. Two basic types of form ties include the prefabricated rod or band type, and the threaded internal disconnecting type. The latter type, shown in figure 20, is more common in bridge construction. Suggested working load for the coil-type units ranges from about 4500 to 36,000 lb (20 to 160 kN). The crimped tie is available in a working load range of 3000 to 9000 lb (13.3 to 40 kN) and the plain disconnecting type is available in a 3000- to 60,000-lb (13.3 to 267 kN) range.(39)

Reference 143 presents information and application details for eight types of form ties, while reference 144 examines advantages and limitations of form ties in common usage. A minimum specification for ties should

Table 10. Minimum safety factors of formwork accessories.[38]

Accessory	Safety factor	Type of construction
Form tie	2.0	All applications
	2.0	Formwork supporting form weight and concrete pressures only
Form anchor	3.0	Formwork supporting weight of forms, concrete, construction live loads, and impact
Form hangers	2.0	All applications
Anchoring inserts used as form ties	2.0	Precast concrete panels when used as formwork

*Safety factors are based on ultimate strength of accessory.

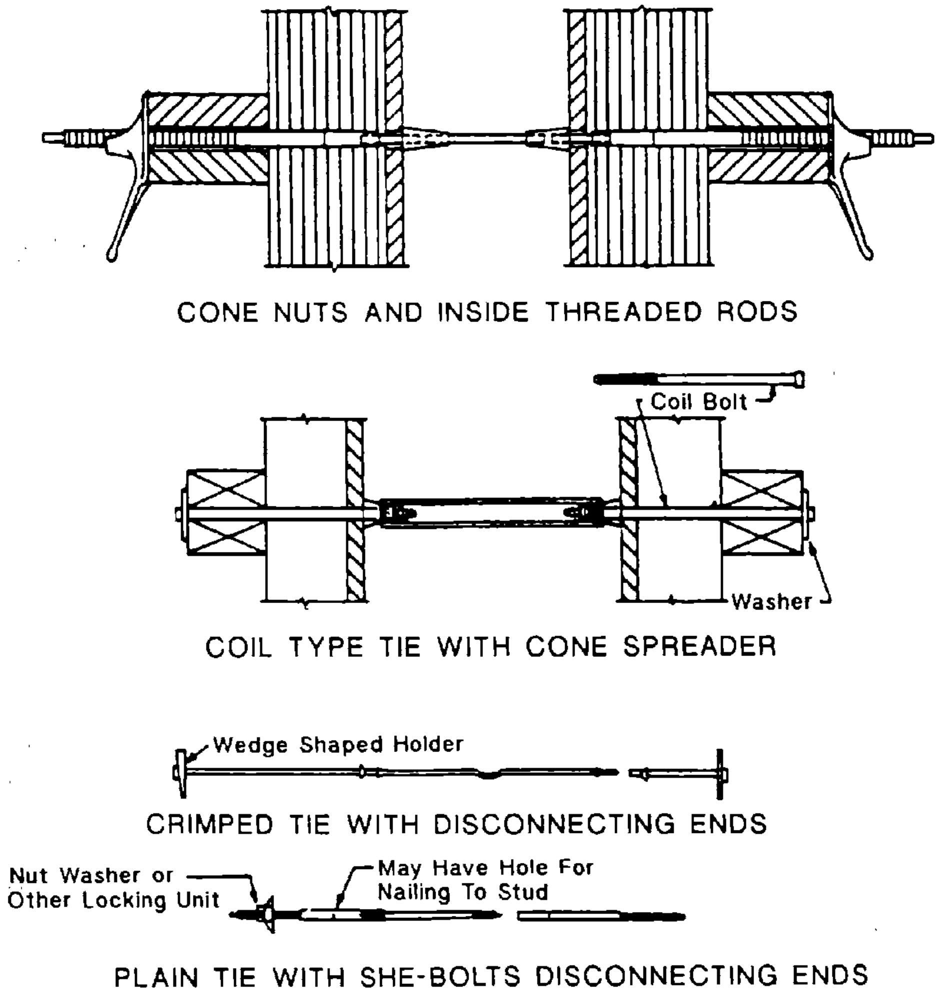


Figure 20. Typical form ties used in bridge construction.[39]

require that the bearing area of external holding devices be adequate to prevent excessive bearing stress in form lumber.

Form hangers are used extensively to form bridge decks constructed with steel stringers or precast AASHTO girders. Two types common in bridgework are coil bolts and joist hangers, illustrated in figure 21. Typical hangers have capacities of 2000 to 3000 lb (8.9 to 13.3 kN) per side, and should be symmetrically arranged on opposite sides of the stringer to minimize twisting or rotation of the stringer.

Cantilever overhang brackets, shown in figure 22, are another common hardware device used for forming highway bridges. A hanger bracket consists of a horizontal member, an adjustable vertical member placed approximately parallel to the beam web, and an adjustable diagonal leg. In general, the longer the vertical leg, the farther apart the brackets can be spaced. However, in cases where a bridge deck finishing machine is supported at the outer edge of a cantilevered deck overhang, particular care must be taken to prevent excessive deflection of the overhang bracket and excessive lateral load on the bridge stringer web. For design purposes, load-deflection curves or tables are generally produced by the manufacturer. An example of this data is also shown in figure 22.

FORMING METHODS

Foundations

In bridge construction, forming begins with the foundations, which may involve caissons, piles or spread footings, depending on the location of the bridge, length of span between supports, whether over water or land, and the type of foundation material. Forms are required for caisson walls, dredge wells, working chambers, and man access tubes, and may be constructed from any of the materials discussed previously. Forms are also generally required for pile caps and spread footings. Both typically require shallow side forms braced against the excavated earth.

Walls

Wall forming incorporates any and all types of vertical formwork used in the bridge structure. These forms are used in the construction of piers, abutment walls, or beam webs. The forms for these elements are generally tall enough such that horizontal concrete pressure loads and stability are primary design concerns.

Piers may be rectangular, circular or have a variable cross-section such as the common hammerhead-type pier. Piers are supported on foundations or pier bases and, in turn, support the bridge superstructure. When a bridge has numerous high piers, it is desirable to achieve maximum reuse of forms. Where considerable reuse is possible, the contractor generally utilizes custom built, wood forms or proprietary steel forms.

Piers are generally classified as solid wall types or an open type consisting of concrete columns topped with a pier cap. Solid piers are usually built from modular form panels with metal or plywood sheathing backed by studs and walers. Horizontal resistance to the concrete pressure is accomplished through exterior bracing, internal form ties anchored to parallel facing forms, or a combination of both.

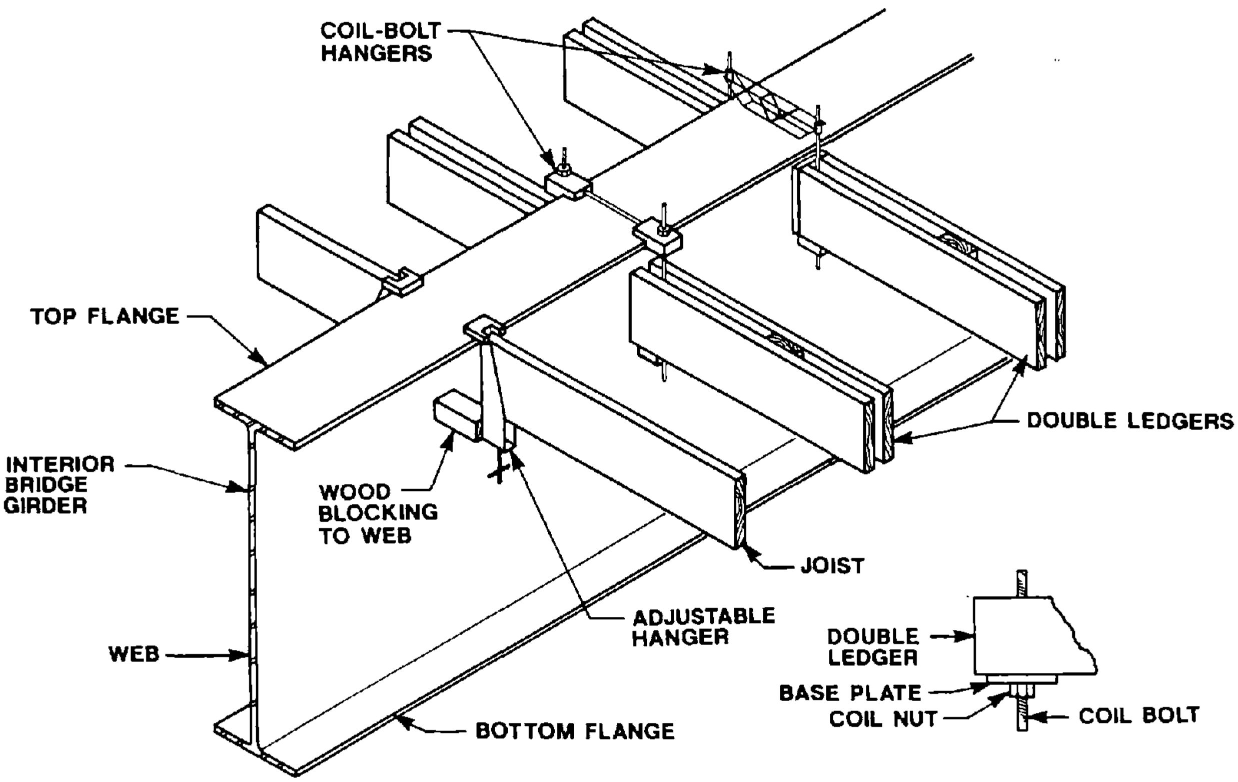
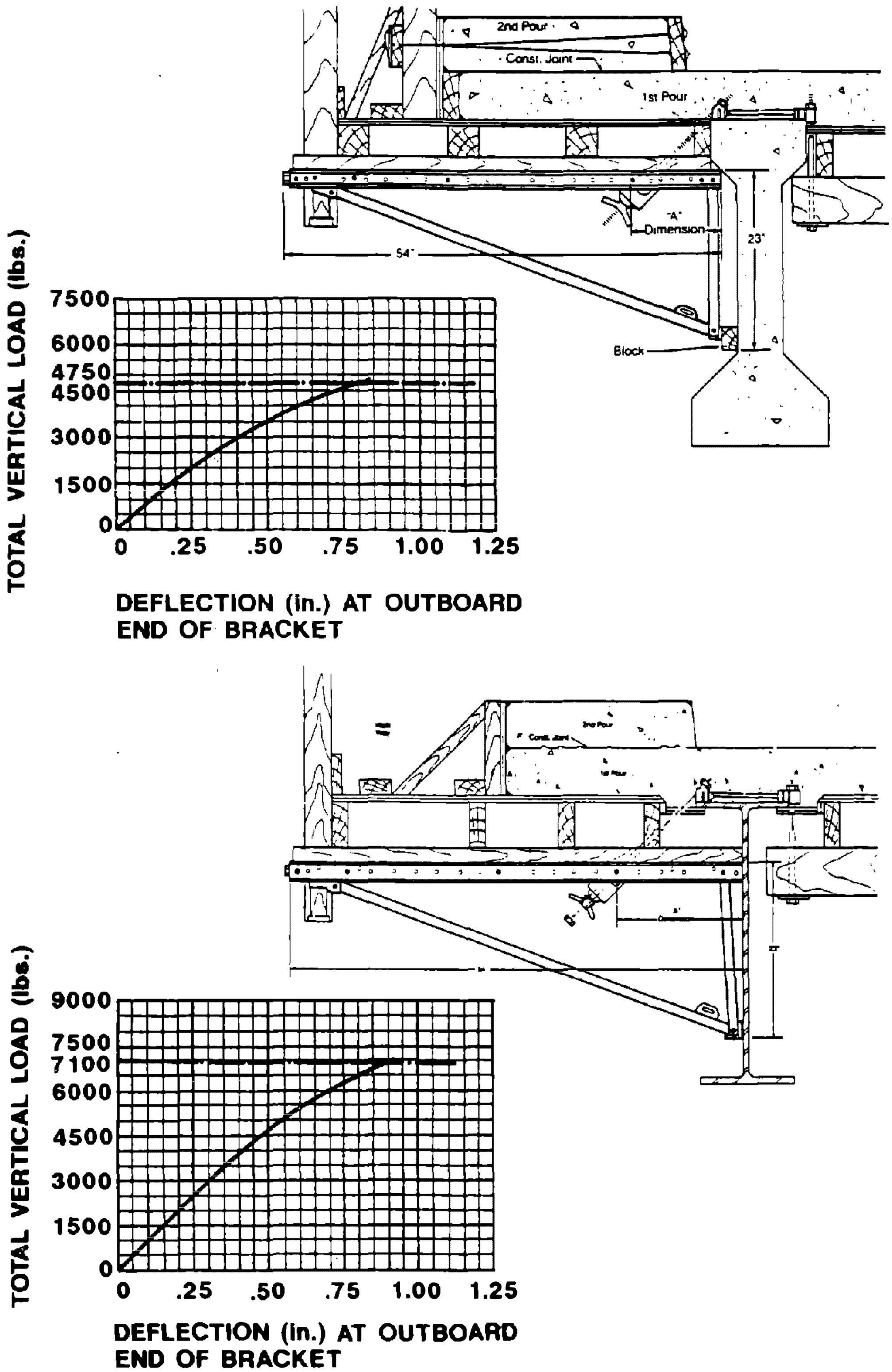


Figure 21. Methods of suspending formwork from bridge stringers.



