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CULVERT INSPECTION MANUAL

Research, Development, and Technology
Turner-Fairbank Highway Research Center
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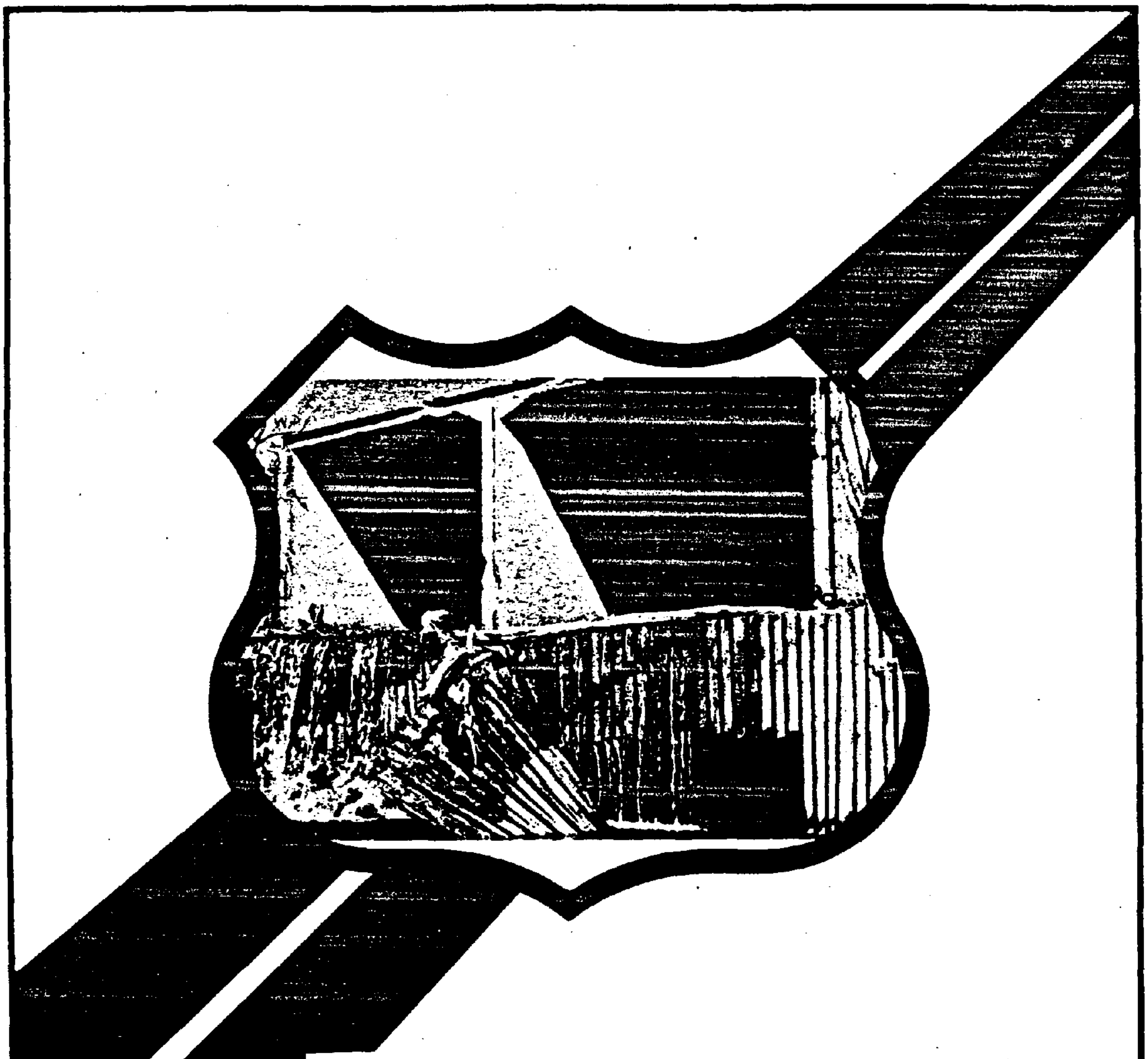
U.S. Department of Transportation
Federal Highway Administration

SUPPLEMENT TO THE BRIDGE INSPECTOR'S TRAINING MANUAL

Report No. FHWA-IP-86-2

Final Report
July 1986



FOREWORD

The Implementation Package provides practical procedures for the inspection and rating of various types of highway culverts. These procedures should be of interest to hydraulic, bridge, and maintenance engineers, technicians and inspectors. This manual is a supplement to the Bridge Inspector's Training Manual and was prepared in accordance with its procedures and rating systems.

Copies of the manual are being distributed to FHWA Region and Division offices, and to each State highway agency for use by their engineers and inspectors. Additional copies of the manual can be obtained from the Superintendent of Documents, U. S. Government Printing Office, Washington, DC 20402 or the National Technical Information Service, Springfield, Virginia 22161.

Ronald E. Heinz
Director, Office of Engineering

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NOTICE

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16. Abstract

Bridges and culverts with openings measuring more than 20 feet (6m) parallel to the centerline of the roadway are inspected on a two year cycle in accordance with National Bridge Inspection Standards. The structural and hydraulic design of culverts is substantially different from bridges as are the construction methods, durability considerations, and inspection procedures.

This manual provides guidelines for the inspection and evaluation of existing culverts. It is a stand alone supplement to the Bridge Inspector's Training Manual.

The text provides procedures for conducting and documenting culvert inspections with specific guidelines for inspecting and evaluating the major hydraulic and structural components of culverts. Discussions on the hydraulic, structural, and durability performance of culverts are also included. Information is provided on personnel qualifications, equipment, and safety procedures required for conducting culvert inspections.

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METRIC (SI*) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

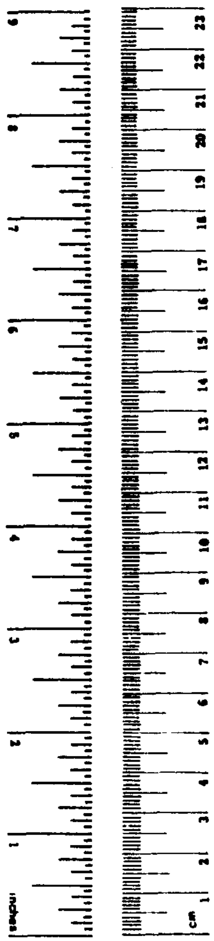
Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
in	inches	2.54	millimetres	mm
ft	feet	0.3048	metres	m
yd	yards	0.914	metres	m
mi	miles	1.61	kilometres	km
	AREA			
in^2	square inches	645.2	millimetres squared	mm^2
ft^2	square feet	0.0929	metres squared	m^2
yd^2	square yards	0.836	metres squared	m^2
mi^2	square miles	2.59	kilometres squared	km^2
ac	acres	0.395	hectares	ha
	MASS (weight)			
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams	Mg
	VOLUME			
fl oz	fluid ounces	29.57	millilitres	mL
gal	gallons	3.785	litres	L
ft^3	cubic feet	0.0328	metres cubed	m^3
yd^3	cubic yards	0.0765	metres cubed	m^3

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

TEMPERATURE (exact)

°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

* SI is the symbol for the International System of Measurements



APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
	LENGTH			
mm	millimetres	0.039	inches	in
m	metres	3.28	feet	ft
m	metres	1.09	yards	yd
km	kilometres	0.621	miles	mi
	AREA			
mm^2	millimetres squared	0.0016	square inches	in^2
m^2	metres squared	10.764	square feet	ft^2
km^2	kilometres squared	0.39	square miles	mi^2
ha	hectares (10 000 m^2)	2.53	acres	ac
	MASS (weight)			
g	grams	0.0353	ounces	oz
kg	kilograms	2.205	pounds	lb
Mg	megagrams (1 000 kg)	1.103	short tons	T
	VOLUME			
mL	millilitres	0.034	fluid ounces	fl oz
L	litres	0.264	gallons	gal
m^3	metres cubed	35.315	cubic feet	ft^3
m^3	metres cubed	1.308	cubic yards	yd^3

TEMPERATURE (exact)

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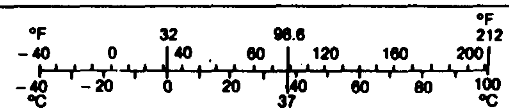

These factors conform to the requirement of FHWA Order 5190.1A.

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Chapter 1

GENERAL ISSUES

Traditional definitions of culverts are based on the span length rather than function or structure type. For example, part of the culvert definition included in the Bridge Inspector's Training Manual 70 states:

> "...structures over 20 feet in span parallel to the roadway are usually called bridges; and structures less than 20 feet in span are called culverts even though they support traffic loads directly."

Many structures that measure more than 20 feet along the centerline of the roadway have been designed hydraulically and structurally as culverts. The structural and hydraulic design of culverts is substantially different from bridges, as are construction methods, maintenance requirements, and inspection procedures. A few of the more significant differences between brid and culverts are:

- Hydraulic--Culverts are usually designed to operate at peak flows with a submerged inlet to improve hydraulic efficiency. The culvert constricts the flow of the stream to cause ponding at the upstream or inlet end. The resulting rise in elevation of the water surface produces a head at the inlet that increases the hydraulic capacity of the culvert. Bridges may constrict flow to increase hydraulic efficiency or be designed to permit water to flow over the bridge or approach roadways during peak flows. However, bridges are generally not designed to take advantage of inlet submergence to the degree that is commonly used for culverts. The effects of localized flooding on appurtenant structures, embankments, and abutting properties are important considerations in the design and inspection of culverts.

- Structural--Culverts are usually covered by embankment material. Culverts must be designed to support the dead load of the soil over the culvert as well as live loads of traffic. Either live loads or dead loads may be the most significant load element depending on the type of culvert, type and thickness of cover, and amount of live load. However, live loads on culverts are generally not as significant as the dead load unless the cover is shallow. Box culverts with shallow cover are examples of the type of installation where live loads are important.

  In most culvert designs the soil or embankment material surrounding the culvert plays an important structural role. Lateral soil pressures enhance the culverts ability to support vertical loads. The stability of the surrounding soil is important to the structural performance of most culverts.

• Maintenance--Because culverts usually constrict flow there is an increased potential for waterway blockage by debris and sediment, especially for culverts subject to seasonal flow. Multiple barrel culverts may also be particularly susceptible to debris accumulation, as shown in exhibit 1. Scour caused by high outlet velocity and turbulence at inlet end is a concern. As a result of these factors, routine maintenance for culverts primarily involves the removal of obstructions and the repair of erosion and scour. Prevention of joint leakage may be critical in culverts bedded in pipeable soils to prevent undermining and loss of support.

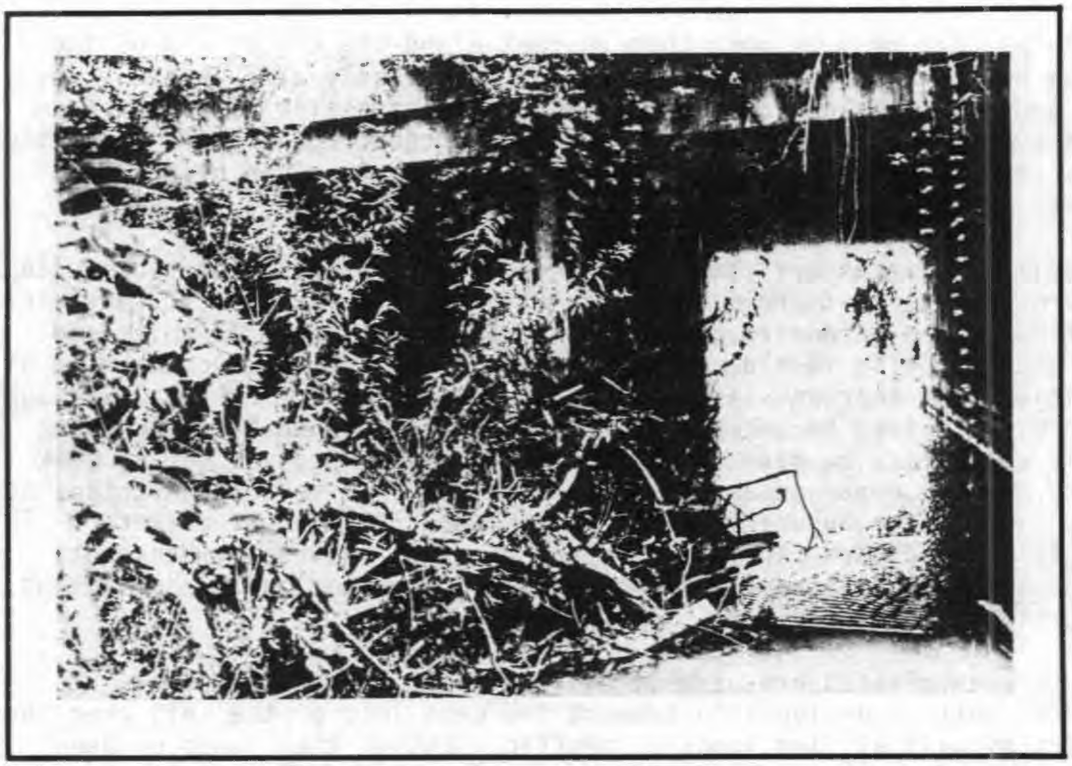


Exhibit 1. Accumulation of debris at culvert inlets may be a recurring problem in some locations.

• Traffic Safety--A significant safety advantage of many culverts is the elimination of bridge parapets and railings. Culverts can usually be extended so that the standard roadway cross section can be carried over the culvert to provide a vehicle recovery area. However, when ends are located near taffic lanes or adjacent to shoulders, guardrails may be used to protect the traffic. Less differential icing, which occurs when water on the bridge deck freezes before water on the nearby roadway, is an additional benefit.

• Construction--Careful attention to construction details such as bedding, compaction, as shown in exhibit 2, and trench width during installation is important to the structural integrity of the culvert. Poor compaction or poor quality backfill around culverts may result in uneven settlement over the culvert and possibly structural distress of the culvert.

Exhibit 2. Attention to construction details such as compaction, bedding, and trench width is critical to proper culvert performance.

• Durability--Durability of material is a significant problem in culverts and other drainage structures. In very hostile environments corrosion and abrasion can cause deterioration of all commonly available culvert materials.

• Inspection--The inspection and assessment of the structural condition of culverts requires an evaluation of not only actual distress but circumstantial evidence such as roadway settlement, pavement patches, and embankment condition.

Until now, there has been little concise information available that deals specifically with the inspection and evaluation of culverts. The purpose of this manual is to meet this need for guidelines for the inspection of structures functioning structurally and hydraulically as culverts regardless of span length.

Section 1. NEED FOR CULVERT INSPECTIONS

1-1.1 Introduction.

Over the years, culverts have traditionally received less attention than bridges. Since culverts are less visible it is easy to put them out of mind, particularly when they are performing adequately. Additionally, a culvert usually represents a significantly smaller investment than a bridge and in the event of a failure usually represents much less of a safety hazard.

Since 1967 there has been an increased emphasis on bridge safety and on bridge rehabilitation and replacement programs. In many cases small bridges have been replaced with multiple barrel culverts, box culverts, or long span culverts. There have also been recent advances in culvert design and analysis techniques. Long span corrugated metal culverts, as shown in exhibit 3, with spans in excess of 40 feet were introduced in the late 1960's.

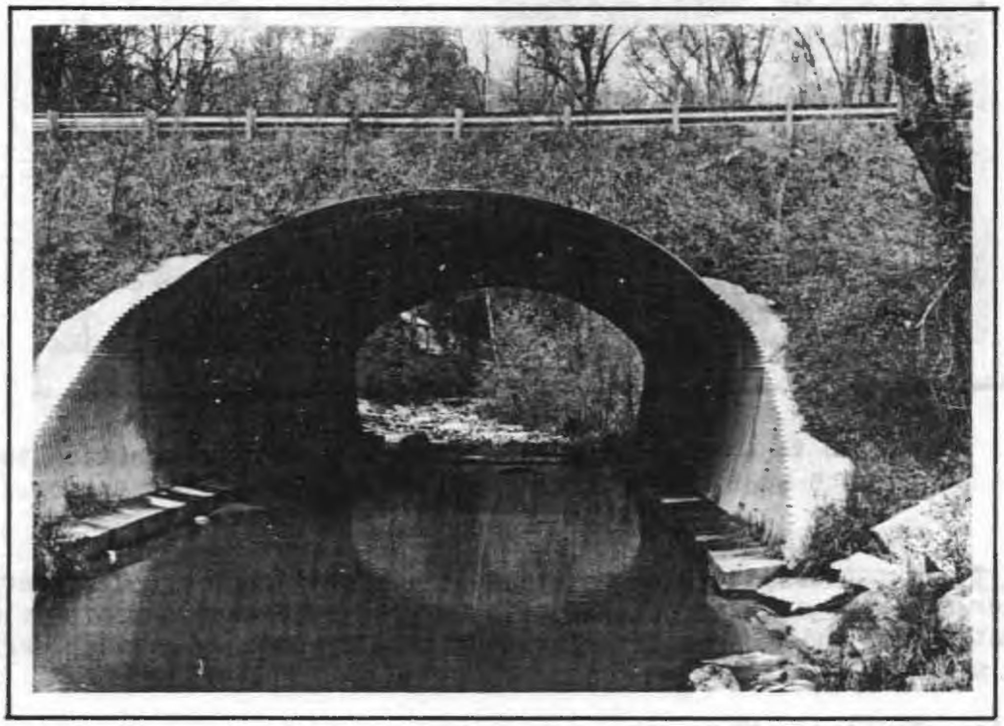


Exhibit 3. This long span high profile arch replaced a small bridge in North Carolina.