(1 in = 25.4 mm, 1 lb = 4.45 N)

Figure 22. Load-deflection curves for cantilever overhang brackets.[145]

Columns for conventional bridge piers are usually sufficiently short in height and small in diameter that forms alone resist concrete pressures through radial resistance or confinement afforded by the circular shape. External bracing for these forms provides stability against overturning and possible uplift. Circular concrete forms are typically constructed from metal or thick cardboard. Cardboard forms are not reusable, but do offer economies in installation and removal. It should be noted that some State specifications require circular cardboard forms to have confinement brackets at specified intervals to maintain the circular shape and prevent potential localized bulging.

Oftentimes, pier formwork is ground supported. Two common conditions precluding ground support are high forming of rectangular pier caps and hammerheads. Vertical formwork for hammerheads can be supported by adjustable brackets attached to the previously cast pier section with thru-bolts or drilled-in anchors. A similar bracket is illustrated in figure 14. Pier cap forms that are not ground supported are commonly set on friction collars. These fabricated steel collars are clamped around the concrete column and develop vertical capacity by friction, which is proportional to the clamping force. There is further discussion on this subject in Minnesota's *Bridge Construction Manual*.[28] Aside from noting that proper bolt tightening is necessary, MnDOT also cautions on proper collar placement to ensure level and full concrete bearing. It further recommends consultation of manufacturer's literature for safe load capacity to prevent failure.

Abutment walls and wing walls are formed and cast in the same manner as piers. Parallel wall forms are typically tied to one another, with external bracing used for stability and resistance to horizontal concrete pressure and overturning. These wall forming principles are also applicable to cast-in-place concrete box culvert walls.

Cast-in-place concrete box girders also require both interior and exterior wall forms. Because the walls are relatively narrow, they can be tied to each other to resist concrete pressures. Most box girders have sloped sides that make conventional wood forming difficult, and adjustable form panels are available for these surfaces. An example of modular form panel is shown in figure 23.

Review of the various State specifications indicates that existing guidelines primarily address concrete finishes. In general, these requirements include minimum surface finish quality, minimum chamfer size for formed corners, approved form lining materials, basic wood appearance (free from knotholes, cracks, splits, etc.), and countersinking of bolt or rivet holes on form facing material.

Nearly every State has criteria regarding permanent concrete inserts, such as form ties or embedded anchor assemblies. Most States require removal of these items after use to a depth ranging from 1/4 in to 1 1/2 in (6.4 mm to 38.1 mm) or more, and patching of the hole. Other State requirements typically pertain to the reuse of forms, proper form surface treatment, a provision for clean-out ports at form bottoms, and the provision of working and inspection holes in the formwork. The requirement to maintain forms true to line and grade is also common in State specifications.

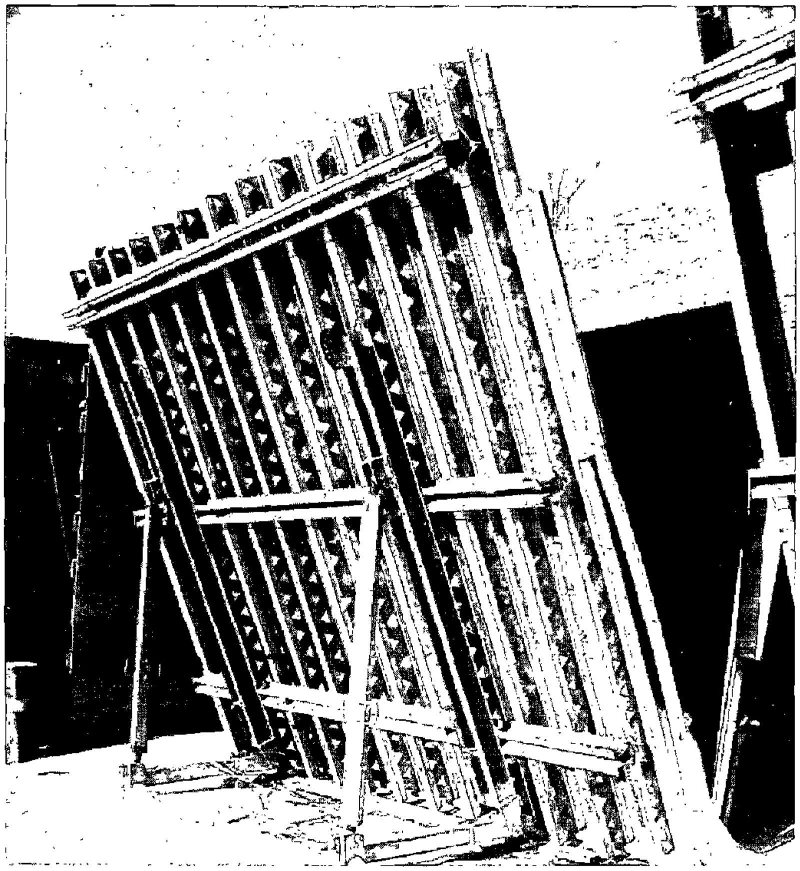


Figure 23. Adjustable vertical side form used to form a box-girder bridge.

Bridge Deck Forming

Bridge deck forms are either ground supported or suspended from the elements of permanent structure. Examples of the former method of construction would be cast-in-place concrete beam and slab bridges, one-way slab bridges, or box girder bridges. The latter method typically consists of forms hung or suspended from permanent steel or precast concrete girders.

Conventionally reinforced, cast-in-place concrete beam and slab bridges are generally cast monolithically, with ground supported formwork. An example of this type of form construction is shown in figure 24. For this particular bridge structure, temporary timber pile bents were constructed between the permanent bridge piers and abutments. Horizontal shoring beams spanned half the normal bridge spans and supported the formwork.

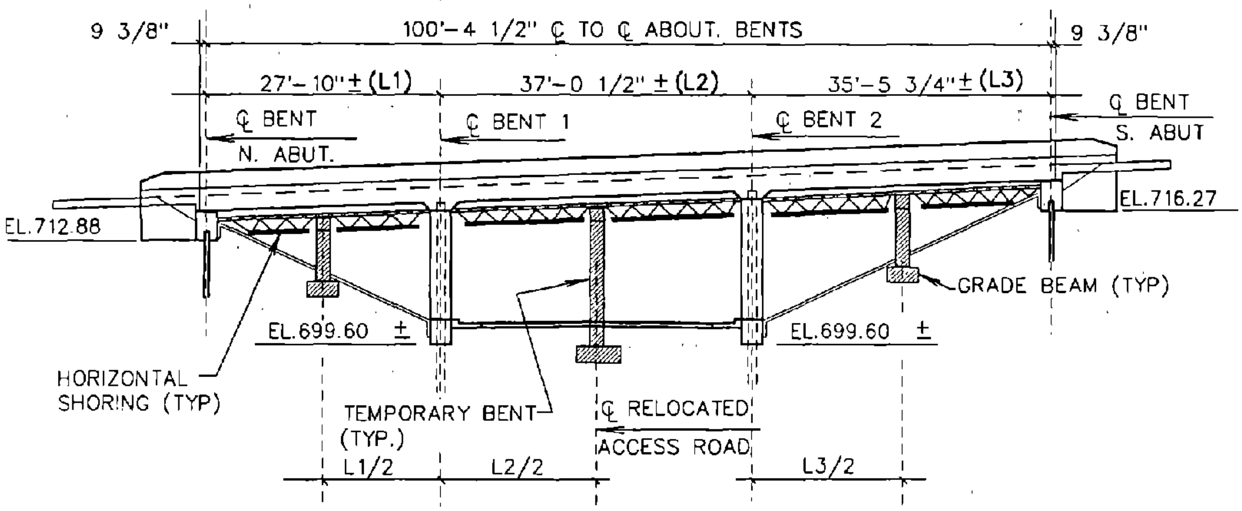
Multiple girder bridges rarely have ground supported deck formwork. Deck casting is usually performed using hanger beams attached to the interior girders, and cantilever brackets affixed to the exterior or fascia girders. Figures 25 and 26 illustrate this forming method with examples for both steel and concrete girders. The deck forms between interior stringers are set on joists hung from the top flange or supported from the bottom flange. Proprietary hangers include removable brackets or coil-bolt assemblies that remain permanently embedded in the deck slab. The embedded hangers are generally hung over the top of the stringer, or welded to stirrups or shear studs projecting from the top surface. Welding the hangers creates a positive connection that will prevent movement during casting. However, several States prohibit welding these devices to the permanent structure.

In order to form the cantilevered portion of the deck slab, a needle beam arrangement or overhang bracket can be used. As shown in figure 25, a needle beam works well for shallow steel girders where bottom flange tension hangers can be easily attached. This support arrangement is temporarily attached to the steel members, with no embedment anchors required in the slab. Reference 71 contains illustrative examples of needle beam design.

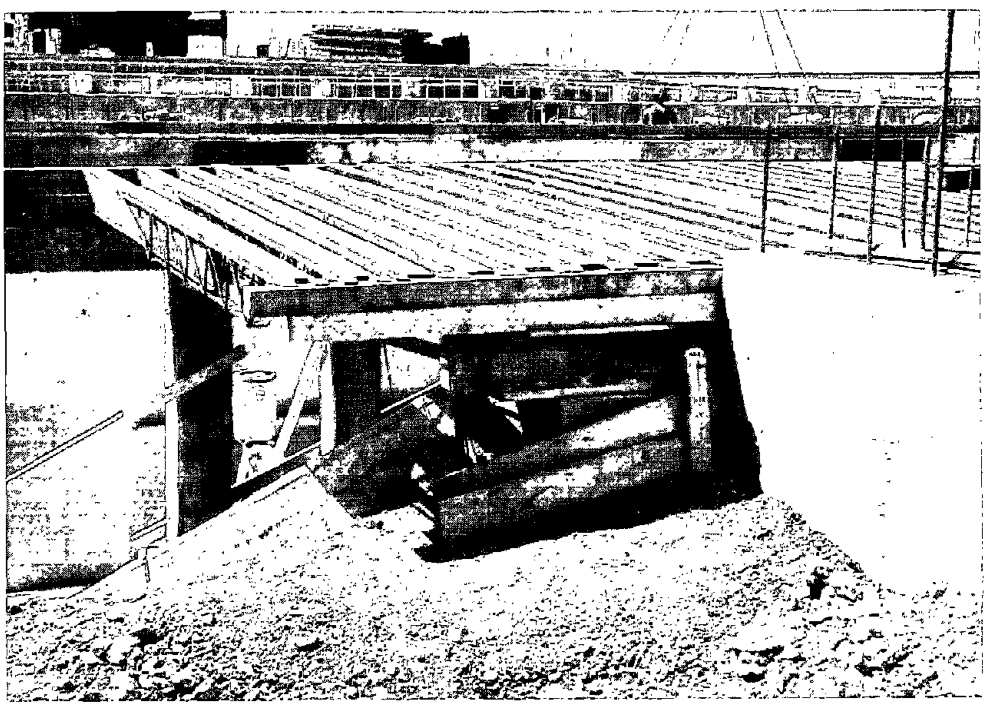
A more common method of forming the overhang consists of an overhang bracket tied to the fascia girder with a hanger support. Field construction of wood overhang brackets is rare, unless field conditions dictate special fabrication. Adjustable, proprietary overhang brackets are much more common due to their adaptability to various bridge dimensions.