As a result of these developments, the number, size, complexity, and cost of culvert installations have increased. The failure of a culvert may be more than a mere driving inconvenience. Failure of a major culvert may be both costly and hazardous, as shown in exhibit 4.

Exhibit 4. Several fatalities occurred due to this culvert failure.

Like bridges, culverts should be inspected regularly to identify potential safety problems and maintenance needs or other actions required to preserve the investment in the structure and to minimize property damage due to improper hydraulic functioning.

1-1.2 Safety.

Safety is the most important reason why culverts should be inspected. To insure that a culvert is functioning safely, the inspection should evaluate structural integrity, hydraulic performance, and roadside compatibility.

a. Structural Integrity--The failure of major culverts can present a life threatening safety hazard. The identification of potential structural and material problems requires a careful evaluation of indirect evidence of structural distress as well as actual deterioration and distress in the culvert material.

b. Hydraulic Performance--When a culvert's hydraulic performance is inadequate, potential safety hazards may result. The flooding of adjacent properties from unexpected headwater depth may occur. Downstream areas may be flooded by failure of the embankment. The roadway embankment or culvert may be damaged because of erosion, as shown in exhibit 5.

Exhibit 5. Roadway and embankment wash-out.

c. Roadside Compatibility--Many culverts, like older bridges, present roadside hazards. Headwalls and wingwalls higher than the road or embankment surface may constitute a fixed obstacle hazard. Abrupt dropoffs over the end of a culvert or steep embankments may represent roll-over hazards to vehicles which leave the roadway.

1-1.3 Maintenance Needs.

Lack of maintenance is a prime cause of improper functioning in culverts and other drainage structures. Regular periodic inspections allow minor problems to be spotted and corrected before they become serious.

Section 2. OBJECTIVES, AUDIENCE, AND ORGANIZATION OF THE MANUAL

1-2.1 Objectives.

a. The primary objective of this manual is to provide information that will enable users to do the following tasks:

(1) Properly inspect an existing culvert.

(2) Evaluate structural adequacy.

(3) Evaluate hydraulic adequacy and recognize potential flood hazards.

(4) Rate the condition of the culvert.

(5) Document the findings of a culvert inspection.

(6) Recognize and document traffic safety conditions.

(7) Recommend corrective actions.

To meet this objective, the manual provides general procedures for conducting, reporting, and documenting a culvert inspection, and guidelines for inspecting and rating specific hydraulic and structural culvert components.

b. A second objective of the manual is to provide users with the information necessary to understand and evaluate the significance of defects found during an inspection of an existing culvert. To meet this objective, a review of how culverts should function structurally and hydraulically is provided. Durability concepts are also reviewed.

c. The third major objective of this manual is to serve as a stand alone supplement to the Bridge Inspector's Training Manual 70. The information that is contained in this manual specifically addresses culvert inspections. To be a stand alone document applicable information in the Manual 70 has been summarized in this manual.

1-2.2 Intended Audience.

a. Bridge Inspectors--Culverts with a total opening length of over 20 feet are conventionally classified as bridges and must currently be inspected as part of the National Bridge Inspection Program. Therefore, the primary group of individuals this manual was written for are bridge inspection personnel responsible for inspecting structures that are designed hydraulically or structurally as culverts.

b. Maintenance Personnel--Although bridges with spans over 20 feet usually are inspected by bridge inspectors, culverts with a total opening length of under 20 feet are usually inspected by maintenance personnel. Maintenance personnel with culvert inspection responsibilities, therefore, should also find this manual helpful.

1-2.3 Organization of the Manual.

This manual is organized into five chapters. Chapter 1, introduces the need for guidelines that specifically address culvert inspection. Chapter 2 describes the personnel qualifications, equipment requirements, and safety considerations for culvert inspection. Chapter 3 reviews basic concepts related to hydraulic, structural, and durability design. Chapter 4 presents general procedures for conducting and documenting culvert inspections. Chapter 5 contains guidelines for inspecting and rating the major structural and hydraulic components of pre-cast concrete, cast-in-place concrete, and corrugated metal structures.

CHAPTER 2

THE INSPECTOR

This chapter deals with the qualifications of personnel and equipment required for bridge inspection. To be an independent supplement to the "Bridge Inspector's Training Manual," some of the material presented in the Manual 70 is summarized in this chapter. The primary purpose of this chapter is to describe any specialized personnel qualifications or supplemental equipment needed for the inspection of culverts.

Section 1. Duties, Qualifications, and Equipment

2-1.0. General.

The National Bridge Inspection Standards (NBIS) describe the minimum qualifications for two levels of bridge inspection personnel. These levels also apply to personnel responsible for the inspection of bridge length culverts. The first level is the individual in charge of the organizational unit that is responsible for managing the bridge and culvert inspection program of that organization. This individual generally provides day-to-day supervision of the bridge and culvert inspection teams and is usually available to provide assistance to the inspection teams when problems are encountered.

The second level defined in the NBIS is the inspection team leader. This individual is in charge of a bridge or culvert inspection team and is responsible for the on-site supervision and direction of the inspection team. Although one inspector is often used for a culvert inspection, for personnel safety, ease of inspection, measuring, and documenting, inspection teams should be composed of at least two people. For the purpose of this manual, the term "inspector" will be used to indicate the team leader.

2-1.1. Qualifications of the Inspector.

a. Training and Experience--The culvert inspector or inspection team leader should meet the qualifications defined in the NBIS which state that the team leader should:

(1) be registered or be qualified for registration as a professional engineer or

(2) have a minimum of five years in culvert inspection assignments and have completed a comprehensive training course based on the "Bridge Inspector's Training Manual."

The culvert inspector should have knowledge of how culverts function hydraulically and structurally and the significance of defects that may be found during a culvert inspection.

b. Physical Ability--The culvert inspector must be capable of working under physically demanding conditions, including cramped spaces, rugged terrain, steep embankments, and in and around water.

c. Skills--Certain skills are needed to adequately prepare for, conduct, and document a culvert inspection. To prepare for an inspection the inspector should be able to read plans, construction documents, and previous inspection reports. To conduct a culvert inspection the inspector should have a working knowledge of the use of measuring devices including rules, tapes, feeler gauges, protractors, and micrometer calipers, as illustrated in exhibits 6 and 7. The ability to use a transit or surveyor's level is desirable. The inspector should also be aware of potential safety hazards. To adequately document the inspection, the inspector must be able to letter legibly, draw technical sketches, and operate a camera.

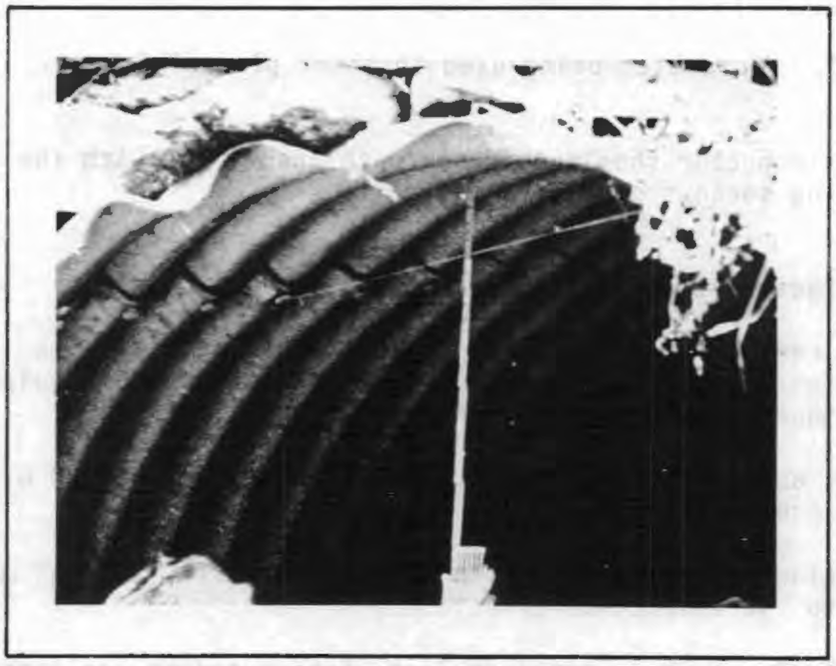


Exhibit 6. Stringline and rule being used to check middle ordinate of top plate of structural plate culvert.

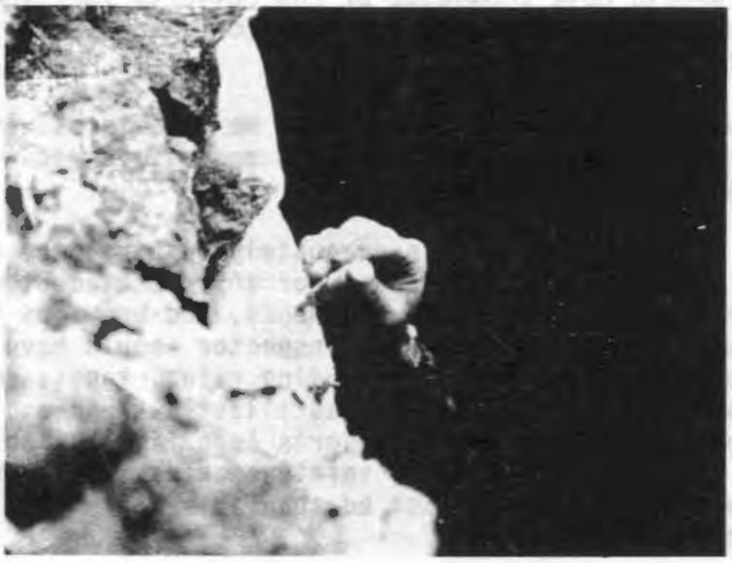


Exhibit 7. Micrometer being used to check plate thickness.

d. Attitude--The inspector should approach each inspection with the expectation of finding serious defects.

2-1.2. Specialized Equipment and Standard Tools.

Tools and equipment needed for culvert inspections are listed in this section. A more extensive listing of bridge inspection tools and equipment is provided in the "Bridge Inspector's Training Manual 70."

a. Standard Tools and Equipment--The inspector should be provided with the following tools and equipment:

(1) Transportation vehicles, such as a van or carry-all, to haul men and equipment to the inspection sites.

(2) Measuring tools, such as tapes, rulers, feeler gauges, calipers, plumb bob, protractor, and sounding line.

(3) Hand tools, such as geologist's hammer, chisel, scraper, pocket knife, wire brush, ice pick, and probes or pointed steel rods.

(4) Debris removal tools, such as hand shovel, pick, and brush hook or machete.

(5) Lighting devices, such as reflection mirror and flashlight. A hat-mounted light such as a miner's lamp is preferable to a hand-held flashlight.

(6) Photographic equipment, such as a camera and flash attachment.

(7) Marking devices, such as scribes, punch, spray paint, and keel.

(8) Record keeping supplies, such as field books, inspection forms, clip boards, straight edge, and pencils.

(9) Personal protective safety equipment, such as gloves, hard hat, safety shoes, boots, or waders.

(10) Traffic safety equipment, such as safety vests, signs, and cones.

(11) First-aid kit, such as emergency supplies to treat cuts, scrapes, bites, or other minor injuries.

b. Specialized Equipment--Specialized equipment includes that equipment which is required to provide access to inspection locations on a structure as well as that equipment which is needed for special sampling and testing. The collection of electrical resistivity data and soil water pH are examples of specialized testing. Tests to obtain pH and resistivity data are not hard to perform, and this information should be collected. Data of this type is useful in analyzing long-term cost benefits.

(1) Ladders. Small portable ladders may be necessary to gain entrance to culverts through manholes or similar structures. Step ladders or other small ladders may be needed for close inspection of top slab or crown of culverts.

(2) Small boat. A small boat may be needed during the inspection of a large pipe culvert with water flow most of the time.

(3) Rope. A rope may be required for use as a safety harness or life line when inspecting steep culverts.

(4) Transit or level surveying equipment. This equipment may be needed for shape inspections of long span culverts. Such equipment is also useful for determining culvert slope, depth of cover, and other information.

(5) Mechanical ventilation and pre-entry air test equipment. These items are necessary for inspection of confined spaces and culverts with poor air circulation.

(6) Hole sawing equipment. Drills equipped with hole sawing or coring attachments may be needed to obtain samples when durability problems are observed. An appropriate power source such as a portable generator will be required. Kits for plugging sampling holes are also needed.

(7) Meters or kits for testing pH. The degree of acidity or alkalinity of soil and water is measured in terms of pH. Testing to determine pH is performed when evaluating durability problems. Meters or test kits may be needed for field testing the pH of soil and water. Empty containers may be needed for sampling soil and water when a laboratory analysis of pH is to be performed.

(8) Resistivity meters. These devices may be needed to measure the electrical resistivity of soil at locations where corrosion problems are found. Electrical resistivity provides an indication of the relative quantity of soluble salts in the soil or backfill materials.

Section 2. SAFETY

2-2.0. General.

The safety of the inspector is extremely important. It is therefore essential that inspectors be aware of and practice safe work procedures. Safety considerations related to culvert inspection are discussed in this section.

2-2.1. Confined Spaces.

a. Hazards. Culverts with inadequate ventilation, such as those with one end blocked by debris, or long runs of culvert pipe in urban drainage systems, may develop a lack of oxygen or hazardous concentrations of toxic gases. Oxygen depletion may result from the slow oxidation of organic matter. Toxic gases, often heavier than air, may seep into and collect in poorly ventilated culverts. When there is any doubt about the quality of air or adequacy of ventilation, safety procedures should be followed.

b. Safety Procedures.

(1) Where air quality is questionable, tests for oxygen content and the presence of hazardous gases should be conducted prior to entry. Hazardous gases may include toxic gases such as hydrogen sulphide and carbon monoxide, and combustible gases such as methane. A variety of devices are available for measuring oxygen levels and detecting hazardous gases. Testing devices for field use range from clip on badges which change color in the presence of a particular gas to portable or hand-held instruments which measure the levels of various gases. Audible alarms are provided with some models. The devices and test procedures used should meet applicable State or Federal Standards such as Occupational Safety and Health Association (OSHA) standards.

(2) When oxygen levels are found to be below established minimum levels, or noxious gases exceed recommended levels, persons should not be allowed to enter the space until proper oxygen and gas contents are established by mechanical ventilation.

(3) Confined spaces should be mechanically ventilated continuously during occupancy. Air tests similar to pre-entry tests should be conducted during the occupancy period if oxygen depletion is suspected. The use of a safety harness and life line may also be required, and one person should always remain outside the confined space.

2-2.2. Drowning Hazards.

a. Scour Holes--Erosion of the streambed during peak flows may leave hazardous pockets of deep water. During periods of low flows, the water in these scour holes may be considerably deeper than the depth of flow in the culvert barrel or normal stream channel. The depth of scour holes may be deceptive, and the inspectors should probe the streambed with a rod prior to wading.

b. Flash Floods--Runoff from high intensity storms may reach peak flow levels in small culverts very quickly, creating hazardous conditions for inspectors inside the culvert barrel. Peak flow levels have been known to occur in culverts before the rain actually falls at the culvert site. Culvert inspectors should exercise caution when storms are approaching.

2-2.3. Traffic Hazards

Inspection activities and the parking of inspection vehicles on or near the roadway may represent a potential hazard to passing motorists, pedestrians, or the inspectors. It is important that proper traffic control measures be used. Traffic control should conform to the Federal or State Manual of Uniform Traffic Control Devices.

2-2.4. Miscellaneous Hazards.

a. Steep Embankments--Roadway embankments may be both high and steep resulting in hazardous footing. Brambles, vines, and other underbrush may create additional hazards which cause stumbling. Inspectors must exercise caution when going up or down the roadway embankment.

b. Toxic Chemicals--On rare occasions streams may carry hazardous chemicals from spills or leaking storage containers. Fires and explosions have resulted from gasoline leaking into storm drainage systems. The inspector should be aware of the potential hazard and exercise caution when toxic chemicals are suspected in the water.

c. Animals--Underbrush and accumulations of drift and debris in and around the culvert barrel may harbor rodents, snakes, or other animals which could represent a hazard to the inspector, as shown in exhibit 8. Poor lighting and reduced space inside the culvert barrel may limit the inspector's ability to react or avoid these hazards. The inspector should exercise caution when removing debris or vegetation.