As illustrated in figures 25 and 26, gravity loads from the formwork, concrete deck, and screed machine act downward on the bracket. These loads create a force couple on the bracket where tension is resisted by a hanger support rod and compression is applied horizontally to the girder web. This compressive force is resisted by bending in the beam web. For steel stringers, the web could buckle inward due to this out-of-plane force if the magnitude of compressive force is large enough. Therefore, bracket reactions should be investigated with respect to compressive force resistance, and interior diagonal struts may be required to prevent bottom flange rotation.

The behavior of overhang brackets attached to steel fascia girders was studied in the early 1970's in South Dakota.[82] In this study, four bracket types with variable depths were analyzed and tested. The brackets studied were commonly used, nonproprietary assemblies fabricated from steel pipe and channel sections. The tops of



(a) Elevation of bridge with temporary horizontal shoring.



(b) Adjustable horizontal shoring beams spanning between an abutment and temporary timber bent.

Figure 24. Example of one-way slab bridge deck construction.

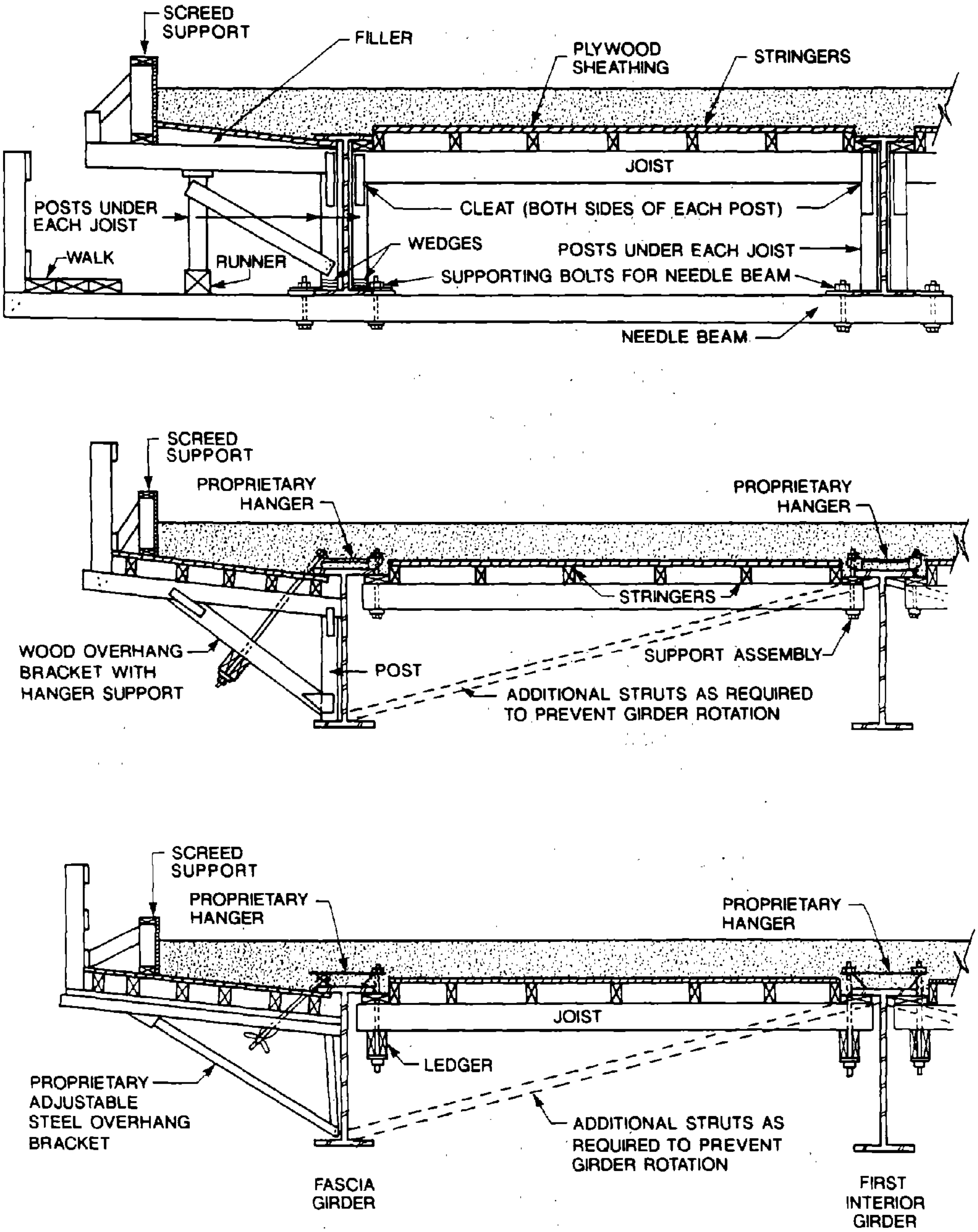


Figure 25. Bridge deck forming methods with steel stringers.
(Adapted from reference 28.)

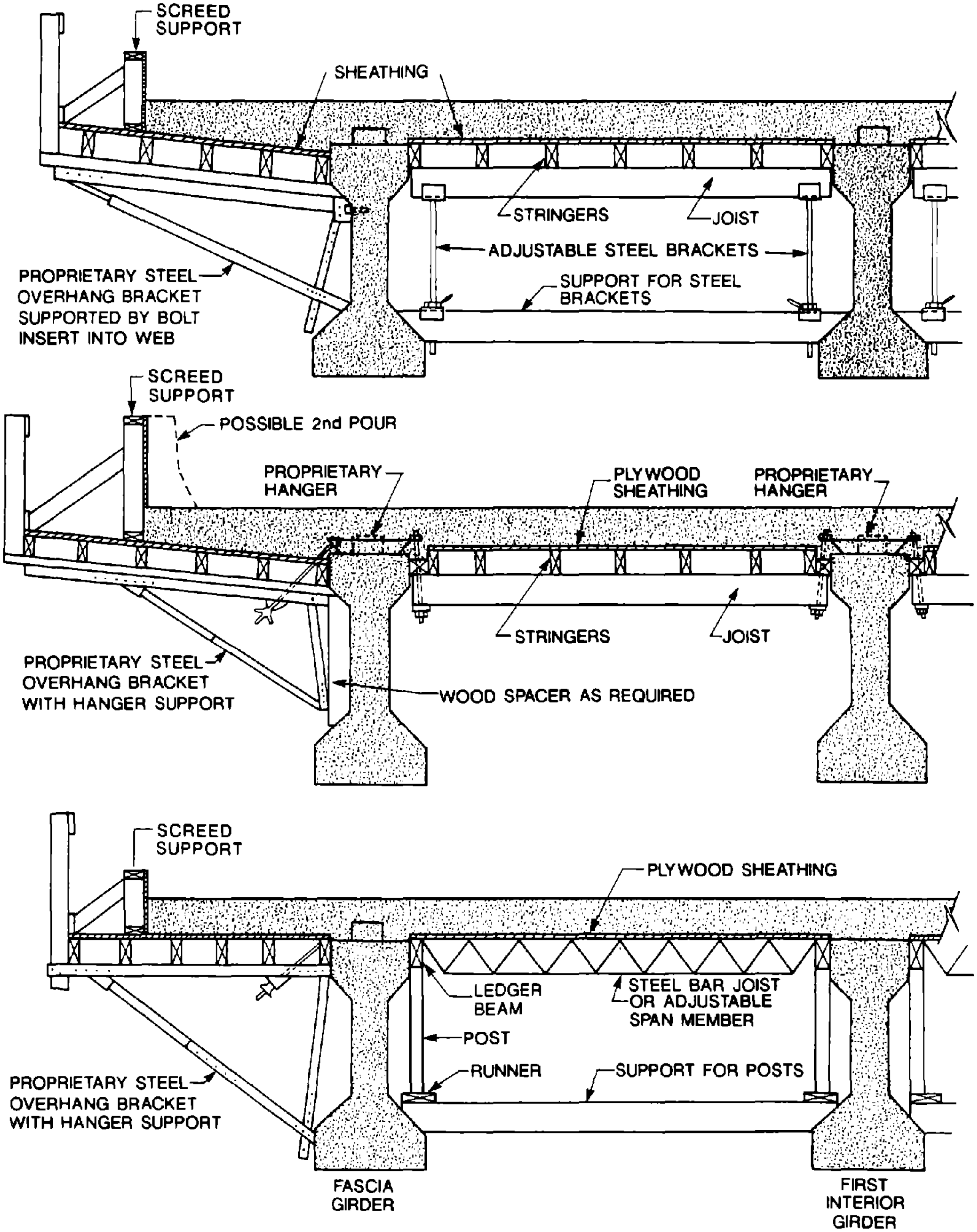


Figure 26. Bridge deck forming methods with precast AASHTO girders.
(Adapted from reference 28.)

the brackets were thru-bolted to the girder web, instead of tied with a tension hanger rod. Although some States currently prohibit web bolting of these brackets, several findings of the testing program remain applicable to current practice. The research results indicated deeper brackets were more effective in reducing out-of-plane deformation of the bottom flange. Both shallow and deep brackets located near stiffeners exhibited less deflection and reduced stresses in the girder web. Conversely, measured deflections and stresses increased when shallow brackets were placed between stiffeners. An effective solution to shallow bracket placement between stiffeners was to incorporate a web stiffening angle into the bracket assembly.

Recently, an approximate procedure has been proposed to estimate flange stress conditions in a steel fascia girder when cantilever deck overhang brackets are used.(146) Loads carried by overhang brackets are eccentric to the exterior girder and create twisting (torsion) in the girder between transverse diaphragms or cross-frames. The proposed analytical procedure accounts for the torsional moments that develop from the load applied to the overhang bracket. Accompanying the procedure is a sample design problem and design tables based on bracket spacing, girder depth, diaphragm spacing, and top flange reinforcing bar ties. Development of the analytical model, and additional design aids and examples are addressed more comprehensively in the final report.(147)

Research has also been conducted on the embedded hangers used on precast, AASHTO-type concrete girders.(148) This study concluded that the tested anchors satisfied the manufacturers' specified allowable loads. However, the ultimate anchor strengths were highly dependent on the edge distance. The report also recommended further emphasis of specific manufacturer installation guidelines with respect to placement of these devices. This report also noted the anchor systems tend to fail in a brittle fashion with no significant deformation prior to failure. Hence, if the hangers are overloaded in the field, little or no warning will accompany failure.

Because several States do not have specific design requirements for superstructure supported formwork, the design considerations noted above may not be recognized by the contractor. For this reason, some States briefly address overhang brackets in their standard specifications, while others have comprehensive requirements for bracket use. Illinois' specification includes the following requirements:(149)

- The diagonal leg brace must bear on the web within 6 in (152 mm) of the bottom flange.
- The exterior stringer must have its top flange tied at regular intervals to prevent outward rotation. The maximum spacing intervals are 4 ft (1.2 m) when finishing machine rails are located on the bracket supported formwork and 8 ft (2.4 m) when finishing machine rails are on the top flange of the stringer.
- Precast, prestressed concrete I-girders are required to have ties at 8 ft (2.4 m) maximum spacing.
- Steel girder diaphragm cross frames are not to be considered as ties if they do not have a top horizontal strut.

- Hardwood blocking [4 in by 4 in minimum (102 mm by 102 mm)] or equivalent is to be wedged between webs of the exterior and interior stringer within 6 in (152 mm) of the bottom flange, located below the top ties.

Minnesota's *Bridge Construction Manual* also contains some general guidelines with respect to overhang brackets, with cautionary notes on the use of manufacturer's load-deflection curves. They also note good concrete appearance lines are difficult to obtain using overhang brackets for beam depths of 24 in (0.6 m) or less and, in such instances, recommend needle beams to support overhang formwork.