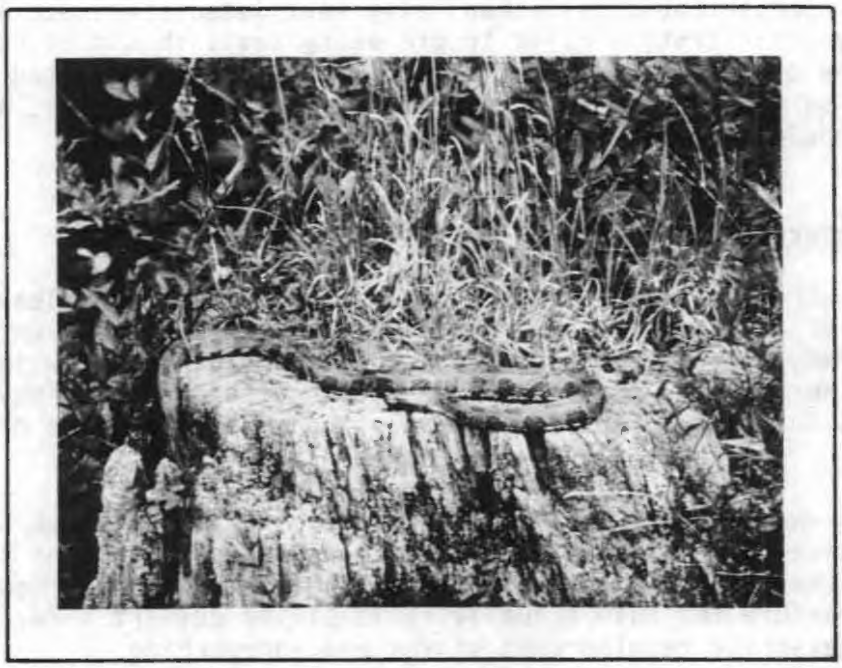


Exhibit 8. Inspectors should use caution when working in areas that may be inhabited by snakes, rodents, or other animal hazards.

d. Other Hazards--Poison ivy, ticks, wasps, and other stinging or biting insects may also be hazardous to the inspector. The inspector should learn to recognize and avoid poisonous plants, should check clothing, skin, and scalp for ticks, as shown in exhibit 9, and should wear appropriate clothing where biting insects may be a problem. Insect repellents and insecticide sprays may also be useful.

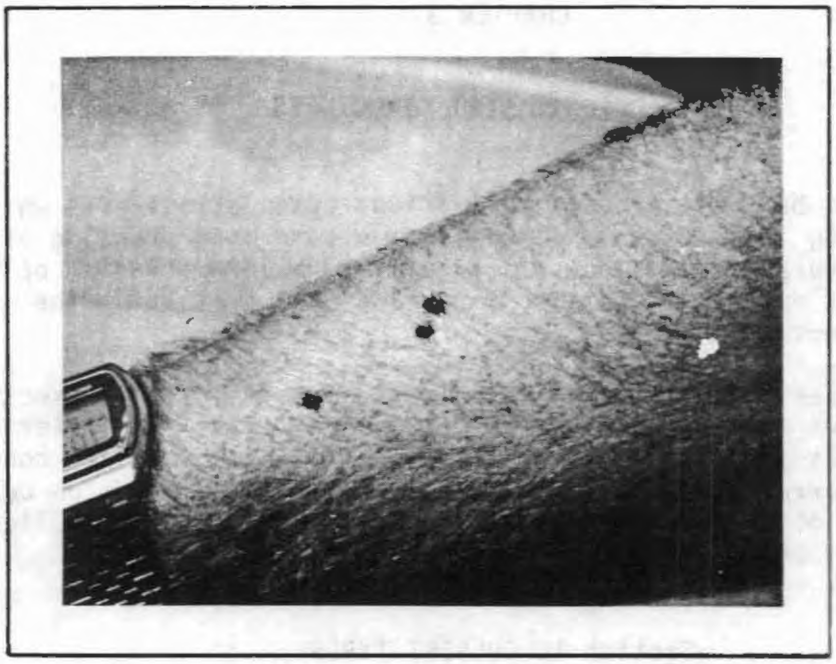


Exhibit 9. Inspectors should check their clothing, skin, and scalp when working in areas where ticks are common.

CHAPTER 3

CULVERT STRUCTURES

The inspector should be familiar with the various types of culverts which may be encountered during inspections and should have some understanding of how culverts function hydraulically and structurally. An understanding of the factors which affect durability is also important when evaluating the condition of a culvert.

This chapter discusses culvert types and culvert performance. The section on culvert types reviews the most common culvert shapes, sizes, and materials. The culvert materials addressed are precast concrete, cast-in-place concrete, corrugated steel, corrugated aluminum, and masonry. The sections on culvert performance consist of a review of basic concepts for culvert hydraulics, structural behavior, and durability of culverts.

Section 1. CULVERT TYPES

3-1.0 General.

A wide variety of culvert structures are currently in use as stream crossings, underpasses, and other highway and railroad applications. The inspector should understand that the selection of a specific type of culvert structure may be based on many factors. These factors can include:

a. Engineering Considerations--An analysis of each site is generally performed to determine hydraulic, structural, and durability requirements. Traffic safety requirements are also important considerations which may vary from site to site.

b. Economic Considerations--An economic analysis may include factors such as construction cost, estimated service life, maintenance cost, replacement cost, risk of failure, and risk of property damage. The most economical culvert is the one with the lowest total cost over the design period. It is not necessarily the culvert with the lowest initial cost or the culvert with the longest service life. An economic analysis should be viewed as a tool to aid in the decision-making process. Economic analysis can be sensitive to service life, discount rate, and other assumptions. Additionally, it is often difficult to assign values to subjective factors.

c. Local Considerations--Local construction capabilities, availability of materials, time available for construction, and local policies or preference may have a strong influence on the selection of culvert type.

d. Other Considerations--Impact on the environment, fish passage requirements, importance of roadway in terms of traffic volume, use by emergency vehicles and school buses, length of detour, land use, and appearance or aesthetics are examples of other considerations which may influence culvert selection.

3-1.1 Culvert Shapes

A wide variety of standard shapes and sizes are available for most culvert materials. Since equivalent openings can be provided by a number of standard shapes, the selection of shape may not be critical in terms of hydraulic performance. Shape selection is often governed by factors such as depth of cover or limited headwater elevation. In such cases a low profile shape may be needed. Other factors such as the potential for clogging by debris, the need for a natural stream bottom, or structural and hydraulic requirements may influence the selection of culvert shape. Each of the common culvert shapes are discussed in the following paragraphs.

a. Circular--The circular shape is the most common shape manufactured for pipe culverts. It is hydraulically and structurally efficient under most conditions. Possible hydraulic drawbacks are that circular pipe generally causes some reduction in stream width during low flows. It may also be more prone to clogging than some other shapes due to the diminishing free surface as the pipe fills beyond the midpoint. With very large diameter corrugated metal pipes, the flexibility of the sidewalls dictates that special care be taken during backfill construction to maintain uniform curvature.

b. Pipe Arch and Elliptical Shapes--Pipe arch and elliptical shapes are often used instead of circular pipe when the distance from channel insert to pavement surface is limited or when a wider section is desirable for low flow levels. These shapes may also be prone to clogging as the depth of flow increases and the free surface diminishes. Pipe arch and elliptical shapes are not as structurally efficient as a circular shape.

c. Arches--Arch culverts offer less of an obstruction to the waterway than pipe arches and can be used to provide a natural stream bottom where the stream bottom is naturally erosion resistant. Foundation conditions must be adequate to support the footings. Riprap is frequently used for scour protection.

d. Box Sections--Rectangular cross-section culverts are easily adaptable to a wide range of site conditions including sites which require low profile structures. Due to the flat sides and top, rectangular shapes are not as structurally efficient as other culvert shapes.

e. Multiple Barrels--Multiple barrels are used to obtain adequate hydraulic capacity under low embankments or for wide waterways. In some locations they may be prone to clogging as the area between the barrels tends to catch debris and sediment. When a channel is artificially widened, multiple barrels placed beyond the dominant channel are subject to excessive sedimentation. The span or opening length of multiple barrel culverts includes the distance between barrels as long as that distance is less than half the opening length of the adjacent barrels.

3-1.2 Precast Concrete Pipe.

Precast concrete pipe is manufactured in six standard shapes: circular, arch, horizontal elliptical, vertical elliptical, pipe arch, and box section, as shown in exhibit 10. With the exception of box culverts, concrete culvert pipe is manufactured in up to five standard strength classifications. The higher the classification number the higher the strength. Box culverts are designed for various depths of cover and live loads. All of the standard shapes are manufactured in a wide range of sizes. Circular and elliptical pipes are available with standard sizes as large as 144 inches in diameter, with larger sizes available as special designs. Standard box sections are also available with spans as large as 144 inches. Precast concrete arches on cast-in-place footings are available with spans up to 40 feet. A listing of standard sizes is provided in the appendix.

3-1.3 Cast-in-Place Concrete Culverts.

Reinforced culverts that are cast-in-place are typically either rectangular or arch-shaped. The rectangular or box shape is more common and is usually constructed with multiple cells (barrels) to accommodate longer spans. One advantage of cast-in-place construction is that the culvert can be designed to meet the specific requirements of a site. Due to the long construction time of cast-in-place culverts, precast concrete or corrugated metal culverts are often selected. However, in many areas cast-in-place culverts are more practical and represent a significant number of installations.

3-1.4 Corrugated Steel.

Corrugated steel culverts are constructed from factory made corrugated steel pipe or field assembled structural plate products. Structural plate steel products are available as structural plate pipes, box culverts, or long span structures. Standard shapes for corrugated steel culverts are shown in exhibit 11.

a. Corrugated Steel Pipe--Factory made pipe is produced in two basic shapes, round and pipe arch. Both shapes are produced in several wall thicknesses, several corrugation sizes, as shown in exhibit 12, and with annular (circumferential) or helical (spiral) corrugations. Pipes with annular corrugations have riveted, spot welded, or bolted seams. Pipes with helical corrugations have continuously welded seams or lock seams. Corrugated steel pipe and pipe arch are usually zinc coated (galvanized). Other metallic coatings such as aluminum and aluminum zinc alloy coatings have recently been developed. Additional protective coatings are used with the metallic coating when there are potential corrosion or abrasion problems.

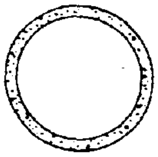
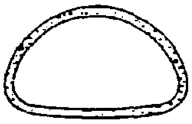
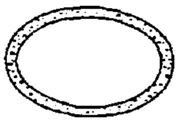
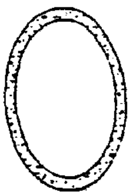
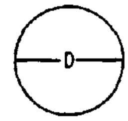
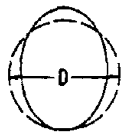
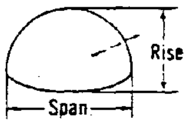
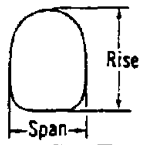
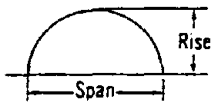
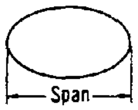
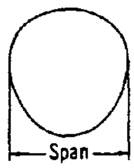
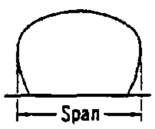
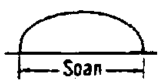
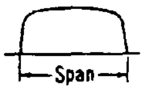
SHAPE	RANGE OF SIZES	COMMON USES
CIRCULAR 	12 to 180 inches reinforced 4 to 36 inches non-reinforced	Culverts, storm drains, and sewers.
PIPE ARCH 	15 to 132 inches equivalent diameter	Culverts, storm drains, and sewers. Used where head is limited.
HORIZONTAL ELLIPSE 	Span x Rise 18 to 144 inches equivalent diameter	Culverts, storm drains, and sewers. Used where head is limited.
VERTICAL ELLIPSE 	Span x Rise 36 to 144 inches equivalent diameter	Culverts, storm drains, and sewers. Used where lateral clearance is limited.
RECTANGULAR (box sections) 	Span 3ft to 12ft	Culverts, storm drains, and sewers. Used for wide openings with limited head.
ARCH 	Span 24 ft to 41 ft	Culvert and storm drains. For low, wide waterway enclosures.

Exhibit 10. Standard concrete pipe shapes.

Shape		Range of Sizes	Common Uses
Round		6 in.–26 ft	Culverts, subdrains, sewers, service tunnels, etc. All plates same radius. For medium and high fills (or trenches).
Vertically-elongated (ellipse) 5% is common		4–21 ft nominal: before elongating	Culverts, sewers, service tunnels, recovery tunnels. Plates of varying radii; shop fabrication. For appearance and where backfill compaction is only moderate.
Pipe-arch		Span x Rise 18 in. x 11 in. to 20 ft 7 in. x 13 ft 2 in.	Where headroom is limited. Has hydraulic advantages at low flows. Corner plate radius, 18 inches or 31 inches for structural plate.
Underpass*		Span x Rise 5 ft 8 in. x 5 ft 9 in. to 20 ft 4 in. x 17 ft 9 in.	For pedestrians, livestock or vehicles (structural plate).
Arch		Soan x Rise 6 ft x 1 ft 9½ in. to 25 ft x 12 ft 6 in.	For low clearance large waterway opening, and aesthetics (structural plate).
Horizontal Ellipse		Span 20–40 ft	Culverts, grade separations, storm sewers, tunnels.
Pear		Span 25–30 ft	Grade separations, culverts, storm sewers, tunnels.
High Profile Arch		Span 20–45 ft	Culverts, grade separations, storm sewers, tunnels, Ammo ammunition magazines, earth covered storage.
Low Profile Arch		Span 20–50 ft	Low-Wide waterway enclosures, culverts, storm sewers.
Box Culverts		Span 10–21 ft	Low-wide waterway enclosures, culverts, storm sewers.
Specials		Various	For lining old structures or other special purposes. Special fabrication.

*For equal area or clearance, the round shape is generally more economical and simpler to assemble.

Source: Handbook of Steel Drainage and Highway Construction Products
American Iron and Steel Institute

Exhibit 11. Standard corrugated steel culvert shapes.

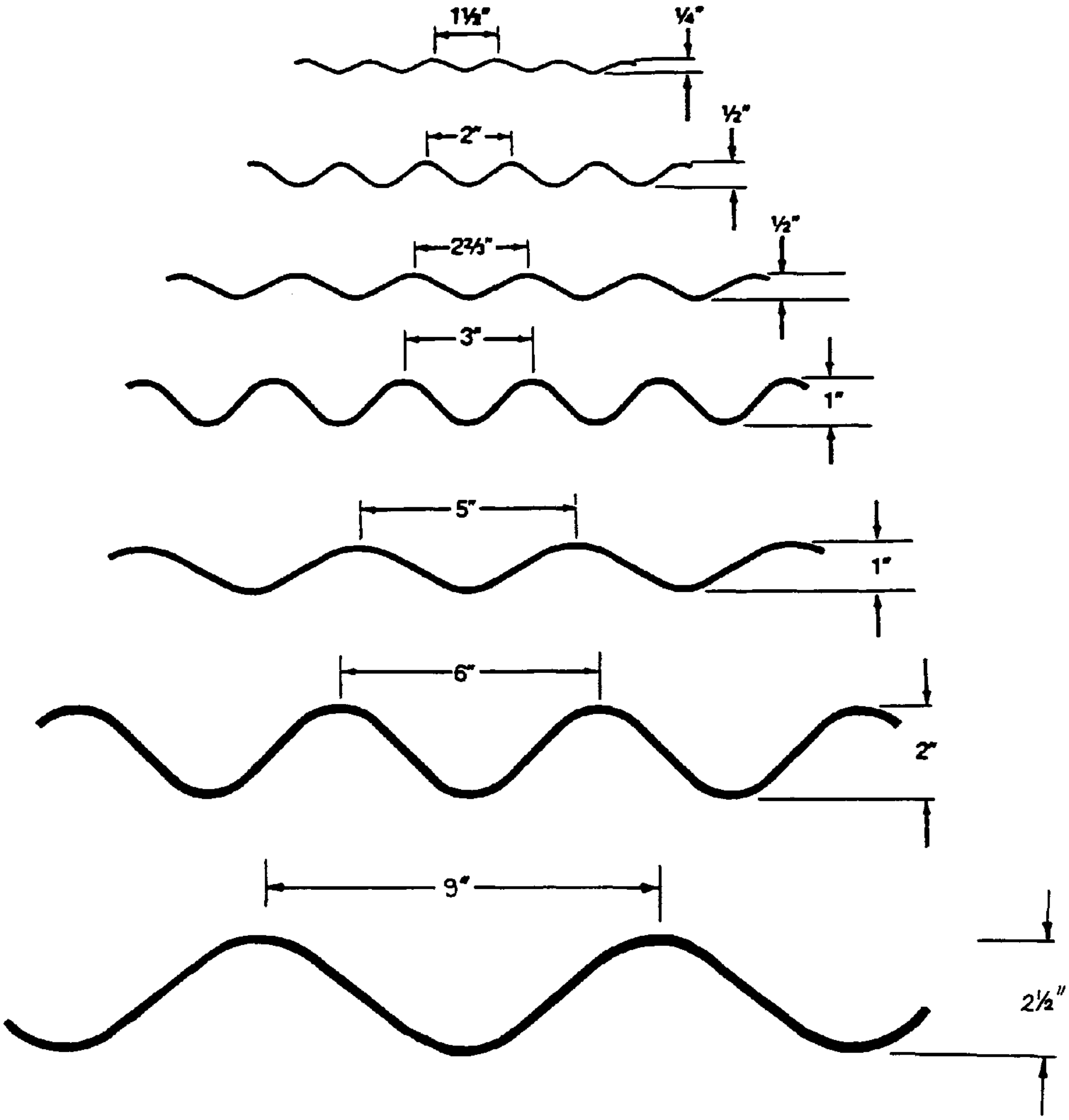


Exhibit 12. Common corrugation patterns (not to scale).