Stay-in-place precast concrete or steel deck forms are another forming method allowed by several States. These forms are typically one-span panels attached to the stringers and remain in-place. Further information on precast form panels can be found in reference 150.

Form Removal

Formwork removal is generally specified in terms of concrete cure time, concrete strength maturation, or a combination of both. ACI Committee 347 recommends the following with respect to time of stripping bridge formwork and its supports:[38]

> *Shoring and centering removal*: should follow recommended practices in Sections 3.5 and 3.7 (see committee report). In no case should supporting forms and shores be removed from horizontal members before concrete strength is at least 70 percent of design strength, as determined by field-cured cylinders or other approved methods, unless removal has been approved by the engineer/architect. In continuous structures, support should not be released in any span until the first and second adjoining spans on each side have reached the specified strength.
>
> *Form removal*: Forms for ornamental work, railings, parapets, and vertical surfaces which require a surface finishing operation should be removed not less than 12 hours, nor more than 48 hours after casting the concrete, depending on weather conditions. Bulkheads at construction joints should not be removed for a period of 15 hours after casting adjacent concrete. Forms under slab spans, beams, girders, and brackets must not be removed until the concrete has attained at least 70 percent of its design strength.

Most of the State specifications contain specific guidelines on formwork and falsework removal and, in general, different curing periods are required for various structural elements. A typical example of these requirements is presented in table 11.

Minimum cure time is usually noted as degree days above a certain temperature. The outdoor ambient temperature must exceed the minimum temperature for a stated number of hours to qualify as an acceptable degree day. Minimum temperatures vary according to each State, but a range of 40 to 50 °F (4.4 to 10 °C) is normal. The Indiana DOH has temperature requirements more elaborate than most States.[10] Their minimum

Table 11. Form and falsework removal and loading of concrete.[33]

	Structural Element	Removal: Minimum Days	Removal: Concrete Strength Based on Percent of Design Strength	Loading: Minimum Days	Loading: Concrete Strength Based on Percent of Design Strength
(a)	Columns and Wall Faces	3	50%	7	80%
(b)	Mass piers and mass abutments, except pier caps	3	50%	7	80%
(c)	Sidewalk on bridges. Sidewalk forms shall, in all cases, be released before the main girder and slab forms are released.	10	70%	14	90%
(d)	Box girders	14	80%	14	100%
(e)	T-beam girders, slabs, cross-beams, caps, pier caps not continuously supported, and struts.	14	80%	14	100%
(f)	Top slabs on concrete box culverts and stiff legs.	10	70%	14	90%
(g)	Slabs, when supported on steel stringers or prestressed concrete girders.	10	70%	14	100%
(h)	Pier caps continuously supported.	7	60%	10	80%
(i)	Arches	21	90%	28	100%
(j)	Rail bases, traffic railings, and median barriers.	3	50%	7	80%

Note: Items (c), (d), (e), (f), (g), (h), and (i) apply to falsework and forms supporting the full load of the concrete. Side forms and forms not supporting loads shall not be removed before 3 days have elapsed after the placing of the concrete except to facilitate finishing. If any forms are removed before 7 days have elapsed, the contractor shall apply membrane forming curing compounds to all exposed surfaces except for construction joints as soon as the forms are released.

temperature is 50 °F (10 °C); concrete poured in March, April, October and November, or between April and October when average temperatures are less than the minimum, shall have cure times increased 20 percent. Likewise, concrete placed in December, January or February will automatically have cure times increased 40 percent.

Several coastal States supplement their removal times with provisions for direct or indirect saltwater exposure. Usually, exposure to a saltwater environment dictates longer forming times to ensure surface hardness and less permeability. As an example, Delaware places form removal restrictions on direct concrete surface exposure to sea water or tidal brackish water based on the salt content or salinity of the water.(9) For concrete between low and high tide levels, New Jersey permits forms to be removed following minimum cure time periods, but restricts concrete surface exposure to sea water for 28 days.(151) Thus, the contractor has the option of leaving the forms in place as protection, or providing other means of protection. Oregon does not increase forming times, but requires deeper removal of form ties or other embedded devices from the exposed concrete surface when bridge construction is near the ocean.(29)

CHAPTER 5. SCAFFOLDING

DESIGN CRITERIA

On most construction projects, the general contractor is responsible for the design, construction, maintenance, and safe performance of all temporary structures including scaffolding. However, specific design criteria or construction standards for scaffolding do not exist in the United States. Instead, there are safety requirements, such as ANSI A10.8-1988 (hereafter referred to as the Standard), a comprehensive standard that includes guidelines for scaffolding.[42] Scaffold types addressed in this document include suspended, tube and coupler systems, fabricated tubular frames, outriggers, needle beam, and ladder types, among others. In the United States, Federal law dictates that all scaffolding be designed, constructed, and used in compliance with the OSHA regulations.[45] This again is a safety standard, as opposed to a design standard.

In accordance with accepted practice developed over many years and ANSI provisions, scaffold work platforms in the United States are categorized and rated as follows:

Light-Duty - Scaffold designed for a 25-lb/ft^2 (1.2 kN/m^2) maximum working load to support workers and tools only. Equipment or material storage on the platform shall not be allowed.

Medium-Duty - Scaffold designed for a 50-lb/ft^2 (2.4 kN/m^2) maximum working load for workers and material. This type is intended for bricklayers' and plasterers' work.

Heavy-Duty - Scaffold designed for a 75-lb/ft^2 (3.6 kN/m^2) maximum working load for workers and material storage, often intended for stone masonry work.

Loads given above are assumed to be uniformly distributed over the platform tributary area. In practice, though, uniform distribution of load is seldom realized. For this reason, the Standard supplements uniform platform loadings with concentrated load combinations representing workers and equipment.

Canada and Great Britain have similar standards, but these documents focus more on specific design criteria. The Canadian standard is CSA-269.2, *Access Scaffolding for Construction Purposes*, and the British standard is BS 5973, *Code of Practice for Access and Working Scaffolds and Special Scaffold Structures in Steel.*[50,58]

SCAFFOLD ASSEMBLIES

Scaffolds come in a variety of configurations as dictated by the particular work requirements. A scaffold may be directly supported by the structure which is being worked on, located next to the structure on its own (temporary) foundation, or suspended/supported from the falsework. This section includes a brief description of the more common types of scaffold assemblies applicable to bridge construction.

Tube and Coupler Scaffolding - This scaffold type is erected by connecting circular steel tubes together to form a frame. Tube and coupler scaffold is classified by ANSI Standard A10.8 as light-duty, medium-duty, and heavy-duty, with the same load capacities specified for platforms. Different diameter tubing, either 2-in or

2 1/2-in nominal (50.8 mm or 63.5 mm), is used in the assembly to achieve the above load classifications. The Standard specifies the tube diameter, member spacing requirements, and material types.

As illustrated in figure 27, tube and coupler scaffolding has several basic elements or components. Posts or legs are the main vertical members supported on grade or other suitable support. Bearers are horizontal members that support the working platform, and tie the scaffold together transversely. Runners provide continuity in the longitudinal direction, and are connected below the bearers. Connections are made with couplers that rotate and allow up to 90 degree connections.

Tube and coupler scaffolds can be erected in various sizes and shapes, which do not necessarily have to be rectangular. For systems greater than 125 ft (38.1 m) in height, the standard requires that the scaffold assembly be designed by a professional engineer. In general, longitudinal diagonal bracing and ties are required for stability. The bracing should be installed at an angle approximately 40 degrees to 50 degrees, with connections at the posts. Reference 152 identifies some of the more common tube and coupler configurations as follows:

- Double Pole Scaffolding - A longitudinal assembly consisting of repetitive pairs of legs or posts, commonly used for vertical work. This system is also known as an independent wall scaffold.

- Single Pole - This configuration is similar to a double pole assembly, except inside posts adjacent to a masonry wall are omitted. The posts are replaced with connections into the mortar joints for inner support. This type is rarely used in construction today because its erection takes longer than other methods.

- Tower Scaffold - This configuration is often one or two bays wide, and can be erected to various heights. As noted in the reference, this assembly is used to provide stair access to high locations where sectional scaffold is not well suited. This assembly can also be placed on casters to allow for movement, where applicable.

Sectional Scaffolding - In the United States, this scaffold type is probably the most popular because of its versatility and ease of erection. As the name implies, sectional scaffold utilizes prefabricated sections or frames assembled to form scaffolding. There are several manufacturers of these units, and each manufacturer has a unique scaffold system. Consequently, intermixing of different manufacturer's equipment is oftentimes not possible, nor recommended. The manufacturers also provide engineering support for their systems, which includes project specific designs.

Scaffold frames are comprised of welded steel tubing. Column or vertical tubes generally have an approximate 1 3/4-in (44.5-mm) outside diameter, while interior frame or bracing members use smaller size tubing. Most frames are available in 2-, 3-, and 5-ft (0.6-, 0.9-, and 1.5-m) widths with some special purpose frames available in 4-ft (1.2-m) widths. Standard frame heights are 3, 4, 5, and 6 ft (0.9, 1.2, 1.5, and 1.8 m) and 6 ft

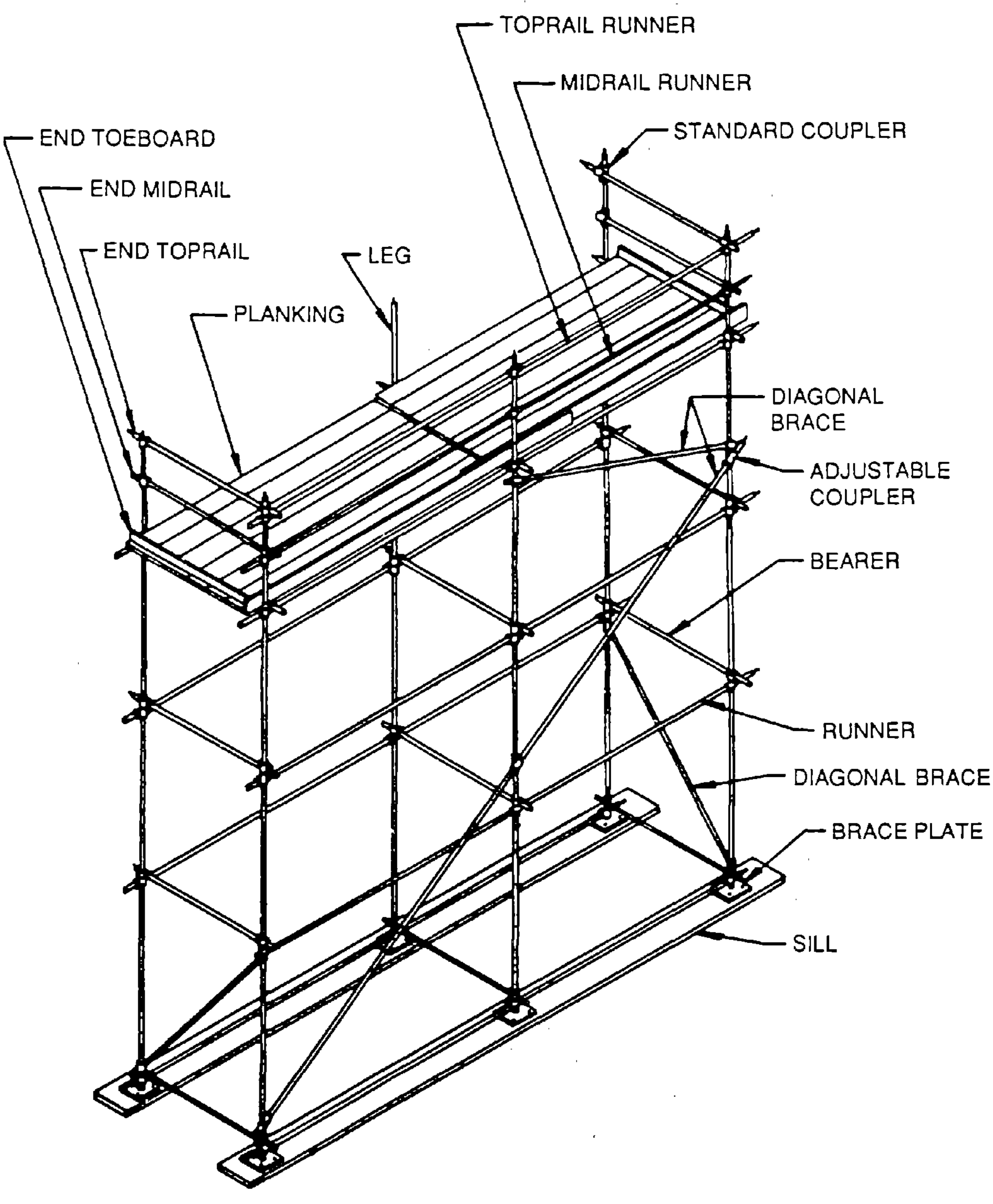


Figure 27. Tube and coupler scaffold.[42]

6 in (2 m). Leveling of the frames is accomplished with threaded screw jacks located at the base. Special purpose frames are available for unique applications.[152]

Stability between frames in the out-of-plane direction is achieved with diagonal x-bracing members. These members typically clip-on each side of the frame, top and bottom. Cross braces are dimensioned to give whole-foot incremental spacing between parallel frames. A typical tubular frame scaffold assembly is shown in figure 28.