Protective coatings include bituminous coatings, bituminous paving, asbestos bonded bituminous coatings, polymer, concrete paving, and concrete coatings. Protective coatings are discussed in more detail in Section 4 of this chapter. Both round and arch shapes are available in a wide range of standard sizes. Round pipe is available in standard sizes up to 144 inches in diameter. Standard sizes for pipe arch are available in sizes up to the equivalent of a 120-inch diameter round pipe. A listing of sizes available for each corrugation is provided in the appendix.

b. Structural Plate Steel Pipe--Structural plate steel pipes are field assembled from standard corrugated galvanized steel plates. Standard plates have corrugations with a 6-inch pitch and a depth of 2 inches. Plates are manufactured in a variety of thicknesses and are pre-curved for the size and shape of structure to be erected. Standard plates have a nominal length of either 10 or 12 feet and are produced in standard widths of 3N, 5N, 6N, 7N, and 8N, where N equals 3 pi or 9.6 inches. Widths are measured along the circumference of the structure. Since the circumference of a circle equals pi times the diameter, the use of dimensions expressed in N or pi permits an easy conversion from pipe circumference to nominal diameter. For example a 60-inch diameter round pipe has a circumference of 60 pi or 20N and would normally be assembled from four 5N plates. Structural plate pipes are available in four basic shapes; round, pipe arch, arch, and underpass. The standard sizes available range in span from 5 feet to 26 feet. Tables showing typical sizes and dimensions are provided in the appendix.

c. Corrugated Steel Box Culverts--Steel box sections use standard corrugated galvanized steel plates with special reinforcing elements applied to the areas of maximum moment. Steel box culverts are available with spans that range from 9 feet 8 inches to 20 feet 9 inches. Typical sizes and dimensions are listed in the appendix.

d. Long Span Corrugated Steel Structures--Long span steel structures are assembled using conventional 6 by 2 inch corrugated galvanized steel plates and longitudinal and circumferential stiffening members. There are five standard shapes for long span structures: horizontal eliptical, pipe arch, low profile arch, high profile arch, and pear shape. The long span pipe arch is not commonly used.

The span lengths of typical sections range from 19 feet 4 inches to 40 feet. Tables illustrating sizes and dimensions of typical sections are provided in the appendix. Longer spans are available for some shapes as special designs. It should be noted that each long span installation represents, to a certain extent, a custom design. The inspector should therefore use design or as-built plans when checking dimensions of existing long span structures.

3-1.5 Corrugated Aluminum.

Corrugated aluminum culverts are constructed from factory assembled corrugated aluminum pipe or field assembled from structural plates. Structural plate aluminum culverts are available as conventional structural plate structures, box culverts, or long span structures.

a. Corrugated Aluminum Pipe--Factory assembled aluminum pipe is available in two basic shapes: round and pipe arch. Both shapes are produced with several different wall thicknesses, several corrugation patterns, and with annular (circumferential) or helical (spiral) corrugations. Round aluminum pipe is available in standard sizes up to 120 inches in nominal diameter. Aluminum arch pipe is available in sizes up to the equivalent of a 96-inch diameter round pipe.

b. Structural Plate Aluminum Pipe--Structural plate aluminum pipes are field assembled with 9-inch-pitch by 2.5-inch-depth corrugations. Plates are manufactured in a variety of plate thicknesses and are pre-curved for the specific size and shape of the structure to be erected. Plates are manufactured in lengths of 8N through 18N (N equals 3 pi or 9.6 inches).

Plate length is measured along the circumference of the structure. Use of measurements in terms of N permits easy conversion from nominal diameter to circumference as previously explained for structural plate steel. Standard plates have a net width of 4 feet 6 inches. Structural plate aluminum pipes are produced in five basic shapes: round, pipe arch, arch, pedestrian/animal underpass, and vehicle underpass. A wide range of standard sizes is available for each shape. Spans as large as 30 feet can be obtained for the arch shape. More detailed listings of available sizes and key dimensions are provided in the appendix.

c. Aluminum Box Culvert--The aluminum box culvert utilizes standard aluminum structural plates with aluminum rib reinforcing added in the areas of maximum moments. Ribs are bolted to the exterior of the aluminum shell during installation. Aluminum box culverts are suitable for shallow depths of fill and are available with spans ranging from 8 feet 9 inches to 25 feet 5 inches. Standard sizes and geometric dimensions are provided in the appendix.

d. Aluminum Long Span Structures--Long span aluminum structures are assembled using conventional 9- by 2.5-inch corrugated aluminum plates and aluminum rib stiffeners. Long span aluminum span structures are available in the same five basic shapes as steel long spans including horizontal ellipse, pipe arch, low profile arch, high profile arch, and pear shape. The typical sizes for aluminum spans are essentially the same as the typical sizes available for steel long span structures. Spans range from 19 feet 4 inches to 40 feet. Listings of typical sizes and dimensions for each shape are provided in the appendix. Inspectors should use design or as-built plans when inspecting existing long span structures because each long span structure represents a custom design.

3-1.6 Masonry Culverts.

Stone and brick are durable, low maintenance materials. Prior to the 1920's, both were used frequently in railroad and road construction projects because they were readily available from rock cuts or local brickyards. Currently stone and brick are seldom used for constructing culvert barrels. Stone is used occasionally for this purpose in locations which have very acid runoff, but the most common use of stone is for headwalls where a rustic or scenic appearance is desired. A stone arch culvert is shown in exhibit 13. While brick is rarely used for culvert barrels, it is frequently used in the construction of manholes and inlets in storm drainage systems.

Exhibit 13. Masonry arch culvert. In some areas masonry arches and masonry box culverts are common. With good foundations these culverts have long service lives.

3-1.7 Other Culvert Materials.

Aluminum, steel, concrete, and stone masonry are the most commonly found materials for existing culverts. There are several other materials which may be encountered during culvert inspections, including timber, as shown in exhibit 14, cast iron, stainless steel, terra cotta, asbestos cement, and plastic. These materials are not commonly found in many areas because they are either relatively new (plastic), labor intensive (masonry), or used for specialized situations (stainless steel and cast iron).

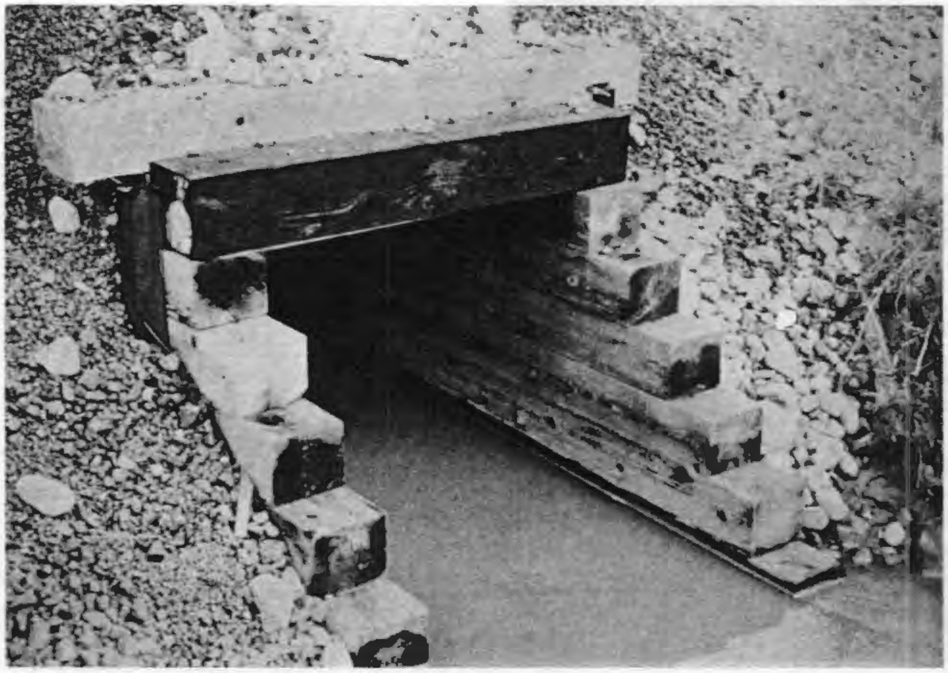


Exhibit 14. Timber culvert. Timber culverts are generally box culverts.

Section 2. HYDRAULICS OF CULVERTS

3-2.0 General.

Culverts are primarily constructed to convey water through a highway, railroad, or other embankment. A culvert which does not perform this function properly may jeopardize the roadway, as shown in exhibit 15, cause excessive property damage, or even loss of life. The hydraulic requirements of a culvert usually determine the size, shape, slope, and inlet and outlet treatments of a culvert. Culvert hydraulics can be divided into two general design elements. The first is a hydrologic analysis to determine the design discharge or the amount of runoff the culvert should be designed to convey. The second is a hydraulic analysis to select a culvert, or evaluate whether an existing culvert is capable of adequately conveying the design discharge. To recognize whether a culvert is performing adequately the inspector should understand the factors that influence the amount of runoff to be handled by the culvert as well as the factors which influence the culvert's hydraulic capacity.

Exhibit 15. Roadway overtopping due to culverts with inadequate capacity may result in extensive damage to the roadway and the embankment.

3-2.1 Estimating Runoff.

Most culverts are designed to carry the surface runoff from a specific drainage area, as illustrated in exhibit 16. While the selection and use of appropriate methods of estimating runoff requires a person experienced in hydrologic analysis and would usually not be performed by the inspector, the inspector should understand how changes in the topography of the drainage area can cause major changes in runoff. Climatic and topographic factors are briefly discussed in the following sections.

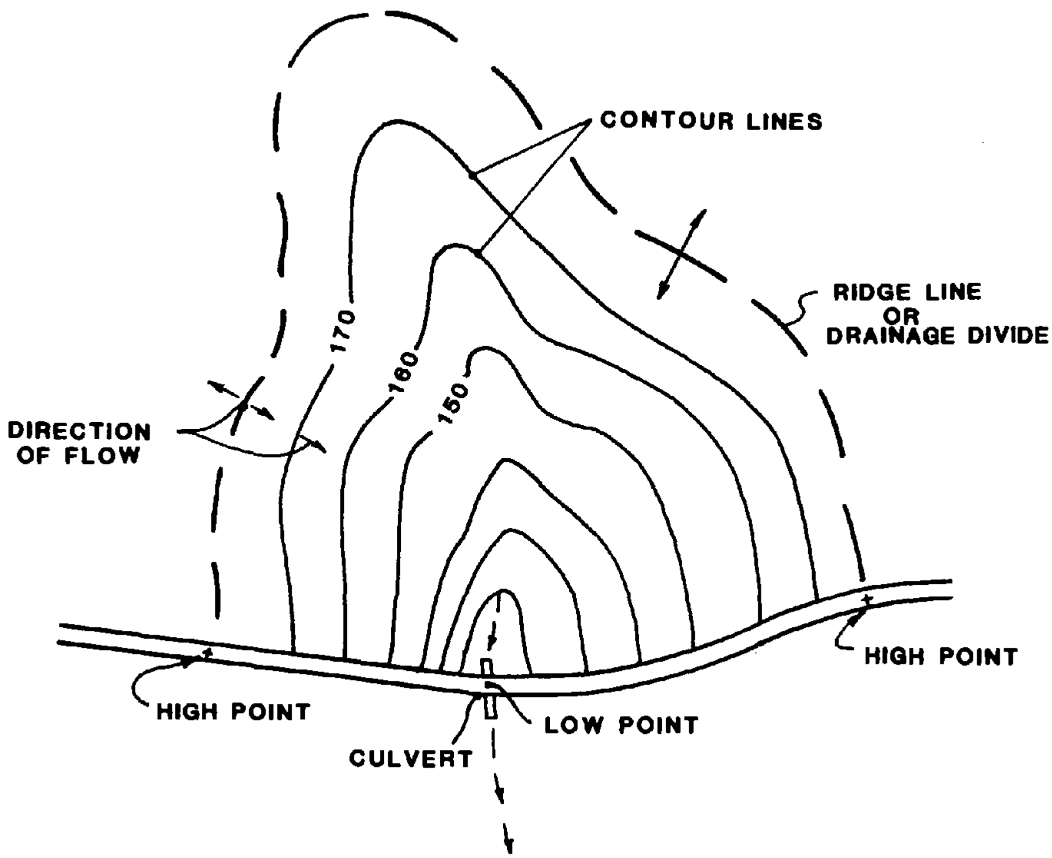


Exhibit 16. A drainage area is defined by drainage divides or lines that connect the high points or follow the ridge lines around the area served by the culvert.

a. Climatic Factors--Climatic factors which may influence the amount of runoff include rainfall intensity, storm duration, rainfall distribution within the drainage area, soil moisture, snow melt, rain-on-snow, rain-hail, and other factors.

b. Topographic Factors--Topographic factors which may influence runoff include the land use within the drainage area; the size, shape, and slope of the drainage area; and other factors such as the type of soil, elevation, and orientation of the area.

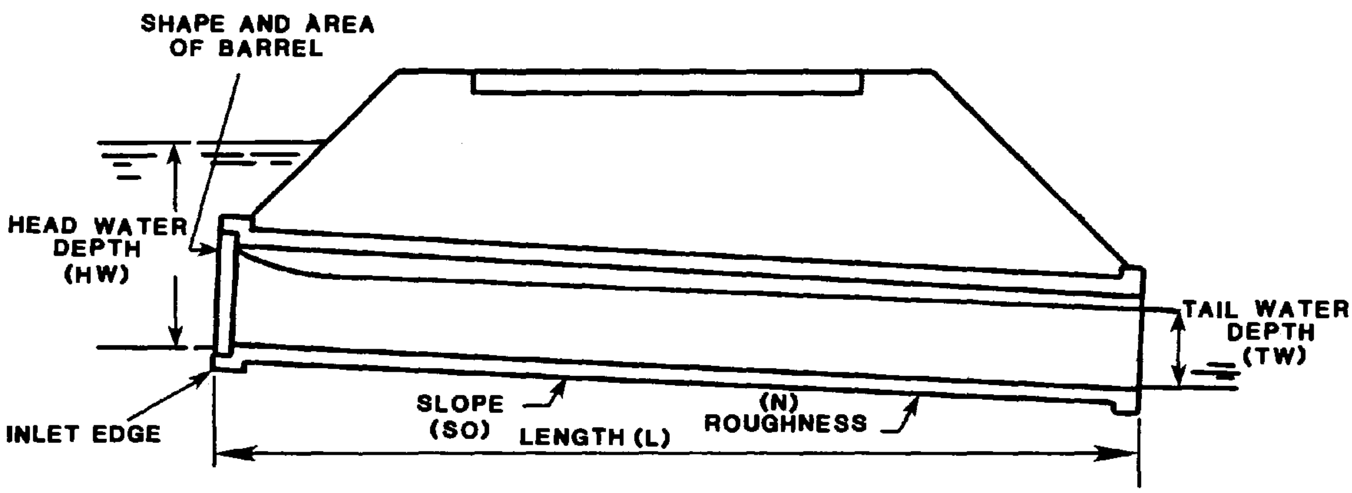
(1) Land use is the most likely characteristic to change significantly during the service life of a culvert. Changes in land use may have a considerable effect on the amount and type of runoff. Some surface types will permit more infiltration than other surface types. Practically all of the rain falling on paved surfaces will drain off while much less runoff will result from undeveloped land. If changes in land use were not planned during the design of a culvert, increased runoff may exceed the capacity of an existing culvert when the land use does change.

(2) The size, shape, and slope of a culvert's drainage area influence the amount of runoff that may be collected and the speed with which it will reach the culvert. The amount of time required for water to flow to the culvert from the most remote part of a drainage area is referred to as the time of concentration. Changes in the drainage area may influence the time of concentration.

Straightening or enclosing streams and eliminating temporary storage by replacing undersized upstream pipes are examples of changes which may decrease time of concentration. Land use changes may also decrease time of concentration since water will flow more quickly over paved surfaces. Since higher rainfall intensities occur for shorter storm durations, changes in time of concentration can have a significant impact on runoff. Drainage areas are sometimes altered and flow diverted from one watershed to another.

3-2.2 Hydraulic Capacity.

The factors affecting capacity may include headwater depth, tailwater depth, inlet geometry, the slope of the culvert barrel, and the roughness of the culvert barrel. These factors are illustrated in exhibit 17. The various combinations of the factors affecting flow can be grouped into two types of conditions in culverts: inlet control and outlet control.



Source: Adapted from Concrete Pipe Handbook.
American Concrete Pipe Association

Exhibit 17. Factors affecting culvert discharge.

3-2.3 Inlet Control.

Under inlet control the discharge from the culvert is controlled at the entrance of the culvert by headwater depth and inlet geometry. Inlet geometry includes the cross-sectional area, shape, and type of inlet edge. Inlet control governs the discharge as long as water can flow out of the culvert faster than it can enter the culvert.

Most culverts, except those in flat terrain, are designed to operate under inlet control during peak flows. Since the entrance characteristics govern, minor modifications at the culvert inlet can significantly effect hydraulic capacity. For example, change in the approach alignment or the stream may reduce capacity, while the improvement of the inlet edge condition, or addition of properly designed headwalls and wingwalls, may increase the capacity.