ANSI has special provisions with respect to sectional frame scaffolds that are safety-oriented. The standard notes the manufacturer should be consulted for design information when using these systems. As with tube and coupler systems, ANSI requires that the scaffold assembly be designed by a licensed professional engineer for frame scaffolds over 125 ft (38.1 m) in height. Other specific provisions apply to erection and the completed construction. References 45 and 153 discuss these provisions in greater detail.

Form Bracket Scaffolds - This scaffold type provides a work platform near the top of pier or wall formwork, allowing workers to place and vibrate concrete from above. The brackets are fabricated from wood, aluminum, or steel, and have an underside diagonal brace inclined approximately 45 degrees as illustrated in figure 29. Form brackets are usually attached to the vertical formwork studs or walers with "hook-over" brackets, nails, or bolts.

ANSI specifies that the bracket spacing should not exceed 8 ft (2.4 m) and the design load should correspond to light-duty scaffold. Other requirements delineate wood planking width(s), railing and toeboard construction, and minimum dimensions.

Planking - Scaffold planking usually consists of nominal 2 in by 10 in (5.1 cm by 25.4 cm) or 2 in by 12 in (5.1 cm by 30.5 cm) dimensional lumber laid flat across supports; the lumber is either solid wood stock or a type of laminated board. According to ANSI, scaffold planks should be certified as "scaffold plank grade" by an approved grading agency, and maximum span tables should be available for the specific planking and load condition. Appendix C of ANSI Standard 10.8 contains a Forest Products Laboratory report entitled "Calculating Apparent Reliability of Wood Scaffold Planks," which ANSI recommends as the basis for plank span tables. The Standard also limits midspan deflection of planking under design load to the span length divided by 60.

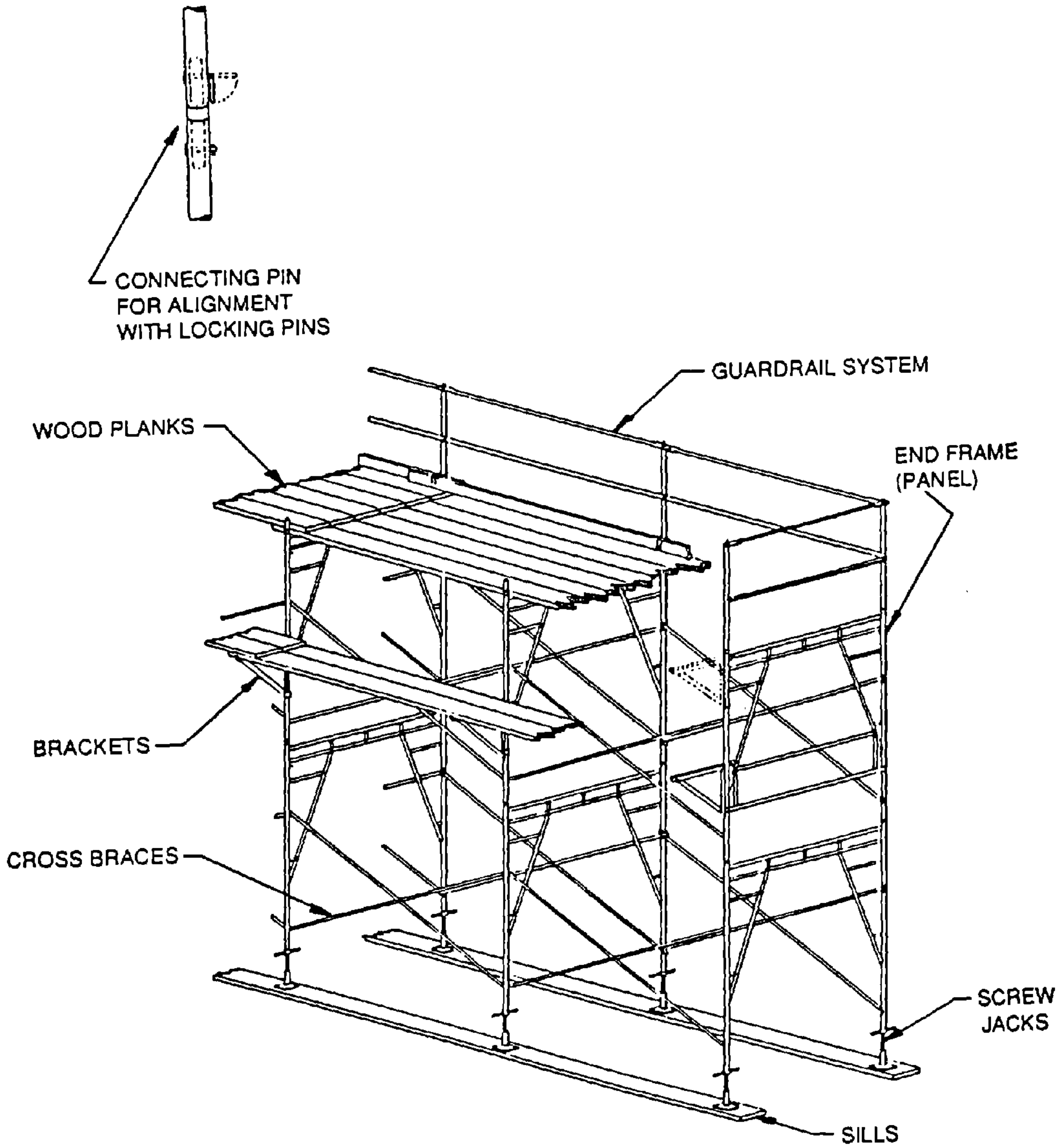


Figure 28. Fabricated tubular frame scaffold.[42]

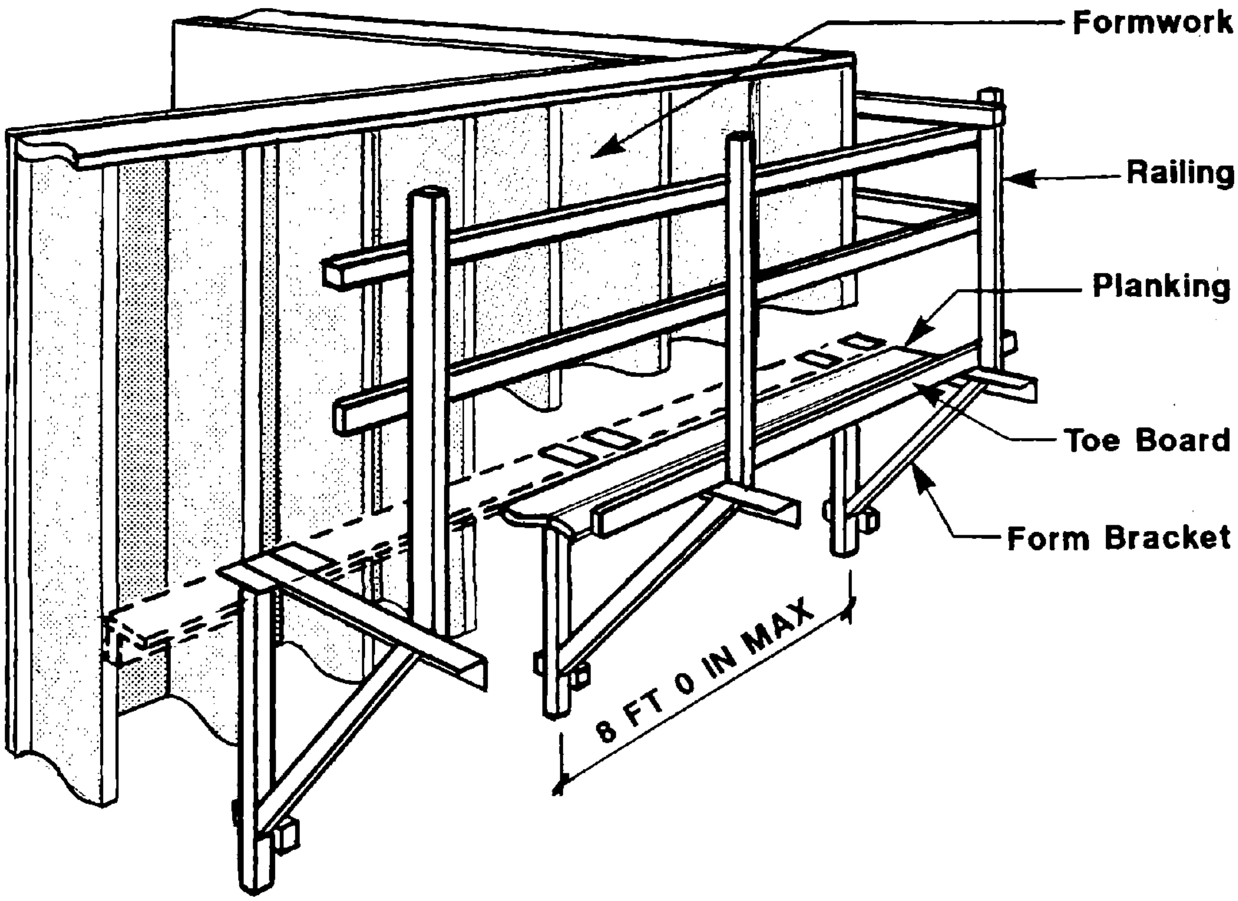


Figure 29. Form bracket scaffold located near the top of vertical pier formwork. (Adapted from reference 42.)

CHAPTER 6. REVIEW AND INSPECTION PROCEDURES

REVIEW AND APPROVAL OF PLANS

In the United States, highway bridge construction is conducted on a competitive bid basis whereby the lowest responsible bidder is awarded the project. The successful bidder, given the project specifications and drawings, is required to build the structure. It is the contractor's responsibility to provide all means and methods necessary to construct the structure, including design and construction of the temporary works used to achieve the final structure.

This concept has been reinforced in a recent model ASCE document, which assigns overall design and construction responsibility of temporary works to the contractor.[154] This document defines temporary structures as structural components not being part of the completed structure, such as shoring, formwork, temporary bracing, scaffolding, or other access used in the construction phase. It also states the contractor is responsible for preparation, review, and approval of shop drawings containing these construction elements.

Similarly, several governing Federal and State standard specifications have incorporated language indicating the contractor is ultimately responsible for falsework and formwork in highway structure construction. On the Federal level, Division II, Section 4.19.1 of the AASHTO *Standard Specifications for Highway Bridges* states:

> Unless otherwise provided, detailed plans for falsework or centering shall be supplied to the Engineer on request, but in no case shall the Contractor be relieved of responsibility for results obtained by the use of these plans.[104]

Nearly every State has a statement similar to AASHTO. Arizona, California, Colorado, and Kansas state:

> The Contractor shall be responsible for designing and constructing safe and adequate falsework which provides the necessary rigidity, supports the loads imposed, and produces in the finished structure the lines and grades indicated on the plans. (See references 22, 23, 30, 35.)

This statement is further amended by California to clarify the role of the State engineer checking the design or inspecting the as-built falsework:

> Approval by the Engineer of the falsework working drawings or falsework inspection performed by the Engineer will in no way relieve the Contractor of full responsibility for the falsework.[30]

Alaska and Connecticut have similar provisions that hold the contractor ultimately responsible for the performance of the falsework, despite review or approval by the State engineer. Illinois and Wisconsin have comparable language on the contractor's responsibility, even when an engineer examines the proposed design. As stated in the Wisconsin Standard Specifications:

> If the plans and computations submitted for review are not satisfactory to the engineer, the contractor shall make such changes in them as may be required. It is understood that whether or not the engineer requests submission of such plans or concurs in the use of the plans as submitted or corrected, the contractor shall in no way be relieved of the responsibility for obtaining satisfactory results.(19)

In practice, suspended bridge deck formwork or structures not affecting public safety are seldom designed by an engineer unless detailed shop drawings prepared by an engineer are required. Whenever shoring or formwork has specific design requirements, however, a professional engineer (PE) licensed in the particular State is usually required to perform the design work. Frequently, temporary support structures fall under the jurisdiction of the applicable State engineering practice and registration law.(155)

Currently, 34 States require a professional engineer's seal on falsework plans. This information was obtained from responses to the falsework questionnaire and compiled in table 12. Several States base their engineering design requirements on the clear height and span of the falsework, and whether the falsework is constructed over or adjacent to a roadway. Seal requirements are also based on the complexity of the falsework system and usually not necessary when the superstructure consists of precast AASHTO girders or steel stringers.

In 31 of the 34 States noted above, the contractor is also required to submit sealed drawings to the State. In addition to sealed drawings, some States require design calculations to accompany the drawings. In Arizona and California, design calculations are required from the contractor, but not subject to formal review and approval.(30,156) To ensure an adequate plan review can be performed, however, a minimum amount of design information is generally required on the drawings. Some of the information required by several States is compiled in appendix B.

Forty-two States responded that they review plans in-house or retain a consultant. Reasons noted for delegating this responsibility included existing workload, shortage of engineering staff, potential liability, or a combination of these factors. In many cases, the consulting engineering firm retained by the State is either the design engineer for the permanent bridge structure or an engineering consultant overseeing the construction. Seven states noted, however, that the contractor is responsible for his own review.

Responses to the questionnaire indicate the nature and detail of submittal review can vary considerably. Some States noted that their reviews were limited to dimensional checks or a basic drawing and calculation review, which does not include an independent design check. Others indicate a more comprehensive in-house review. Arizona and Iowa were among the latter States and provided their criteria for checking falsework designs. As a matter of policy, California performs a design review of the entire falsework system. Their *Falsework Manual* includes extensive discussion of review criteria and can be referred to for specific guidelines.

Arizona's draft general administrative procedures and guidelines highlight specific items to examine when reviewing falsework drawings, in addition to common departmental checking procedures. Emphasis is placed on horizontal bracing, especially bracing connections near traffic openings. The review of connections, however, is generally not a detailed analysis, but rather a cursory examination of the details. Other more specific checklist items include allowable soil bearing pressure, bracing details for box girder walls, overhang bracket details, and allowable settlements. The document also refers to the *California Falsework Manual* and ACI SP-4 for further guidance.[156]

With their response to the questionnaire, Iowa provided a fairly comprehensive in-house checking procedure.[157] These guidelines include administrative procedures, recommended plan format, miscellaneous details, design loads, material grades and stresses, and analysis procedures. Additionally, the guidelines include general information and refer to Iowa DOT policy or experience, along with common construction practices. Iowa also includes relevant sections from ACI SP-4 for reference.

In reference 158, the author advocates assigning responsibility for falsework review to the bridge design engineer. Although it seems logical, the author concedes that many engineers are not inclined to accept this type of assignment because of the potential liability. For the same reason, the inspection or engineering firm monitoring a project's construction phase may not want to "sign-off" on the drawings. In both situations, the engineering firm is entrusted with an adequate review of drawings as a consultant to the State. Unfortunately, the meaning of adequate is often ill-defined and left to the discretion of the individual engineer, with little contractual guidance provided by the State. As a result, the review sometimes is commensurate with available budget or time rather than the technical requirements of the project.

The requirement of having a licensed engineer design falsework for a contractor is not limited to the United States. The CSA standards adopted by Canadian provinces require that all falsework drawings be prepared by a professional engineer.[49] In practice, design reviews of falsework are conducted by the province (territory) or its consultant, and the level of review varies between provinces.

In Britain, falsework and formwork designs do not necessarily require design by an engineer, hence, for economy they are oftentimes subcontracted to specialty contracting firms. The Bragg Committee recommended that all major falsework designs be checked and signed by a chartered engineer, and reviewed by the original designer.[54] In response to the Bragg Committee recommendations, the Department of Transport amended their standard contractual conditions to incorporate independent checking of contractor's falsework design. This amendment specifies the type of checking required for three classes of falsework: small systems or systems where failure would be inconsequential, medium-sized systems, and large and complex systems.[159]

In West Germany, the review procedure is somewhat similar to British practice. Either the contractor is responsible for the falsework, or he subcontracts this responsibility. As required, the contractor's falsework plans are checked by an engineer known as a Prufingenieur (proof engineer), whose qualifications include the necessary engineering education and 10-years minimum structural design experience. The Prufingenieur is a licensed position granted in 5-year terms for a particular discipline within structural engineering, such as prestressed concrete or structural steel.[54]

Design of falsework for highway structures in Australia is also the responsibility of the contractor. The NAASRA *Bridge Design Specification* requires that the contractor submit to the engineer detailed drawings and calculations for approval.[62] NAASRA specifically states that engineering approval does not relieve the contractor of his responsibility for satisfactory performance and structural adequacy of the proposed falsework system. In a sample tender document obtained from the Roads and Traffic Authority (RTA) of Australia, falsework design and checking criteria were outlined more specifically.[160] Prior to submitting detailed drawings and design calculations, they must be independently checked by a structural engineering firm. Upon completion of this review, the drawings are signed and sealed for compliance with the NAASRA Bridge Design Specification. Costs associated with both falsework design and checking are usually borne by the contractor.

Falsework design for highway structures in New Zealand is categorized into four classes. For three classes, encompassing all falsework designs except simple installations or emergency temporary structures, the contractor must engage an experienced, registered civil engineer to prepare the falsework design and perform site inspection. A design review by an independent, registered civil engineer is required for only two falsework classes, comprising the more complex systems. The New Zealand Code outlines requirements for each class of falsework and prescribes the duties and responsibilities of all individual parties involved in the falsework design and construction process.[63,64]

As a point of clarification, Great Britain does not have registration by the government or licensing regulations for engineers analogous to the professional engineer in the United States. The "chartered engineer" title is granted to individuals meeting professional competence standards established by professional societies, such as the Institution of Structural Engineers.[159] Australian registration is similar to both the United States and Great Britain in that government and professional groups have established separate, yet similar engineering practice standards; the applicable standards to be used are project and client dependent. Likewise, Australian registration is prerequisite on formal engineering education and practical experience, although no examination is necessary to become a registered professional engineer.

INSPECTION

Falsework inspection is important to ensure the design is implemented according to plan, so construction or performance problems can be avoided. Unfortunately, not all temporary structures are inspected, or time and construction constraints limit the inspection level when performed. In the questionnaire, several States identified various falsework accidents that have occurred on their bridge projects and some recurring patterns were noted. Aside from poor workmanship, failures were commonly attributed to foundation conditions and inadequate stability. Foundation problems included inadequate bearing, excessive settlement, and wash-out of temporary footings. Misalignment, improper bracing, and web deformations due to overhang brackets were cited as causes of stability failures. Other common problems included form tie failures, slippage of friction collars, material failure(s), and premature falsework removal. It is conceivable that many of these problems or failures could be avoided with proper inspection.

Inspection of temporary structures for highway bridges is usually conducted by the contractor, the State inspecting engineer, or both. As reported in table 12, 15 States indicated falsework inspection procedures were the responsibility of the contractor alone. Out of these 15 States, nine require that the falsework plans be prepared by a professional engineer, and one requires it on an as-needed basis. None of the latter 10 States indicated that the same engineer was required to perform inspection. Thirty-five States responded that the State or its consultant was responsible for field inspection of the falsework and formwork. Seven of these States noted that the inspection was performed by both the State and contractor. In Canada, four Provinces indicated the contractor alone was responsible for inspection, while three noted that inspection was the Province's responsibility. As discussed in the previous section, all Provinces that responded require falsework plans to be prepared by a licensed professional engineer.

Currently, 10 States require the contractor's engineer to inspect the as-built falsework and certify in writing its compliance with the design drawings. Generally, each of the 10 States has a statement in their specifications outlining the compliance requirements. For example, the California Construction Safety Orders, otherwise known as Cal/OSHA, require that:[161]

> (1) After construction of the falsework or vertical shoring system enumerated in 1717(b) (1) and prior to placement of concrete, an engineer who is registered as a civil engineer in the State of California or his authorized representative, shall supervise the inspection of the falsework or vertical shoring system for conformity with the working drawings, and the civil engineer or his authorized representative performing the inspection shall certify in writing that the falsework or vertical shoring system substantially does so conform to the working drawings, and that the material and workmanship are satisfactory for the purpose intended. A copy of this certification shall be available at the site of the work at all times.
>
> (2) After the construction of any other falsework or vertical shoring system, a registered civil engineer in the State of California or a manufacturer's authorized representative or a licensed contractor's representative qualified in the usage and erection of falsework and vertical shoring shall inspect such falsework or vertical shoring prior to the placement of concrete and shall certify in writing that it complies with the falsework plan or shoring layout and that the materials and workmanship are satisfactory for the purpose intended. A copy of this certification shall be available at the site of the work at all times.

Inspecting falsework or formwork during construction can be a time consuming process. Depending on the complexity of the system and size of the overall project, this task alone could be a full time job for the inspector. The Bragg Committee recommended that the contractor employ a "Temporary Works Coordinator" or TWC.[54,158] The primary duty of the TWC is to check the as-built falsework and formwork against design drawings, identify potential problems, and ensure that discrepancies between the design and as-built system have been reviewed by the designer, as appropriate. Following inspection, the TWC issues a work continuation permit authorizing work to proceed in the inspected area.

Reference 162 contains similar discussion and recommendations in terms of construction practices in the United States. The author suggests that the contractor's project engineer design the falsework system, submit the design to the State for approval (as required), inspect the condition of the contractor's falsework material, and supervise erection. Furthermore, he proposes that after erection the project engineer is charged with inspection of the as-built falsework system and monitoring its performance in service. In terms of retaining an engineer for falsework inspection, this reference summarizes the point quite succinctly:

> It is a common misconception on the part of many contractors that the engineer's job is finished once the falsework plans are approved and handed to the field superintendent. The need for the engineer to follow the project through cannot be overemphasized. No one is as familiar with the design, the overall capacity, and the danger areas of the system as is the engineer, and that knowledge must be available at the job site.

In the falsework questionnaire, the investigators tried to ascertain the level of field inspection performed by the State or its consultant. In regards to inspection policy, the questionnaire included a punchlist of the following items:

a. Verify as-built members, frames, and other components are consistent with approved drawings.
b. Check screw jack extensions, alignment, etc.
c. Check bracing for conformance with plans.
d. Check forms for bowing or other potential problems.
e. Check connections for visible distress, weld quality, etc.
f. Check settlement of temporary foundations.
g. Check falsework deflection before/after concrete pours.
h. Check falsework for plumbness.

Out of the 34 States that responded, every State indicated that item a. was the primary focus of their inspections. The level of response to the remaining tasks (b through h) varied. Although no conclusive trends can be established from the data, it can be stated that items b, e, and f represented the lower response levels.

Several of the State construction manuals provided useful information with respect to inspection guidelines. Specific topics include foundations, timber falsework, steel falsework, manufactured steel shoring, and formwork. A summary of these documents and their specific guidelines are in appendix B. Depending upon the type of bridge and its construction requirements, not all items in this checklist will be applicable.

Inspection of a falsework system should continue while in service to ensure its proper performance and maintenance.[88,163] This point is especially important on large projects, which could last for several months. Although monitoring of temporary structures in service is generally not well defined by the States, several States specify criteria to limit the maximum settlement of falsework relative to the anticipated values noted on design drawings. For example, Georgia requires that:[32]

Should unanticipated events occur, including settlements that deviate more than $\pm$ 3/8 inch from those indicated on the falsework drawings, which in the opinion of the Engineer would prevent obtaining a structure conforming to the requirements of these Specifications, the placing of concrete shall be discontinued until corrective measures satisfactory to the Engineer are provided.