3-2.4 Outlet Control.

Under outlet control water can enter the culvert faster than water can flow through the culvert. The discharge is influenced by the same factors as inlet control plus the tailwater depth and barrel characteristics (slope, length, and roughness). Culverts operating with outlet control usually lie on flat slopes or have high tailwater.

When culverts are operating with outlet control, changes in barrel characteristics or tailwater depth may effect capacity. For example, increased tailwater depth or debris in the culvert barrel may reduce the capacity.

3-2.5 Special Hydraulic Considerations.

a. Inlet and Outlet Protection--The inlets and outlets of culverts may require protection to withstand the hydraulic forces exerted during peak flows. Inlet ends of flexible pipe culverts which are not adequately protected or anchored may be subject to entrance failures due to buoyant forces. The outlet may require energy dissipators to control erosion and scour and to protect downstream properties. High outlet velocities may cause scour which undermines the endwall, wingwalls, and culvert barrel. This erosion can cause end-section drop-off in rigid sectional pipe culverts.

b. Protection Against Piping--Seepage along the outside of the culvert barrel may remove supporting material. This process is referred to as piping since a hollow similar to a pipe is often formed. Piping can also occur through open joints. Piping is controlled by reducing the amount and velocity of water seeping along the outside of the culvert barrel. This may require watertight joints and in some cases anti-seep collars. Good backfill material and adequate compaction of that material are also important.

Section 3. STRUCTURAL CHARACTERISTICS OF CULVERTS

3-3.1 Loads on Culverts.

In addition to their hydraulic functions, culverts must also support the weight of the embankment or fill covering the culvert and any load on the embankment. There are two general types of loads that must be carried by culverts: dead loads and live loads.

a. Dead Loads--Dead loads include the earth load or weight of the soil over the culvert and any added surcharge loads such as buildings or additional earth fill placed over an existing culvert. If the actual weight of earth is not known, 120 pounds per cubic foot is generally assumed.

b. Live Loads--The live loads on a culvert include the loads and forces which act upon the culvert due to vehicular or pedestrian traffic plus an impact factor. The highway wheel loads generally used for analysis are shown in exhibit 18. The effect of live loads decreases as the height of cover over the culvert increases. When the cover is more than two feet, concentrated loads may be considered as being spread uniformly over a square with sides 1.75 times the depth of cover. This concept is illustrated in exhibits 19 and 20.

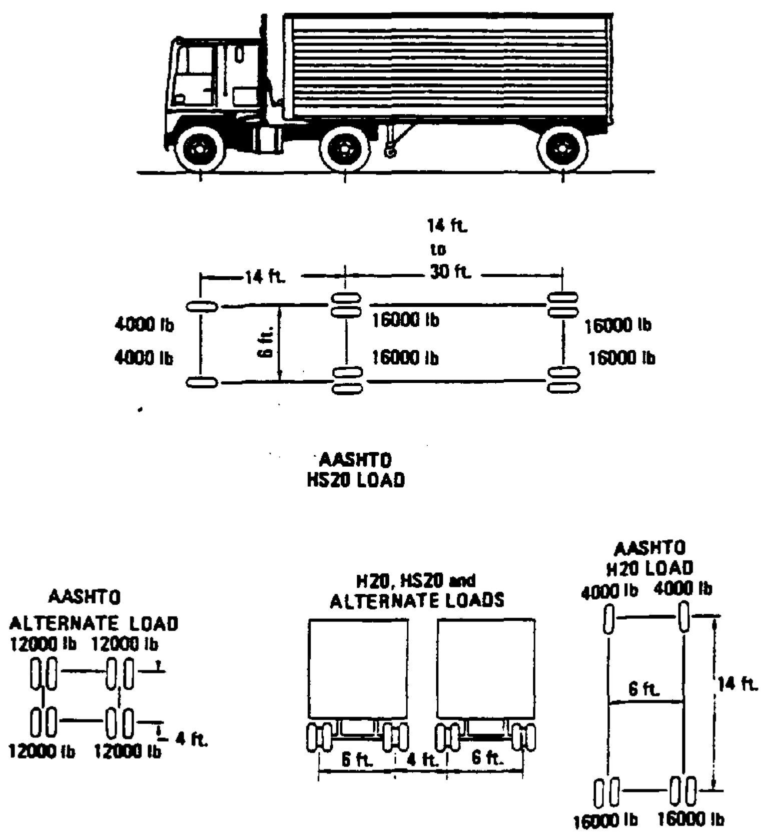
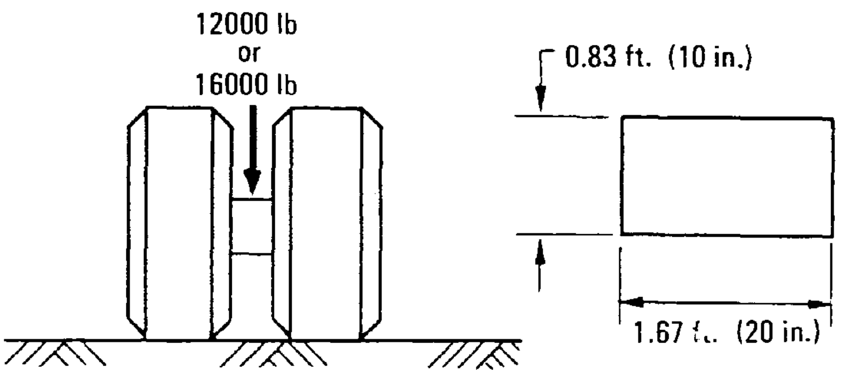
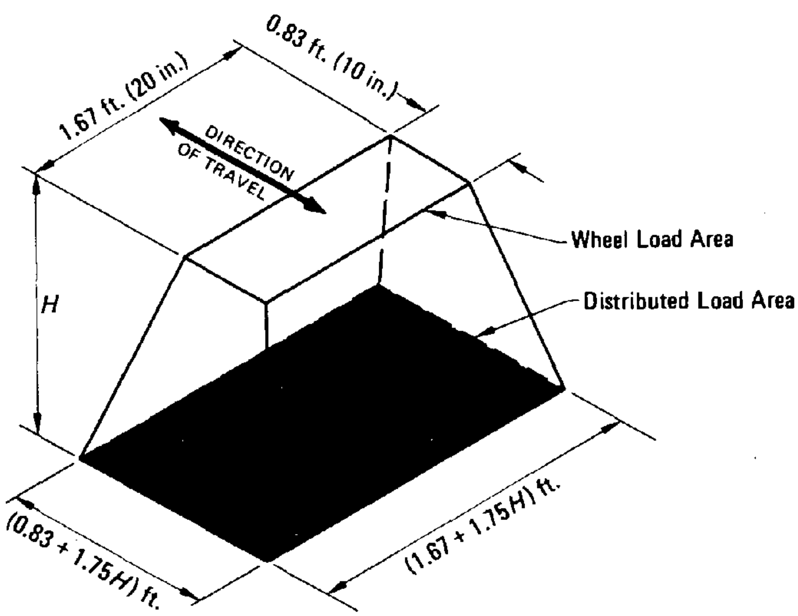


Exhibit 18. AASHTO live load spacing for highway structures.



Source: Concrete Pipe Handbook
American Concrete Pipe Association

Exhibit 19. Surface contact area for single dual wheel.



Source: Concrete Pipe Handbook
American Concrete Pipe Association

Exhibit 20. Distribution of live load (single dual wheel) for depth of cover H.

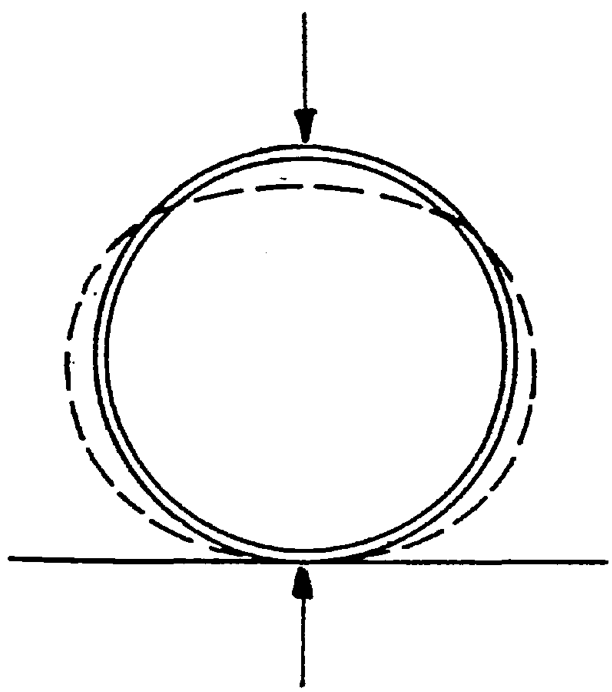
3-3.2 Categories of Structural Materials.

Based upon material type, culverts can be divided into two broad structural categories: flexible and rigid. Flexible culverts have little structural bending strength on their own. The material from which they are made, such as corrugated steel or aluminum, can be flexed or bent and can be distorted significantly without cracking. Consequently, flexible culverts depend on the backfill support to resist bending. Rigid culverts, however, are stiff and do not deflect appreciably. The material from which they are made, such as reinforced concrete, provides resistance to bending.

3-3.3 Structural Behavior of Flexible Culverts

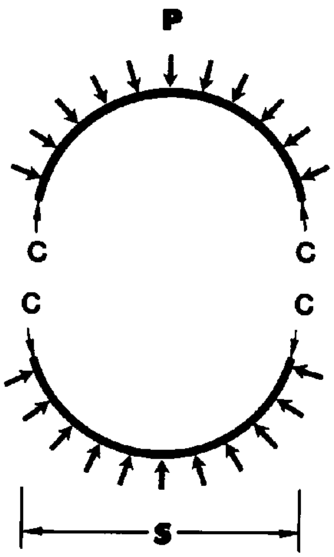
A flexible culvert is a composite structure made up of the culvert barrel and the surrounding soil. The barrel and the soil are both vital elements to the structural performance of the culvert.

Flexible pipe has relatively little bending stiffness or bending strength on its own. As loads are applied to the culvert, it attempts to deflect. In the case of a round pipe, the vertical diameter decreases and the horizontal diameter increases, as shown in exhibit 21. When good embankment material is well compacted around the culvert, the increase in horizontal diameter of the culvert is resisted by the lateral soil pressure. With round pipe the result is a relatively uniform radial pressure around the pipe which creates a compressive thrust in the pipe walls. As illustrated in exhibit 22, the compressive thrust is approximately equal to vertical pressure times one-half the span length ($C = P \times \frac{S}{2}$ or $C = P \times R$).



AS VERTICAL LOADS ARE APPLIED A FLEXIBLE CULVERT ATTEMPTS TO DEFLECT. THE VERTICAL DIAMETER DECREASES WHILE THE HORIZONTAL DIAMETER INCREASES. SOIL PRESSURES RESIST THE INCREASE IN HORIZONTAL DIAMETER.

Exhibit 21. Deflection of flexible culverts.



SUMMING THE VERTICAL FORCES ON HALF OF THE PIPE AT A TIME SHOWS THAT

$$C = P \times \frac{S}{2}$$

WHERE

C= COMPRESSIVE THRUST IN THE CULVERT WALL

P= SUM OF SOIL PRESSURE ACTING ON THE CULVERT

S= THE SPAN OR DIAMETER

$\frac{S}{2}$= THE RADIUS (R)

Exhibit 22. Formula for ring compression.

An arc of a flexible round pipe, or other shape will be stable as long as adequate soil pressures are achieved, and as long as the soil pressure is resisted by the compressive force C on each end of the arc. Good quality backfill material and proper installation are critical in obtaining a stable soil envelope around a flexible culvert.

In long span culverts the radius (R) is usually large. To prevent excessive deflection due to dead and/or live loads, longitudinal or circumferential stiffeners are sometimes added. The circumferential stiffeners are usually metal ribs bolted to the outside of the culvert. Longitudinal stiffeners may be metal or reinforced concrete, as shown in exhibit 23. The thrust beams are added to the structure prior to backfill. Concrete thrust beams provide some circumferential stiffening as well as longitudinal stiffening. They also provide a solid vertical surface for soil pressures to act on and a surface which is easier to backfill against. The use of concrete stress relieving slabs is another method used to achieve longer spans or reduce minimum cover. A stress relieving slab is cast over the top of the backfill above the structure to distribute live loads to the adjacent soil.

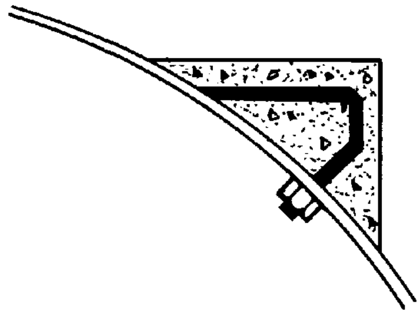
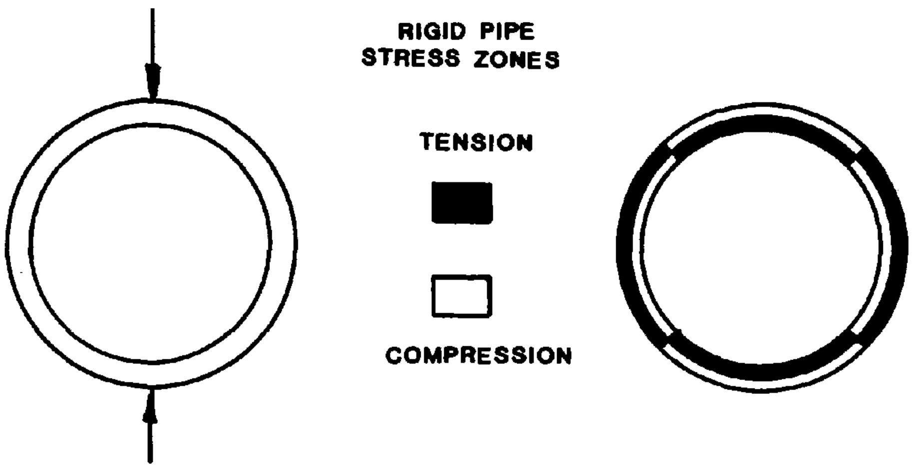


Exhibit 23. Concrete thrust beams may be used as longitudinal stiffeners.

3-3.4 Structural Behavior of Rigid Culverts.

The load carrying capability of rigid culverts is essentially provided by the structural strength of the pipe itself and little benefit from the surrounding soil is required. When vertical loads are applied to a rigid pipe, zones of tension and compression are created as illustrated in exhibit 24. With the exception of non-reinforced circular pipe, reinforcing steel is added to the tension zones to increase the tensile strength of the pipe. Shear stress in the haunch area can be critical for heavily loaded rigid pipe on hard foundations, especially if the haunch support is inadequate. Because rigid pipe is stiffer than the surrounding soil, it carries a substantial portion of the load.

The weight of earth that must be carried varies with soil characteristics and installation conditions. The installation conditions can have a significant influence on the loads that must be carried by a rigid culvert. There are two major classes of installation conditions: 1) trench, where culverts are placed in natural ground or compacted fill with a controlled trench width and 2) embankment, where culverts are placed in or covered by an embankment.



Source: American Concrete Pipe Association

Exhibit 24. Zones of tension and compression in rigid pipes develop to resist vertical loads.

In narrow trench installations, the pipe is placed in a relatively narrow trench and covered with backfill material. The backfill tends to settle more than the undisturbed soil beside the trench. Friction between the backfill material and the sides of the trench tends to help support the backfill material reducing the load on the pipe. In effect the width of the soil column over the pipe is decreased. This concept is illustrated in exhibit 25.

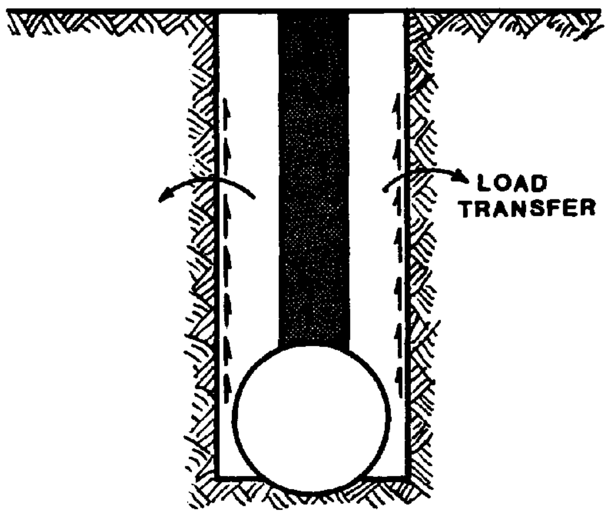


Exhibit 25. Trench installation. Friction on trench sides reduces the size of the column of fill carried by the pipe.

As the trench width increases, the effect of the friction at the sides of the trench is reduced and dead load on the pipe is increased. The amount that the loading is increased depends on trench width and the amount of backfill settlement, which is related to compaction. Poorly compacted soil will settle more than well compacted soil. In a trench that is too wide, poor compaction can result in an increase in the dead load on the pipe. Pipes placed in a shallow bedding on top of the original ground surface and then covered by the embankment material will have loads similar to the very wide trench. Pipes placed in trenches in the original ground prior to being covered by embankment have reduced earth loads similar to those described for the narrow trench installations.

3-3.5 Construction and Installation Requirements.

The structural behavior of flexible and rigid culverts is often dependent on construction practices during installation. Items which require particular attention during construction are discussed briefly in the following text.

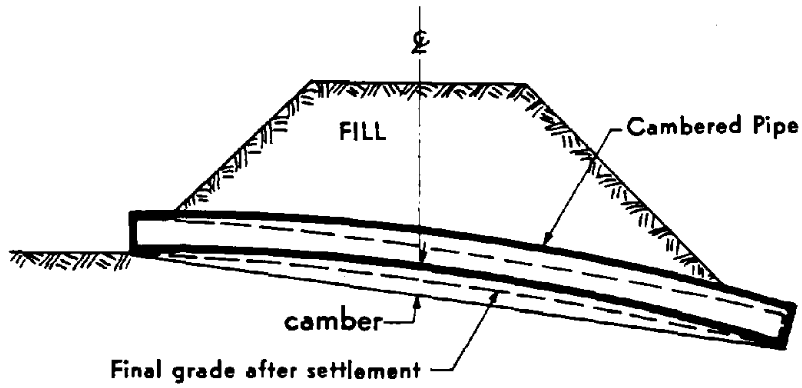
a. Compaction and Side Support--Good backfill material and adequate compaction are of critical importance to flexible culverts. A well-compacted soil envelope is needed to develop the lateral pressures required to maintain the shape of flexible culverts. Well-compacted backfill is also important to the performance of rigid culverts. Poorly compacted soils do not provide the intended lateral support.

b. Trench Width--Trench width can significantly affect the earth loads on rigid culverts. It is therefore important that trench widths be specified on the plans and that the specified width not be exceeded without authorization from the design engineer.

c. Foundations and Bedding--A foundation capable of providing uniform and stable support is important for both flexible and rigid culverts. The foundation must be able to support the structure at the proposed grade and elevation without concentration of foundation pressures. Foundations should be relatively yielding when compared to side fill. Establishing a suitable foundation requires removal and replacement of any hard spots or soft spots. Bedding is needed to level out any irregularities in the foundation and to insure uniform support. When using flexible culverts, bedding should be shaped to a sufficient width to permit compaction of the remainder of the backfill, and enough loose material should be placed on top of the bedding to fill the corrugations. When using rigid culverts, the bedding should conform to the bedding conditions specified in the plans and should be shaped to allow compaction and to provide clearance for the bell ends on bell and spigot type rigid pipes. Adequate support is critical in rigid pipe installations, or shear stress may become a problem.

d. Construction Loads--Culverts are generally designed for the loads they must carry after construction is completed. Construction loads may exceed design loads. These heavy loads can cause damage if construction equipment crosses over the culvert installation before adequate fill has been placed or moves too close to the walls, creating unbalanced loadings. Additional protective fill may be needed for equipment crossing points.

e. Camber--In high fills the center of the embankment tends to settle more than the areas under the embankment side slopes. In such cases it may be necessary to camber the foundation slightly, as shown in exhibit 26. This should be accomplished by using a flat grade on the upstream half of the culvert and a steeper grade on the downstream half of the culvert. The initial grades should not cause water to pond or pocket.



Source: Handbook for Steel Drainage and Highway Products
American Iron and Steel Institute

Exhibit 26. Camber allows for settlement of a culvert under a high fill.

Section 4. DURABILITY

3-4.0 General.

Although the structural condition is a very important element in the performance of culverts, durability problems are probably the most frequent cause of replacement. Culverts are more likely to "wear away" than fail structurally. Durability is affected by two mechanisms: corrosion and abrasion. Each are discussed in the following sections:

a. Corrosion--Corrosion is the deterioration of culvert materials by chemical or electrochemical reaction to the environment. Culvert corrosion may occur in many different soils and waters. These soils and waters may contain acids, alkalis, dissolved salts, organics, industrial wastes or other chemicals, mine drainage, sanitary effluents, and dissolved or free gases. However, culvert corrosion is generally related to water and the chemicals that have reacted to, become dissolved in, or been transported by the water.

Corrosion can attack the inside or outside of the culvert barrel. The chemicals in drainage water can attack the material on the interior of the culvert. Culverts subject to continuous flows or standing water with aggressive chemicals are more likely to be damaged than those with intermittent flows. The exterior of culverts can be attacked by chemicals in the ground water which can originate in the soil, be introduced through contaminates in the backfill soil, or be transported by subsurface flow.

Corrosion affects all metals and alloys, although the rates can vary widely depending both upon the chemical and physical properties of the metal and upon the environmental condition to which it is exposed. When a metal corrodes a very low voltage electrical current is established between two parts of a metal surface that have different voltage potential. The difference in voltage potential may be caused by slight variations in the material, changes in surface condition, or the presence of foreign materials. The current removes metallic ions from one location and deposits them at another location, causing corrosion, as shown in exhibits 27 and 28. The chemicals present in the water greatly influence its effectiveness as an electrolyte.

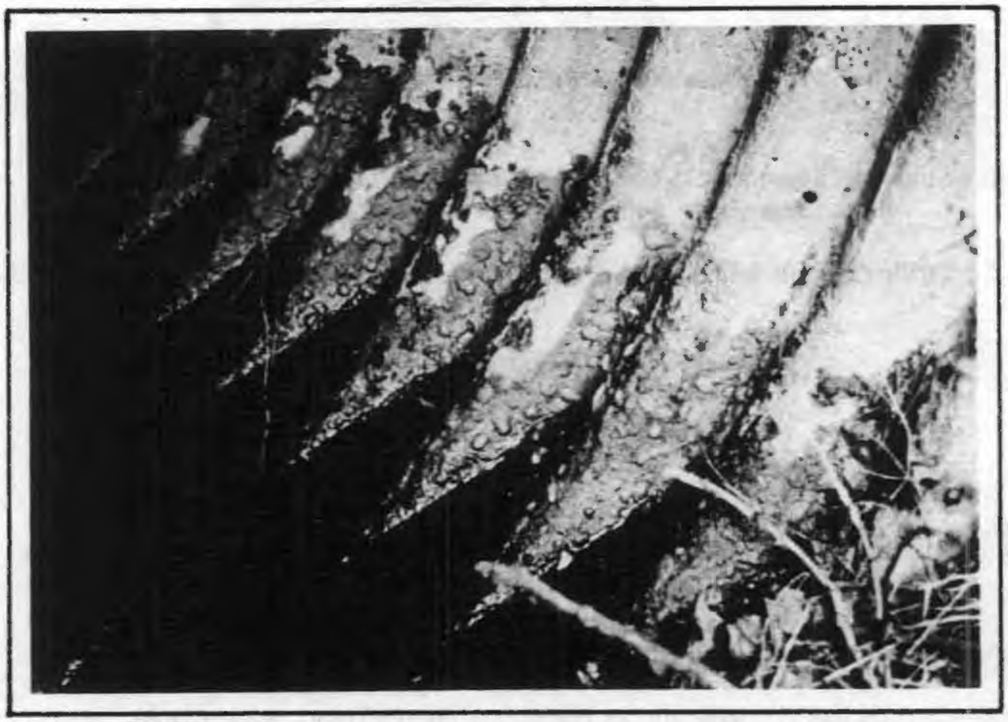


Exhibit 27. Severe corrosion of corrugated steel culvert due to aggressive water.

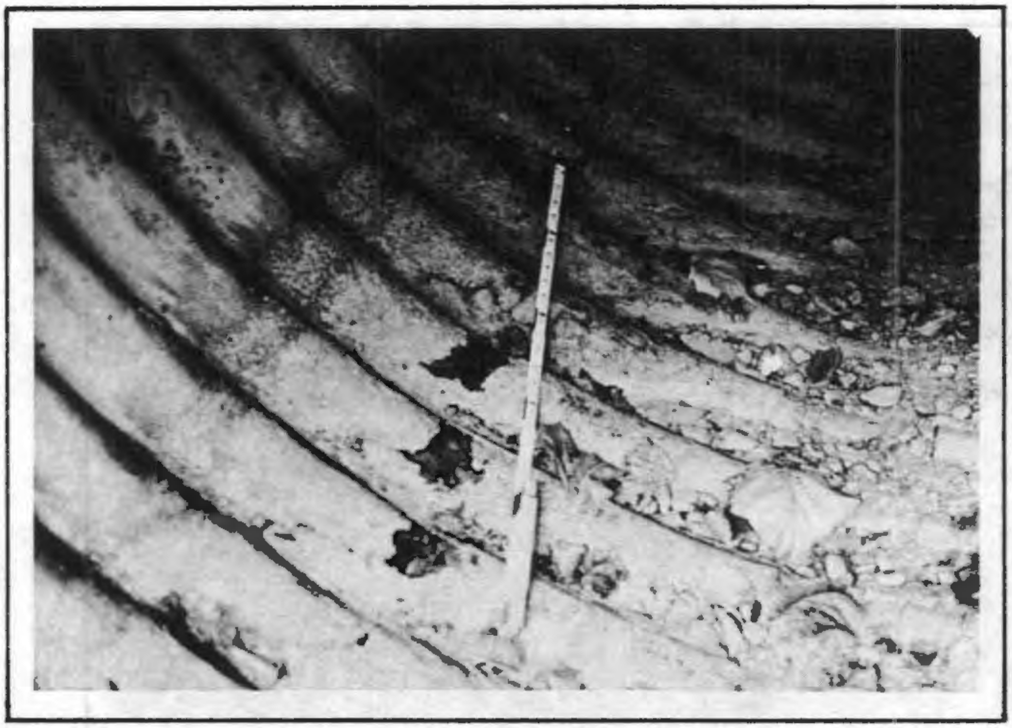


Exhibit 28. Corrugated steel culvert with invert perforations.

Although less common than with metal pipe, corrosion can occur in concrete culverts. Metallic corrosion can take place in the reinforcing steel when it is exposed by cracking or spalling, when the concrete cover is inadequate or when the concrete is porous enough to allow water to contact the reinforcing steel, as shown in exhibit 29.

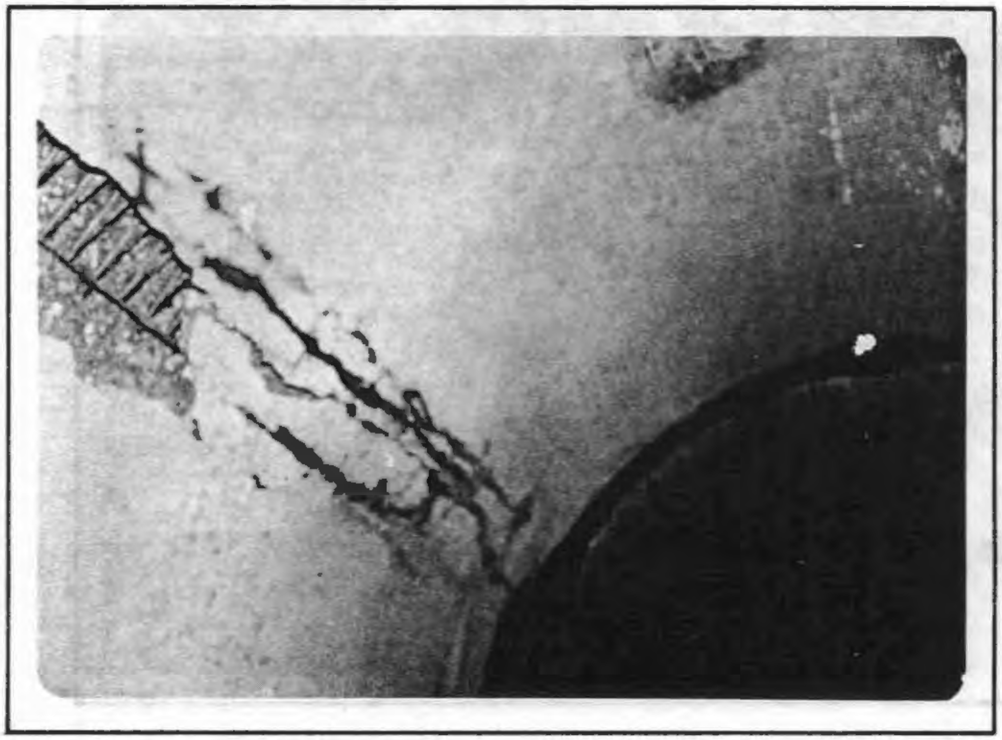


Exhibit 29. Reinforcing steel in concrete may corrode when exposed to water due to spalling or cracking.

If the steel corrodes, the corrosion products expand and may cause spalling of the concrete. Corrosion can also take place in the concrete itself. It is not, however, the same type of electrochemical reaction that occurs in metal. Other reactions between the concrete materials and the chemicals present in the stream flow or ground water are involved and can result in deterioration of the concrete, as shown in exhibit 30.

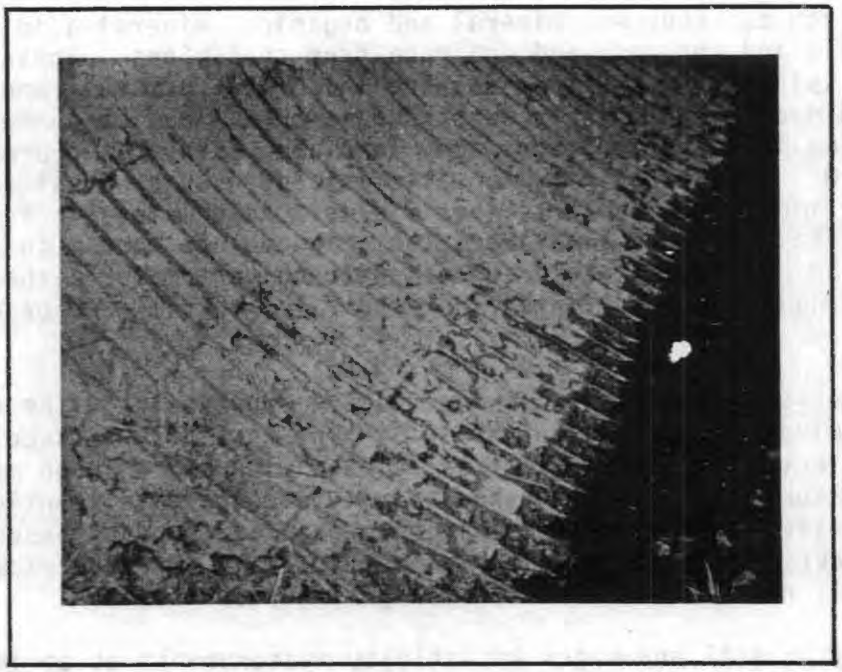


Exhibit 30. Reinforcing steel exposed in concrete pipe due to concrete deterioration.

b. Abrasion--Abrasion is the process of wearing down or grinding away the surface material of culverts as water laden with sand, gravel, or stones flows through a culvert. Abrasive forces increase as the velocity of the water flowing through a culvert increases; for example, doubling the velocity of a stream flow can cause the abrasive power to become approximately four-fold.

Often corrosion and abrasion operate together to produce far greater deterioration jointly than would result from either alone. Abrasion can accelerate corrosion by removing protective coatings and allowing water-borne chemicals to come into contact with corrodible culvert materials.

3-4.1 Aggressive Soil and Water Conditions.

Certain soil and water conditions have been found to have a strong relationship to accelerated culvert deterioration. These conditions are referred to as "aggressive" or "hostile." The most significant conditions of this type are:

a. pH Extremes--pH is a measure of the relative acidity or alkalinity of water. A pH of 7.0 is neutral, values of less than 7.0 are acid, and values of more than 7.0 are alkaline. For culvert purposes, soils or water having a pH of 5.5 or less are strongly acid and those of 8.5 or more are strongly alkaline.

Acid water stems from two sources, mineral and organic. Mineral acidity comes from sulfurous wells and springs, and drainage from coal mines. These sources contain dissolved sulfur and iron sulfide which may form sulfurous and sulfuric acids. Mineral acidity as strong as pH 2.3 has been encountered. Organic acidity usually found in swampy land and barnyards rarely produces a pH of less than 4.0. Alkalinity in water is caused by strong alkali-forming minerals and from limed and fertilized fields. Acid water (low pH) is more common to wet climates and alkaline water (high pH) is more common to dry climates. As the pH of water in contact with culvert materials, either internally or externally, deviates from neutral, 7.0, it generally becomes more hostile.

b. Electrical Resistivity--This measurement depends largely on the nature and amount of dissolved salts in the soil. The greater the resistance the less the flow of electrical current associated with corrosion. High moisture content and temperature lower the resistivity and increase the potential for corrosion. Soil resistivity generally decreases as the depth increases. The use of granular backfill around the entire pipe will increase electrical resistivity and will reduce the potential for galvanic corrosion.