When considering deflection based criteria, it should be noted that initially a falsework system may exhibit large deflections attributed to joint "take-up" or the "settling-in" of the members. As a rule-of-thumb, some States indicate each level of timber joints can settle 1/16 in to 1/8 in (1.6 m to 3.2 mm). (See references 17, 19, 33, 164.)

As discussed in chapter 4, the State engineer or consultant will ordinarily authorize removal based on concrete strength maturation or curing period. Inspection during falsework removal by a qualified engineer is generally recommended to reduce the probability of damaging the permanent structure. Gradual removal or lowering of falsework is commonly achieved by loosening screw-jacks or removing (striking) hardwood wedges. Once clear of the structure, falsework removal methods are generally left up to the contractor. Reference 165 describes three methods of removal applicable to steel and timber falsework bents.

Table 12. Submittal, review and inspection policy.

		Submittals		Review		Inspection		
State	PE Seal	Sealed Drawings	Calculations	State[a]	Other	State	Other	Notes
Alabama	x	x		x		x		
Alaska	x	x		x		x		
Arizona	x	x	x	x		x		
Arkansas				None		x		Drawings would be submitted for info only.
California	x	x	x	x		x	x	PE if h >14 ft or span >16 ft or thru traffic.
Colorado	x	x			x		x	
Connecticut			AR[b]	x		x		Basic review.
Delaware	x	x	x	x		x		
Florida	x	x	x		x		x	Basic review.
Georgia	x	x	x	x		x		PE if h >14 ft or span >16 ft.
Hawaii	x	x	x	x		x		PE if h >40 ft or span >20 ft.
Idaho	x	x	x	x	x	x		
Illinois				x		x		
Indiana	x	x		x			x	
Iowa			AR	x		x		
Kansas	x	x	AR	x	x	x		
Kentucky	x	x	x	x		x		
Louisiana				x			x	
Maine	x	x	x	x		x	x	PE seal for structures next to or over travelled ways or as required.
Maryland	x	x	x	x			x	
Massachusetts	x	x	x	x		x		
Michigan				x		x	x	Reviewed for concrete slabs or T-beam spans.
Minnesota	AR	AR	AR	x			x	Simple forming systems not reviewed.
Mississippi	x	x	x		x		x	
Missouri	x	x	x	x	x	x	x	Review of falsework for small structures may be waived.
Montana	x	x	x	x		x		Minor structure falsework systems not reviewed.

1 ft = 0.305 m

Table 12. Submittal, review and inspection policy (continued).

State	PE Seal	Submittals: Sealed Drawings	Submittals: Calculations	Review: State	Review: Other	Inspection: State	Inspection: Other	Notes
Nebraska				None			x	
Nevada	x	x	x	x		x		Drawings required for cast-in-place concrete span >20 ft or over traffic. Also, if falsework span >16 ft.
New Hampshire			AR	AR	x	x	x	
New Jersey		AR	AR	x		x		Drawings typically reviewed.
New Mexico				x			x	
New York	x	x	x	x		x		Temp. structures not supporting vehicle or pedestrian traffic not reviewed.
North Carolina	x	x	x	x		x		PE seal for temp. bridge structures.
North Dakota				x			x	Falsework not reviewed unless required by plans.
Ohio	x	x	x	x		x		Falsework plans submitted for cast-in-place spans >20 ft.
Oklahoma	x	x	x	x		x		
Oregon	x	x	x	x		x	x	
Pennsylvania	x	x	x	x			x	
Puerto Rico								
Rhode Island	x	x	x	x			x	
South Carolina	x	x	x	x		x	x	Falsework for low level, simple structures where safety is of no concern are not checked.
South Dakota	AR			x		x		Complex falsework requires a PE seal; complete design check performed by State.

1 ft = 0.305 m

Table 12. Submittal, review and inspection policy (continued).

State	PE Seal	Submittals: Sealed Drawings	Submittals: Calculations	Review: State	Review: Other	Inspection: State	Inspection: Other	Notes
Tennessee	x			None			x	PE for cast-in-place structures over pedestrian or vehicular traffic.
Texas			AR	x		x		
Utah				x			x	
Vermont			AR	x		x		
Virginia	x			None			x	
Washington	x	x	x	x		x		
West Virginia	x	x	x	x		x		PE for major projects.
Washington, D.C.								
Wisconsin	x			x		x		
Wyoming	x	x	x	x		x		State reviews designs and drawings for dimensions primarily.
Canadian Province								
Alberta	x	x		x	x	x		Drawings reviewed in principal only.
British Columbia	x	x		x		x		Drawings reviewed for comment and information.
Manitoba								
New Brunswick								
Newfoundland	x	x	x	x			x	
N.W. Territory								
Nova Scotia								
Ontario	x	x	AR	x			x	Calculations required only in review discrepancies.
Prince Edward Island		Not	Available					
Quebec	x	x			x		x	
Saskatchewan	x	x		x			x	
Yukon	x	x		x		x		

Notes:

a. State includes any agency of the State or consulting engineering firm retained by the State.
b. As required (AR) by the State or project specifications.

CHAPTER 7. CONCLUSIONS AND RECOMMENDATIONS

As is evident from the references and bibliography, a significant amount of information is available on falsework, formwork, and scaffolding for highway bridge structures. After reviewing the state-of-practice in Great Britain and abroad in 1975, the Bragg Committee concluded that "nothing in the evidence we have reviewed has suggested that there are major gaps in the understanding of temporary structures." A considerable amount of standardization and related research has been conducted since that time by professional groups, engineers, and universities, making this conclusion even more applicable today.

In 1975, Great Britain and Canada produced model standards for falsework which apply to bridge and building construction. As noted in its foreword, the British Standard represents "a standard of good practice which has drawn together all those aspects that need to be considered when preparing a falsework design, and in so doing has included recommendations for materials, design and work on site." Since then, the Works and Development Services Corporation in New Zealand has produced a similar code of practice. Other non-English standards are known to exist and are referenced or identified in the bibliography.

While the existing standards serve as good models, they are not entirely adaptable to U.S. codes and construction practices, and the proprietary shoring systems common to the U.S. construction industry. Furthermore, despite the available information, the mistakes that contributed to prior falsework failures continue to be repeated. Based on a review of current State practice, it is evident that design, review, and inspection procedures vary considerably from one State to another. As expected, States that are more active in constructing cast-in-place concrete highway bridges generally have more comprehensive specifications and design guidelines. There are also many States, however, with significant bridge inventories that do not fall into this group.

Given the current state-of-the-practice in the United States, a clear need exists to develop unified design criteria and standards for the temporary structures used to construct highway bridge structures. Towards this end, both the technical and procedural requirements of temporary construction should be considered. Specific topics that should be addressed include:

Materials - The materials used in temporary construction, whether new or salvaged, should conform to the same standards as new construction. Current standards, such as those of the American Institute of Steel Construction, National Forest Products Association, and American Concrete Institute, serve their purpose well and development of the proposed standard should be conducted within the framework of existing standards. With respect to proprietary shoring systems, it is anticipated that test procedures and erection guidelines developed by the Scaffolding, Shoring and Forming Institute, or other industry groups, could be readily adopted by or incorporated within a code of practice.

Loads - ANSI A10.8 and A10.9 serve as basic source documents on this subject. At the present time, both AASHTO and ASCE are revising or, in the latter case, developing new standards with respect to temporary works or design loads during construction. These new standards, coupled with the existing ANSI and ASCE

7-88 (formerly ANSI A58.1) standards, and the AAHSTO *Standard Specifications for Highway Bridges*, could form the basis of the load provisions.

Although these standards thoroughly prescribe the wide range of potential gravity loads and identifiable lateral loads, the actual total lateral force is difficult to quantify and, therefore, more susceptible to being underestimated or ignored. Most standards include guidelines which are expressed in terms of percentage of the total vertical load. However, these expressions are general and have been found to vary between one and four percent. This problem is compounded by incidental loads due to post-tensioning of the permanent structure, deck shrinkage, and so forth. A more conservative figure such as the 3 percent recommended by the Bragg Committee seems appropriate.

Design and Analysis - As a general observation, the most common cause of falsework failures are lack of attention to the details which contribute to stability. Specific guidelines are required, particularly with respect to the lateral and longitudinal stability of falsework systems, and the lateral buckling, web crippling, and overturning resistance of beam grillages. The *California Falsework Manual* is perhaps the single most authoritative document on this subject and could serve as the principal source document for this section. Some of the more conventional design aspects of falsework, applicable to both temporary and permanent structures, could be based on information found in other publications, such as the AISC *Manual of Steel Construction,* the AASHTO *Standard Specifications for Highway Bridges,* the NFPA *National Design Specifications for Wood Construction,* and the AITC *Timber Construction Manual.* This information can be further supplemented by information found in some of the foreign standards and published literature identified in chapter 2.

Foundations and Soil Conditions - Information on soil properties, prescriptive measures to verify these properties, and design requirements for falsework foundations should be incorporated within the standard. Examples of this information can be found in the *California Falsework Manual,* the British *Code of Practice for Falsework* and New Zealand *Code of Practice for Falsework.*

Construction (Work-on-site) - Workmanship, erection methods and tolerances, bracing, and removal fall under the general topic of construction, or work-on-site. As noted in chapter 3, there are some existing guidelines that address the erection and bracing of temporary construction, particularly with respect to modular shoring systems. There are also standards for permanent construction, such as the AISC *Code of Standard Practice,* with provisions that could be readily adapted to temporary construction.

While some of the more common construction methods have been identified in this report, these methods can vary considerably depending upon the contractor's preference, available materials, and construction type. The development of "standard solutions," as found in the British *Code of Practice for Falsework* and the *California Falsework Manual,* would be useful. However, when considering this recommendation, a reasonable balance is required so the standard is sufficiently perscriptive, yet flexible enough for competitive bidding and constructive innovation.

Procedures - Procedural inadequacies can and often do contribute to falsework failures. Inadequate design review, unauthorized changes from design to as-built conditions, and lack of proper inspection have all led to such failures. Therefore, improvements in specification, review, and inspection methods will invariably translate to improved standards of falsework construction.

For example, possible variations in positioning and alignment, which are inevitable even with good workmanship, should be accounted for. Erection tolerances should be specified and conform to a recognized standard. Design criteria, including foundation requirements, should be indicated on the plans and verified. For more complex permanent structures, such as post-tensioned bridges, the falsework design and assumptions made with respect to the permanent structure need to be coordinated with the bridge design engineer. Responsibility for these tasks should be clearly delineated and prescribed.

The lack of standardization and attendant difficulties associated with falsework does not necessarily apply to formwork. Through the efforts of the American Concrete Institute, the practice of concrete formwork has been well defined and ACI 347-88, *Guide to Formwork for Concrete*, together with ACI Publication SP-4, *Formwork for Concrete*, are widely recognized as the authoritative documents on this subject. Therefore, there is no real need to duplicate this effort. However, the code of practice should include or, as a minimum, reference information on form material and accessories, minimum safety factors and lateral concrete pressures.

In summary, it is envisioned the proposed standard, or code of practice, could be modeled after existing standards. Virtually all of the potential reference or source documents necessary to develop such a standard have been identified in this synthesis. While sufficient information currently exists to develop this document, additional research would still be beneficial for such topics as load redistribution due to post-tensioning and deck shrinkage. It is further recommended that the proposed standard be administered under the auspices of the FHWA or AASHTO.

APPENDIX A - FALSEWORK QUESTIONNAIRE

FALSEWORK QUESTIONNAIRE

Scaffolding, Shoring, and Forming of Highway Structures
FHWA No. DTFH61-91-C-00014

Please answer all of the questions. If you have further comments or wish to qualify your answer, use the margins or a separate sheet of paper.

Respondent: ____________________

Title: ____________________

Address: ____________________

City: ________ State: ______ Phone: __________

Please return the completed form and any attachments to:

Wiss, Janney, Elstner Associates, Inc.
330 Pfingsten Road
Northbrook, Illinois 60061-2195

Attn: Neal S. Anderson

Your cooperation in completing this questionnaire is appreciated.