Several states rely on soil and water resistivity measurements as an important index of corrosion potential. Some states and the FHWA have published guidelines that use a combination of the pH and electrical resistivity of soil and water to indicate the corrosion potential at proposed culvert sites. The collection of pH and electrical resistivity data during culvert inspections can provide valuable information for developing local guidelines.

c. Soil Characteristics--The chemical and physical characteristics of the soil which will come into contact with a culvert can be analyzed to determine the potential for corrosion. The presence of base-forming and acid-forming chemicals is important. Chlorides and other dissolved salts increase electrical conductivity and promote the flow of corrosion currents. Sulfate soils and water can be erosive to metals and harmful to concrete. The permeability of soil to water and to oxygen is another variable in the corrosion process.

d. Abrasion Potential--Velocity of the water in the culvert can be determined if the amount of flow, slope, size of pipe, material of pipe, and inlet and outlet conditions are known. The higher the velocity, the more the potential for abrasion. The soil characteristics of the streambed are also indicators of abrasion potential. Erosive large-grained materials such as sand, gravel, and stones will increase the potential for abrasion.

3-4.2 Methods to Increase Service Life.

There are various methods available to culvert designers and maintenance forces to offset identified potential for corrosion and abrasion. Each culvert site should be considered individually and the culvert material, shape, and size selected that best fits the conditions of that site while meeting the agency's objectives for hydraulic effectiveness, service life, maintainability, durability, and total costs. Some of the design features which can increase durability are:

a. Selection of Culvert Materials--Some materials can be expected to perform better than others under any given set of conditions. Each agency should carefully investigate the soil and water conditions that affect culvert durability in its jurisdiction and develop meaningful guidelines to aid in the selection of culvert materials.

Special attention should also be given to standards and specifications used at the time of the culvert's installation,. Changes in gauge thickness and chemical composition of metal pipes, or cement content and steel reinforcement for concrete pipes, may affect the durability of the pipe. The following guidelines reflect common durability characteristics observed on culverts installed prior to 1983.

(1) Galvanized Steel. Bare, uncoated, galvanized steel pipe generally performs well when the pH of the soil immediately adjacent to the pipe and the pH of the flow which the pipe will carry are between 6 and 10 and when the electrical resistivity of the soil is 3,000 ohm-cm or greater. Bare galvanized steel pipe should not be used in salt or brackish environments.

(2) Aluminum. Bare, uncoated, aluminum alloy pipe generally performs adequately well when the pH of the soil immediately adjacent to the pipe and the pH of the flow which the pipe will carry are between 4 and 9, and when the electrical resistivity of the flow and the minimum electrical resistivity of the soil are 500 ohm-cm or greater. When backfilled with a clean, granular, well-draining soil, aluminum pipe has shown excellent resistance to corrosion even when exposed to seawater and tidal flow. Aluminum may not perform well in very acid or heavy metal (copper, iron, etc.) environments.

(3) Concrete. Concrete of good quality is resistant to many corrosive agents. When the effluent has a pH of 5.0 or less, protective measures are generally required.

(4) Other Materials. Very aggressive environments may require special pipe materials such as vitrified clay, stainless steel, and plastic. These materials are generally used in culvert applications only when detailed analysis indicates the potential for serious durability problems.

b. Pipe Protective Measures--There are several protective measures that can be taken to increase the durability of culverts. The more commonly used measures are:

(1) Extra Thickness. For some aggressive environments, it may be economical to provide extra thicknesses of concrete or metal.

(2) Bituminous Coating. This is the most common protective measure used on corrugated steel pipe. This procedure can increase the resistance of metal pipe to acidic conditions if the coating is properly applied and remains in place. Careful handling during transportation, storage, and placement is required to avoid damage to the coating. Bituminous coatings can also be damaged by abrasion. Field repairs should be made when bare metal has been exposed. Fiber binding is sometimes used to improve the adherence of bituminous material to the metallic-coated pipe.

(3) Bituminous Paved Inverts. Paving the inverts of corrugated metal culverts to provide a smooth flow and to protect the metal has sometimes been an effective protection from particularly abrasive and corrosive environments. Bituminous paving is usually at least 1/8-inch (3 mm) thick over the inner crest of the corrugations. Generally only the lower quadrant of the pipe interior is paved. Fiber binding is sometimes used to improve the adherence of bituminous material to the metallic-coated pipe.

(4) Other Coatings. There are several other coating materials that are being used to some degree throughout the country. Polymeric, epoxy, fiberglass, clay, and concrete field paving, have all been used as protection against corrosion. Galvanizing is the most common of the metallic coatings used for steel. It involves the application of a thin layer of zinc on the metal culvert. Other metallic coatings used to protect steel culverts are aluminum and aluminum-zinc.

CHAPTER 4

CULVERT INSPECTION PROCEDURES

Section 1. INTRODUCTION

4-1.0 General.

Conducting and reporting inspections are important elements of an overall structure inspection program. A systematic inspection program also requires planning to establish the purpose and scope of the program, as well as budgeting and scheduling to accomplish the planned program. The usefulness of the information that is collected in the field depends to a large extent upon how well the inspection is accomplished and documented. The information must be recorded in a manner that provides a permanent record, is easy to understand, furnishes an accurate assessment of conditions at the time of inspection, makes information readily available for a variety of uses, and is easily verified and updated.

This chapter reviews the various elements of an inspection program and provides general procedures for conducting and reporting inspections of culvert structures. Detailed inspection guidelines for the major components of a culvert are provided in chapter 5, Culvert Component Inspection Guide.

4-1.1 Purpose and Scope of Inspections.

The National Bridge Inspection Program was designed to insure the safe passage of vehicles and other traffic. The inspection program provides a uniform data base from which nationwide statistics on the structural and functional safety of bridges and large culvert-type structures are derived. Although these bridge inspections are essentially for safety purposes, the data collected is also used to develop rehabilitation and replacement priorities.

Bridges with spans over 20 ft in length are inspected on a two-year cycle in accordance with the National Bridge Inspection Standards (NBIS). According to the American Association of State Highway and Transportation Officials (AASHTO) the definition of bridges includes culverts with openings measuring more than 20 ft along the centerline of the road and also includes multiple pipes where the distance between openings is less than half of the pipe opening.

Multiple barrel culvert installations with relatively small pipes can therefore meet the definition of a bridge. Structures included in the NBIS are evaluated by utilizing a standardized inventory appraisal process that is based on rating certain structural and functional features. The data obtained is recorded on standardized inspection forms. The minimum data required for bridge length culverts is shown on the Structure Inventory and Appraisal Sheet (SI&A), as shown in exhibit 31. Procedures for coding these items are

STRUCTURE INVENTORY & APPRAISAL SHEET

IDENTIFICATION

1 State 374
2 Hwy. Dis. 09
3 County 067 (FORS) 4 City/Town 0000
5 Inventory Route 131029310 On ☒ Under ☐
6 Features Intersected CREEK

CLASSIFICATION

24 Fed. Aid System 09 NFA-R
25 Administrative 1
26 Functional 05

	By	Date
Transfer of Data	CJR	9·4·80
Maintenance Insp.	DRG	8·23·80
Condition Analysis	DRG	8·23·80
Appraisal		
Cost Estimate		
General Review		

7 Facility Carried by Structure SR 2931
8 Structure No. 24C293100623370
9 Location 0.5MI S JCT SR 2983
10 Min. Vert. Clearance, Inv. Rte. 9999
11 Milepoint
12 Road Section No.
13 Defense Bridge Description — —
14 Defense Milepoint
15 Defense Section Length
16 Latitude
17 Longitude
18 Physical Vulnerability
19 By-pass, Detour Length 03
20 Toll Bridge ☐ On Toll Road ☐ On Free Road 3
21 Custodian 1
22 Owner 1
23 F.A.P. No.

STRUCTURE DATA

27 Year Built 6000
28 Lanes on Str. 02 under 00
29 ADT 000090 30 Year 78
31 Design Load 5 (HS 20)
32 Appr. Rdwy. Width W/sh'ld 037
33 Br. Median 0 None ☐ Open ☐ Closed
34 Skew 18
35 Structure Flared ☐ Yes 0 No
36 Traffic Safety 0 0 0 0 0
37 Historical Significance 5
38 Navigation Control ☐ Yes 0 No
39 -Vertical 000 ft.
40 -Horizontal 0000 ft.
41 Open-Closed-Posted A

42 Type Service 1 5
43 Structure Type-Main 1 1 9
44 -Approach 0 0 0
45 No. of Spans-Main 002
46 -Approach 0000
47 Total Horiz. Clearance 37.0 ft.
48 Max. Span Length 0010 ft.
49 Structure Length 000022 ft.
50 Sidewalk Rt. 00.0 ft. Lt. 00.0 ft.
51 Br. Roadway Width (curb-curb) 000.0 ft.
52 Deck Width (out-out) 000.0 ft.
53 Vert. Clearance over Deck 99 ft. 99 in.
54 Underclearance-Vertical 00 ft. 00 in.
55 -Lateral-Right 99.9 ft.
56 -Left 00.0 ft.
57 Wearing Surface N

CONDITION

	Material	Condition Analysis	Rating
58 Deck			N
59 Superstructure			N
60 Substructure			N
61 Channel & Channel Protection			5
62 Culvert & Retaining Walls			7
63 Estimated Remaining Life 20		65 Approach Roadway Condition	7
64 Operating Rating HS26 246		66 Inventory Rating HS20	236

APPRAISAL

	Deficiencies	Rating
67 Structure, Adequacy		5
68 Deck Geometry		8
69 Underclearances-Vertical & Lateral		N
70 Safe Load Capacity		8
71 Waterway Adequacy		6
72 Approach Roadway Alignment		6

PROPOSED IMPROVEMENTS

73 Year Needed 00 Completed
Describe (Item 75)
74 Type of Service 0
75 Type of Work 000
76 Improvement Length 000000 ft.
77 Design Loading 0
78 Roadway Width 0000 ft.
79 Number of Lanes 00
80 ADT 000000 81 Year 00
82 Prop. Rdwy. Improvement-Year 00
83 -Type 0

COST OF IMPROVEMENTS

84 Total Cost $ 000
85 Preliminary Engineering Cost 000
86 Demolition Cost 000
87 Substructure Cost 00000
88 Superstructure Cost 00000

Remarks

Revised 5-77

Exhibit 31. Standard SI&A Form--Example shown is for a two-barrel reinforced concrete box culvert.

provided in the Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges (Coding Guide).

While the importance of the NBIS inspection program cannot be overemphasized, the SI&A data sheets are oriented toward bridges rather than culverts; thus, they do not allow an inspector to collect either detailed condition data or maintenance data. Additionally, the NBIS program does not specifically address structures where the total opening length is less than 20 feet. However, some type of formal inventory and inspection is needed for culverts that are not bridge length. In many cases, the failure of a culvert or other structure with openings less than 20 ft long can present a life-threatening hazard. Although the primary purpose of this manual is to provide inspection guidelines for culverts included in the NBIS program, the guidelines should also be generally applicable to culverts with openings which are less than 20 feet long.

Ideally, all culverts should be inventoried and periodically inspected. Some limitations may be necessary because a considerable effort is required to establish a current and complete culvert inventory. Small culverts may not warrant the same rigorous level of inspection as large culverts. Each agency should define its culvert inspection program in terms of inspection frequency, size, and type of culverts to be inventoried and inspected, and the information to be collected. Of course, culverts larger than 20 ft must be inspected every two years under the NBIS program. If possible all culverts should be inventoried and inspected to establish a structural adequacy and to evaluate the potential for roadway overtopping or flooding.

The types and amount of condition information to be collected should be based on the purpose for which the information will be used. For example, if small pipes are not repaired but are replaced after failures occur, then the periodic collection of detailed condition data may not be warranted. Documentation of failures as well as the causes of failures, may be all the condition data that is needed. However, the inventory should be updated whenever a replacement is accomplished.

Section 2. REPORTING

4-2.1 Reporting Requirements.

The requirements of a good field reporting system include the following:

a. inventory data.

b. a structure file for each structure to be inspected.

c. a procedure for planning and scheduling inspections.

d. a system for recording the inspection results.

e. a system for updating the structure files.

4-2.2 Inventory Data

Accurate inventory records are fundamental to the management of inspection and maintenance programs. Inventory records serve as a data base for planning, scheduling, and reporting inspection and maintenance activities.

Bridge culvert information such as the identification number assigned to the structure, location, type of structure, number of spans, cells or barrels, length of span, road or facility served by the structure, and the stream or feature crossed by the structure should be available since this data is required in accordance with the Coding Guide under items 1 through 57. This data may also be available on inventory cards or forms maintained by maintenance personnel.

If inventory data is not currently available on small culverts, inventory guidelines should be established for the size of culvert to be inventoried and the amount of data to be collected. As previously mentioned an initial inventory requires a significant effort and may represent a sizeable investment of manpower. Inventory listings and cards should be kept current as work is done on a structure or as a replacement is accomplished. A sample inventory card is shown in exhibit 32.

4-2.3 Structure Files.

Structure files are used to maintain detailed information on each important structure. A thorough study of the available historical information can be extremely valuable in identifying possible critical areas of structural or hydraulic components and features. Because this information may require considerable effort to assemble, a separate file should be established for each structure.

The contents of any particular file may vary depending upon the size and age of the structure, the functional classification of the road carried by the structure, and the informational needs of the agencies responsible for inspection and maintenance. A very small culvert may be documented in an inventory listing or with a file that contains little more than an inventory card plus dates and comments of previous inspections. For larger culverts it is recommended that the following types of information be assembled when possible:

a. Construction and Design Data--"As built" or design plans should be included in a structure file. If plans are not available, the following types of construction information should be determined: date built; type of structure including size, shape and material, wall thickness (or gauge); class of pipe; joint types, size of corrugations if applicable; height of cover; end treatments; type and thickness of pavement; design capacity; and design service life. Standard drawings that indicate minimum and maximum allowable depth of cover, wall thickness, gauge, and end treatments are often as useful as plans. Hydraulic data should also be assembled where available, including slope of structure, elevation of inverts, stream channel and water surface during normal and high flows, design storm frequency, drainage area, design

(FRONT)

LOCATION	County [3]	Division	District [2]	Culvert Number [8]	
	Route [5][7]	Milepost [11]	Located ____ miles [9] from	Over [6]	
APPROACH ROAD	Left shoulder width	Roadway width	Median width	Right shoulder width	Total [22]
ROAD OVER CULVERT	Left sidewalk width [50]	Left shoulder width	Roadway width [51]	Median [33] None Open Closed	
	Median width [51]	Right shoulder width	Right sidewalk width [50]	Total cross section width [52]	Number of lanes on culvert [28]
CULVERT	Shape	Material [43]	Coating Type/ Cathodic Protection	Skew [34]	Length along roadway ℄ [49]
	Barrel size [48]	Barrel length	Number of barrels [45]	Type of end treatment	Depth of cover
UNDER CLEARANCE	Left [55]	Vertical [54]	Right [56]		
MISCELLANEOUS	Bypass length [19]	Federal Aid System [24]	Functional Classification [26]	Year built [27]	FA project number [23]
	ADT [29]	ADT year [30]	Design load [31]	Culvert status Open, Closed, Posted	

☐ SI & A Item Numbers

(BACK)

HYDRAULICS	**DRAINAGE AREA**	**DESIGN STORM FREQUENCY**
	DESIGN DISCHARGE 'Q'	**HEAD WATER ELEVATION**
SKETCH OF CULVERT		
PLAN VIEW		CROSS SECTION

Exhibit 32. Sample inventory card.

discharge, date of design policy, flow conditions, limits of flood plain, type of energy dissipators, cut of wall depth, channel alignment, and channel protection.

b. Repair History--Information on repairs, culvert extensions, and rehabilitation activities should be collected. The types and amount of repairs performed at a culvert site can be extremely important. Frequent roadway patching due to recurring settlement over a culvert may indicate serious problems that are not readily apparent through inspection of the culvert barrel itself.

c. Inspection History--Data from previous inspections can be particularly useful in identifying components that require special attention during an inspection. Information from earlier inspections can be compared against current conditions to estimate rates of deterioration and to help judge the seriousness of the problems detected and the anticipated remaining life of the structure.

4-2.4 Inspection Scheduling.

Scheduling is necessary to insure that the planned inspection program is accomplished within the time and resources available. Scheduling helps to achieve a well-organized, complete, and efficient inspection. Factors which should be considered when developing an inspection schedule include:

a. Inspection Type--Inspections which collect SI&A and other supplemental information must be made at least every two years. More frequent or interim inspections may also be needed. For example, when there is a risk of damage to a structure by high stream flows, the structure should be inspected after major storms. Similarly structures with a history of significant structural deficiencies such as excessive tearing of the bolt holes, severe corrosion in corrugated metal structures, or severe invert or crown cracking in concrete structures, should be inspected frequently until the problem is resolved. Hydraulic deficiencies causing severe embankment erosion, stream alignment changes, or undermining of the structure may also require interim inspections.