I. GENERAL

1a. How Many new state or federal aid bridges were constructed in your state betw-een

1970 - 1979? ______

1980 - 1989? ______

1990? ______

b. Please break down the total number of bridges identified in item 1a. according to their construction type.

Cast-in-place concrete ______

Precast concrete ______

Structural steel ______

Timber ______

Other ______

2. Are you aware of any significant falsework or form failures that occurred on these projects?

Yes No

If yes, please identify the project(s) and for each briefly describe the failure and its apparent cause.

____

____

____

3. Has your department conducted any formal or informal research on this subject.

Yes No

If yes, please provide a list of publications or other end products.

II. DESIGN AND INSPECTION POLICIES

4. Do falsework plans in your state require a Professional Engineer's Seal?

Yes No

5. Does your state have an established policy for the structural design of falsework, formwork, and/or shoring?

Yes No

If yes, please attach a copy.

6. Is the Contractor or his engineer required to submit:

falsework calculations? Yes No

sealed drawings? Yes No

7a. When falsework calculations and/or drawings are submitted by the Contractor, who reviews the design? (*check as many that apply*)

- ☐ State (bridge engineer, district engineer, etc.)
- ☐ Engineer-of-Record
- ☐ Third Party Consultant
- ☐ Other (*please explain*): ____________________

____

____

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7b. Under what circumstances would the State not review a falsework design?

____

____

____

____

8. What is the general nature and extent of falsework review performed by the State or the State's consultant? (*circle as many that apply*)

a. Not applicable (ref. item 7)

b. Basic flexure and shear analysis

c. Analysis of connection details

d. Deflection analysis of falsework and/or formwork

e. Lateral load analysis for wind and/or seismic conditions

f. Foundation analysis based on available soil data

g. Other (*please explain*): _______________

____

____

Any supplemental information, such as an in-house punch list, or contract between the State and the State's Consultant indicating the level of structural review, would be helpful.

9. Who is responsible for verification of the as-built falsework construction?

- ☐ State (bridge engineer, district engineer, etc.)
- ☐ Engineer-of-Record
- ☐ Third Party Consultant
- ☐ Other (*please explain*): _______________

____

____

10. Regarding falsework or form inspection, what is the primary focus of the state engineer when inspecting temporary construction? (*circle as many that apply*)

a. Verify as-built members, frames, and other components are consistent with approved drawings.

b. Check screw jack extensions, alignment etc.

c. Check bracing for conformance with plans

d. Check forms for bowing or other potential problems

e. Check connections for visible distress, weld quality, etc.

f. Check settlement of temporary foundations

g. Check falsework deflection before/after concrete pours

h. Check falsework for plumbness

i. Other (*please explain*): _______________

____

____

____

III. DESIGN CRITERIA

11. Does your state specify any codes other than AASHTO for falsework design?

Yes No

If yes, please specify:

____

____

12. For steel or timber falsework design, does your state permit any overstress relative to AASHTO allowables?

Yes No

If yes, please specify:

a. Steel: ________%

b. Timber: ________%

13. Does your state specify a minimum construction live load?

Yes No

If yes, please specify: _______________

14. Other comments:

APPENDIX B - REVIEW AND INSPECTION GUIDELINES

REVIEW

In order to permit a detailed review, a minimum amount of design information should be furnished on the drawings. Listed below is compilation of guidelines contained in standard specifications or construction/design manuals from five States.

Falsework (adapted from California, Colorado, and Idaho; see references 23, 30, 33, 88.)

- Superstructure placing diagram and construction joint locations.
- Soil bearing values for wet and dry soil conditions.
- Maximum allowed deviation of the pile top from vertical.
- Anticipated total footing settlement.
- Anticipated total falsework deflections.
- Temporary bracing or methods to be used during erection and removal.
- Stresses and deflections in load supporting members.
- All design loads including dead, live, wind, impact, post-tensioning, and ice loads.
- Special requirements for traffic openings.
- Special construction details.
- Type and grade of structural materials.
- Assumed allowable material stresses including bending, shear, compression, tension, and bearing and the modulus of elasticity of the material.
- Load duration factor(s) for timber construction.
- Summary of critical leg loads for proprietary shoring systems.
- Weight of all temporary machinery used in construction including deck finishing machines, screeds, power buggies, construction equipment, etc.
- Allowable load data for manufactured assemblies.
- Reference to the specific design specification used (for example, AASHTO, AISC, NDS, etc.).
- All necessary dimensions.

Formwork (adapted from Delaware and Washington; see references 9, 18.)

- Member sizes and spacing of bents, posts, joists, studs, walers, stringers, collars, bolts, wedges, and bracing.
- Allowable capacities for form ties and column clamps.
- All design loads including dead and live loads, and weights of moving equipment operating on the formwork.
- Assumed concrete pressure distribution, rate of concrete placement, concrete temperature, and height of concrete drop into the formwork.
- Design stresses in the individual members.
- Deflection and camber diagrams.
- Connection details.
- Material types, sizes, lengths, and related information.

In addition to the basic requirements noted above, Delaware requires the following details:[9]

- Anchors, shoring, and bracing.
- Field adjustment of the form during placing of concrete.
- Waterstops, keyways and inserts.
- Working scaffolds and runways.
- Weepholes.
- Screed and grade strips.
- Crush plates or wrecking plates.

- Removal of spreaders or temporary blocking.
- Clean out holes.
- Construction, control and expansion joints.
- Chamfer strips.
- Notes to cover conduits and pipes to be embedded.
- Details on shoring, reshoring or leaving original shores in place as forms are stripped.

INSPECTION

Inspection items listed below are common elements that require field checking on projects. This inspection punchlist was developed from several sources, but should not be considered all inclusive. (See references 26, 88, 96, 97, 166, 167, 168.)

Footings

- Verify the relative supporting capacity of the soil by soil report, heel test, pocket penetrometer, etc.
- Uniform soil bearing under footing.
- Construction joints in continuous pads located outside the effective length.
- Top surface of footing or pad level.
- Footing or pad protected from wash-out or undermining with proper surrounding drainage.
- Footing or pads set back far enough from a cut in the slope.

Piling

- Pile placement conforms with specified driving tolerances.
- Piles driven to permissible bearing values.
- Pile caps set properly and level to insure uniform bearing over the supporting piles.

Timber Falsework

- Timber free of noticeable defects, such as splits, open knots, rot and cuts.
- Timber appears to be well seasoned so warping and shrinkage will be minimal.
- Posts wedged at either top or bottom to permit grade adjustments.
- Double, hardwood wedges used where required.
- All members in contact have full bearing.
- Rough sawn timber measured to ensure actual dimensions conform to minimum sizes shown on Drawings for dressed members.
- Size, spacing, and length of members conform to design Drawings.
- Diagonal bracing installed per drawings.
- Connections checked for tightness of joint.
- Vertical members plumb and horizontal members level.
- Camber provided where required to offset dead load deflections.
- Full bearing connections examined for crushing.

Structural Steel Falsework

- Salvaged beams examined for section loss, web penetrations, rivet or bolt holes, and local deformation that could affect the member's load carrying capacity.
- Columns or pile bents set plumb and beams placed level.
- Member size and spacing in conformance with drawings.
- Bracing installed per drawings, especially where called out on beam compression flanges.
- Beam bearing connections examined for stiffeners and tack welds.
- Bolted connections sufficiently tightened with proper number of bolts.
- Welded connections evaluated and tested to prescribed standard(s).
- Splices located at designated locations per drawings.

Manufactured Steel Shoring Assemblies

- Manufactured shoring system in full compliance with manufacturer's recommended usage.
- Base plates, shore heads, extensions, or adjusting screw legs in firm contact with the foundation or support.
- Shoring tower assemblies set to correct spacing.
- Cross-bracing in conformance with drawings, including frame-to-frame braces and tower-to-tower braces.
- Screw leg extensions within allowable limits or adequately cross-braced, and snug to tower frame.
- Tower frames checked for plumbness.
- Ensure top U-heads are in full contact with joist or ledger, and hardwood wedges are snug.
- Frames examined for section loss, kinks, broken weld connections, damaged cross-bracing lugs, or bent members.
- Loads on shore heads applied concentrically, and not eccentrically.
- Ensure all locking devices are in the closed position.
- Guy wires adequately attached to towers and ground support.

Formwork

- Formwork is placed in accordance with the drawings.
- Forms are erected in compliance with the shape, lines, and dimensions shown on the drawings.
- Forms are rigid, watertight, and sufficiently braced and tied together so their position and shape will be maintained during concrete placement operations.
- Forms are clean and treated with an approved form release agent; pre-wetting before casting is performed as required.
- Form face surfaces are smooth in accordance with the desired concrete surface finish.
- Face grain of plywood sheathing properly oriented with respect to studs.
- Splices in wales staggered several studs apart.
- Form clean-out holes closed prior to concreting.
- All form hardware checked for tightness.
- Forms monitored for excessive loading conditions prior to use, such as reinforcing bar piles, equipment stacking, etc.
- All lines are true horizontal or vertical.
- Chamfer strips correctly placed.
- Clear cover for reinforcing bars maintained on all surfaces.
- Fascia girders on bridges adequately braced to prevent rotation from bridge overhang bracket reactions.

APPENDIX C - INFORMATION SOURCES

United States

American Association of State Highway
and Transportation Officials (AASHTO)
444 North Capitol Street, N.W., Suite 225
Washington, D.C. 20001

American Concrete Institute (ACI)
P.O. Box 19150
Detroit, Michigan 48219-0150

American Institute of Steel Construction (AISC)
400 North Michigan Avenue
Chicago, Illinois 60611

American Iron and Steel Institute (AISI)
1000 16th Street, N.W.
Washington, D.C. 20036

American Institute of Timber Construction (AITC)
333 West Hampden Avenue
Englewood, Colorado 80110

American National Standards Institute (ANSI)
1430 Broadway
New York, New York 10018

American Plywood Association (APA)
P.O. Box 11700
Tacoma, Washington 94811-0700

American Society for Testing and Materials (ASTM)
1916 Race Street
Philadelphia, Pennsylvania 19103-1187

American Society of Civil Engineers (ASCE)
345 East 47th Street
New York, New York 10017-2398

American Welding Society (AWS)
550 N.W. LeJeune Road
P.O. Box 351040
Miami, Florida 33135

California Department of Transportation
Division of Structures
P.O. Box 942874
Sacramento, California 94274-0001

Federal Highway Administration (FHWA)
Turner - Fairbank Highway Research Center
6300 Georgetown Pike
McLean, Virginia 22101-2296

National Forest Products Association (NFPA)
1250 Connecticut Avenue, N.W.
Washington, D.C. 20036

Precast/Prestressed Concrete Institute (PCI)
175 West Jackson Boulevard
Chicago, Illinois 60604

International Conference of Building Officials
(ICBO)
5360 South Workman Mill Road
Whittier, California 90601

Canada

Canadian Standards Association (CSA)
178 Rexdale Boulevard
Rexdale, Ontario, Canada M9W 1R3

Great Britain

British Standards Institution (BSI)
2 Park Street
London W1A 2B5
England

Cement and Concrete Association (CCA)
Wexham Springs
Slough 5L3 6PL
England

Construction Industry Research and
Information Association (CIRIA)
6 Storey's Gate
London SW1P 3AU, England

The Concrete Society
Devon House
12-15 Dartmouth Street
London SW1H 9BL
England

Australia

Concrete Institute of Australia
100 Walker Street
North Sydney 2060
New South Wales, Australia

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National Association of Australian
State Road Authorities (NAASRA)
P.O. Box J141, Brickfield Hill
Sydney 2000
New South Wales, Australia

Standards Association of Australia
Standards House
80 Arthur Street
North Sydney 2060
New South Wales, Australia

New Zealand

Cement and Concrete Association of
New Zealand
13 Wall Place, Private Bag
Porirua, New Zealand

Transit New Zealand
Vogel Bldg., Aiken Street
P.O. Box 12446
Wellington, New Zealand

Japan

Japan Concrete Institute
Room 708 Shuwa Kioicho TBR Bldg.
No. 7, Kojimachi 5-Chrome, Chofu-shi
Tokyo 182, Japan

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