Such interim inspections may be limited to the critical areas affected by the deficiency. Other types of interim inspections may also be necessary. For example, culverts with multiple barrels or flat gradients should be checked frequently for blockage. Small culverts that are performing well may be assigned an inspection frequency that is longer than two years. However, new culverts should be checked at least once a year for the first two years. Structural problems in culverts are often related to improper construction practices such as inadequate compaction and poor bedding preparation. Construction related problems are frequently evident within the first year after construction.

b. Inspection Resources--The manpower, equipment, and materials required to perform an inspection program should be determined and then compared against available resources to identify additional resource requirements in any of the resource categories. If additional manpower is required and not available, a policy should be developed to establish priorities for the inspection of culverts with openings under twenty feet long. When data is available, prioritization could be according to condition, opening length, rise, or other factors. Specialized equipment and personnel may also be needed on occasion for problems that are beyond the scope of an SI&A inspection. Specialists in hydraulics, soils, materials, or structual analysis may be needed to support the inspection program by investigating unusual or potentially hazardous situations.

c. Scheduling Requirements--Inspection schedules are generally prepared at several levels including organizational, supervisory, and working levels. The organizational schedule is prepared to insure that all structures are inspected at the appropriate intervals. The supervisory schedule is prepared to coordinate the use of manpower and equipment. The level of detail is greatest at the working level. The detailed working schedule is very specific in terms of the date, structure to be inspected, and personnel to conduct the inspection. The working schedules for culvert inspections may require that special consideration be given to seasonal stream levels and weather. Brush clearing may be required before culverts can be inspected. Ideally structures should be inspected during periods of lowest flow. However, it is often advantageous to check the hydraulic operating characteristics of culverts during or immediately after heavy rainstorms. Because of the special scheduling considerations previously mentioned, culvert inspection schedules must contain flexibility.

4-2.5 Recording the Inspection.

When inspecting culverts, information will usually be recorded by a variety of methods including standard forms, standard prepared sketches, narrative descriptions, and photographs. Collection methods include the following:

a. Inventory Data--A standard inventory card or form should be used to record basic information such as location and structure type. A sample inventory form was shown in exhibit 32.

b. Standard Inspection Report Forms--Standard inspection report forms are usually the most convenient method for recording specific items of information such as numerical data and brief descriptions or remarks. Properly designed forms can provide assistance in field data collection by providing a list of the items that must be evaluated or measured and can also organize data, making it more accessible for review. Because very few of the items on bridge inspection forms apply to culverts, it is highly recommended that forms developed specifically for culverts be used to record culvert inspection results. A sample culvert inspection report form is shown in exhibit 33.

The form shown is basically an adaption and expansion of the SI&A condition rating items that apply to culverts. Numerical ratings are used to record the condition of each item and rating systems are described in section 3 of this chapter. The expanded SI&A items provide information that identify the

LOCATION

County__________ Division__________ District__________

On Route__________ at Milepost__________ or Miles From__________

IDENTIFICATION	**TYPE OF CULVERT**	**BARRELS**
Culvert No.________	Shape________	Size________
Over________	Material________	Number________
	Coating________	

CONDITION

	Condition Rating	Remarks	
61 Channel & Channel Protection			
Channel Scour	☐		
Embankment Erosion	☐		
Drift	☐		
Silt	☐		
Vegetation	☐	General Rating	☐
62 Culvert & Retaining Walls			
Barrel	☐		
Headwall	☐		
Wingwall	☐		
Settlement	☐		
Adequacy of Cover	☐	General Rating	☐
63 Estimated Remaining Life			
Inspectors Appraisal of Structural Condition (years)			☐
65 Roadway			
Shoulders	☐		
Embankment	☐		
Pavement	☐	General Rating	☐

APPRAISAL

71 Waterway Adequacy			
Opening	☐		
Alignment	☐		
Scour	☐	General Rating	☐
72 Roadway Alignment			
Appraisers Estimate of General Rating			☐

Recommendations and Miscellaneous Comments

Exhibit 33. Culvert inspection report.

components of a structure which may require rehabilitation or maintenance. Forms may also be developed for collecting other supplemental information including traffic safety, durability, hydraulic and hydrologic data. The information recorded on forms is primarily summary type data and should be supported by other types of documentation such as narrative descriptions, photographs, and sketches. Supplemental data is particularly important when actual maintenance requirements are needed or a hydraulic or structural analysis is to be performed.

c. Standard Prepared Sketches--Standard prepared sketches are a convenient method for recording field measurements. Exhibit 34 illustrates standard sketches for recording basic culvert measurements.

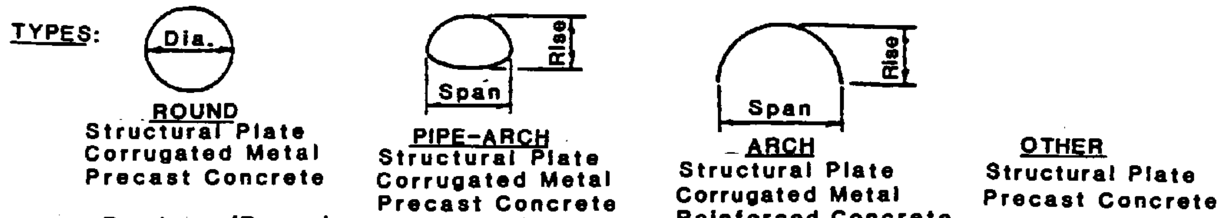
d. Sketches--Additional sketches may need to be prepared in the field to document deficiencies found during the inspection. An overall sketch should also be made to show the general layout of the stream, structure, and roadway, to indicate skew and the direction of flow during low and peak flows, and to show the location of scour or other stream channel problems. A sample overall sketch is shown in exhibit 35.

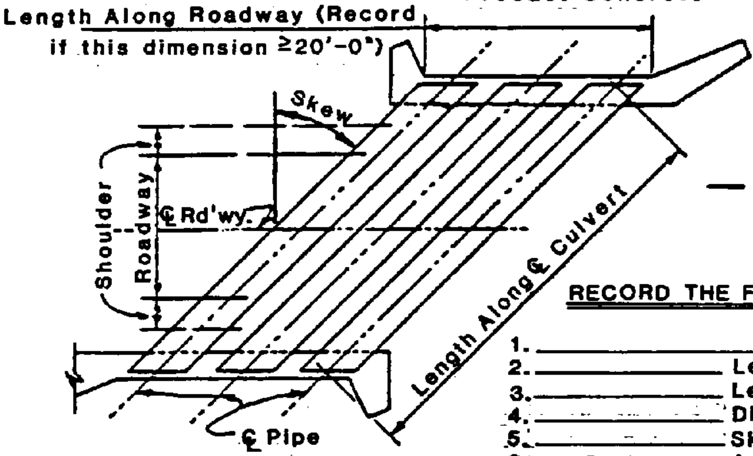
e. Narrative Descriptions--Narrative descriptions supplement the information recorded on forms, photographs, and sketches. Descriptions of the condition of each component such as the culvert barrel, headwalls, wingwalls, and stream channel should be prepared by the inspector. The descriptions should be clear and concise, yet completely describe the structure's condition at the time of inspection. An appraisal of flood hazard conditions, and comments concerning the characteristics of the drainage area should be included in the narrative. The narrative should reference appropriate sketches and photographs, and the narrative descriptions should be written or recorded on tape at the site.

f. Photographs--Photographs are an excellent method for documenting problems found during an inspection. It is good practice when taking close-up photographs to place a scale or rule next to the item being photographed to clearly indicate the extent of the problem. Lumber crayon (keel) can be used to point to or highlight defects. Writing the date, structure number, and other comments on the structure with keel prior to taking the photograph can also be helpful.

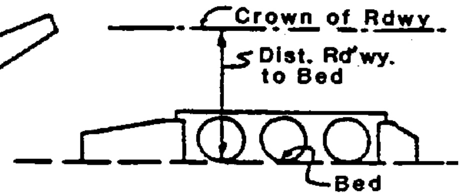
Photographs are of particular value to anyone reviewing the report as well as for individuals making follow-up inspections. Photographs showing the structure in side elevation and from the roadway are useful in providing the reviewer an overall picture of the structure. A few traffic control cones on the roadway over the culvert may be necessary to indicate the location of the culvert in roadway photographs. An alternative is to draw a line across the photograph indicating the culvert centerline, as shown in exhibit 36. Panoramic photographs of the upstream and downstream flood plan zones are important to document existing property development. Old outdated photos should be retained and supplemented with new photos as conditions change. While photographs are extremely useful they do not eliminate the need for sketches and narrative descriptions; and, in many cases, a sketch is more useful than a photograph.

PIPE CULVERTS





TYPICAL PLAN

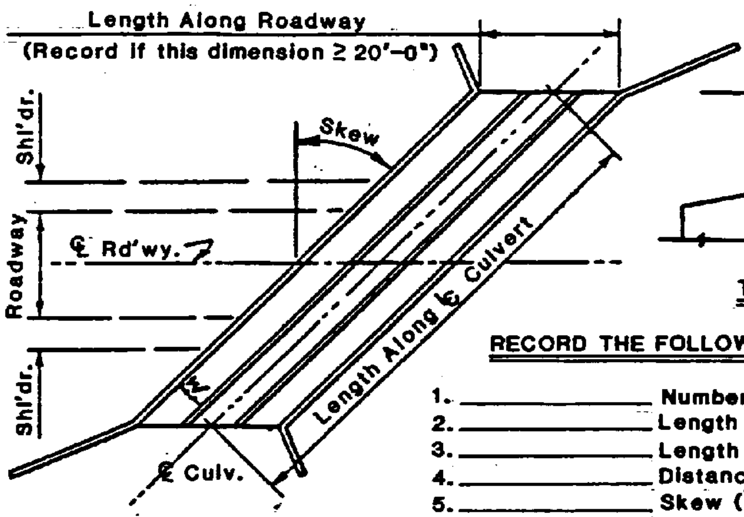


TYPICAL END ELEVATION

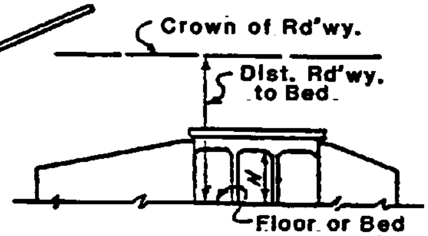
RECORD THE FOLLOWING ITEMS:

1. __________ Member, Size, & Type of Culvert
2. __________ Length Along ℄ Roadway
3. __________ Length Along Culvert
4. __________ Dist. from Crown of Roadway to Bed
5. __________ Skew
6. __________ Approach Rd'wy. Width(Paved or Unpaved)
7. __________ Approach Shl'dr Width(Show Left & Right)
8. Include sketches to show culvert situations and rd'wy. clearances that can not be detailed on this sheet.

BOX CULVERTS



TYPICAL PLAN

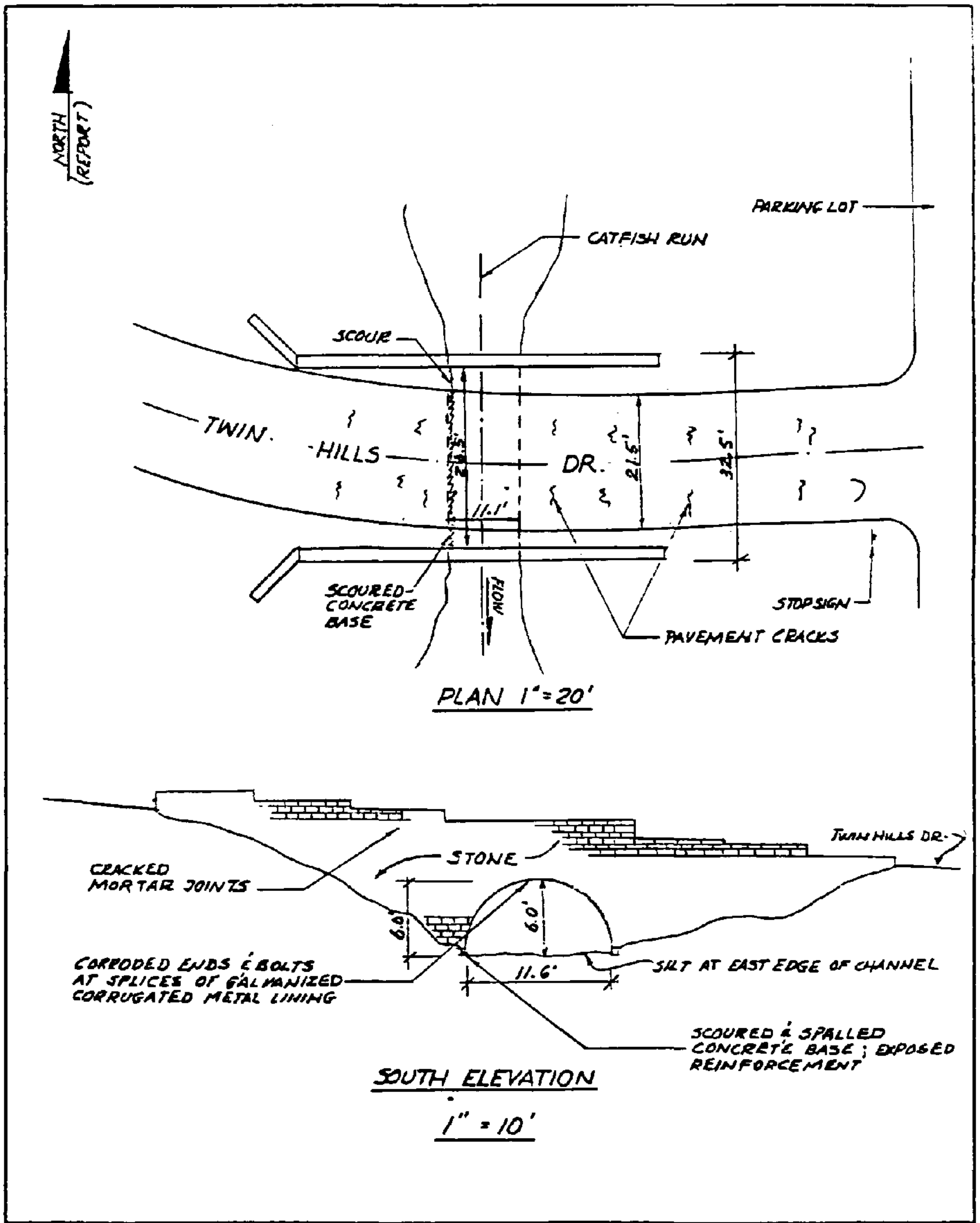


TYPICAL END ELEVATION

RECORD THE FOLLOWING ITEMS:

1. __________ Number & Size of Barrels(WxN)
2. __________ Length Along ℄ Roadway
3. __________ Length Along ℄ Culvert
4. __________ Distance from Crown Roadway to Bed.
5. __________ Skew (±)
6. __________ Approach Rd'wy.Width(Show Paved or Unpaved)
7. __________ Approach Shoulder Width(Show Left & Right)
8. Include Sketches to show culvert situations and roadway clearances that can not be detailed on this sheet.

Exhibit 34. Standard prepared sketches (adapted from North Carolina inspection forms).



BRIDGE CODE CT-10-05 DATE 5-5-80
BRIDGE NAME CATFISH RUN NO. 10
LOCATION SOUTH PARK
ROAD CARRIED TWIN HILL DRIVE
STREAM CROSSED CATFISH RUN

Exhibit 35. Sample sketch.

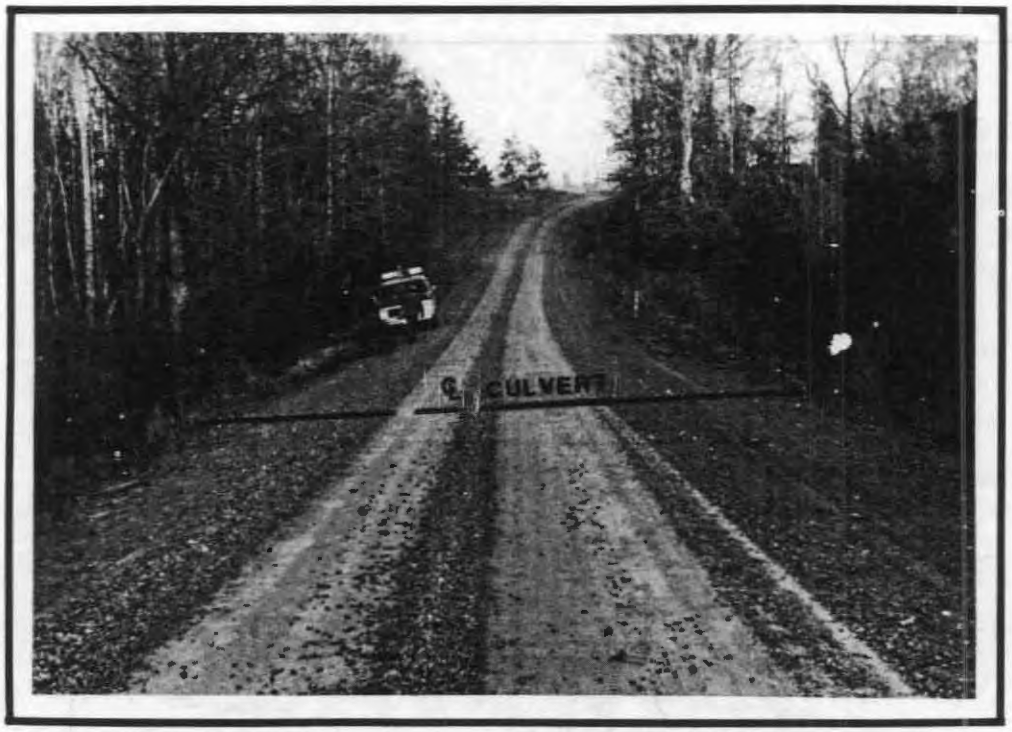


Exhibit 36. A line indicating a culvert centerline.

Exhibits 37, 38, and 39 provide comparisons of toe-wall scour as shown in photographs and as shown in a sketch.

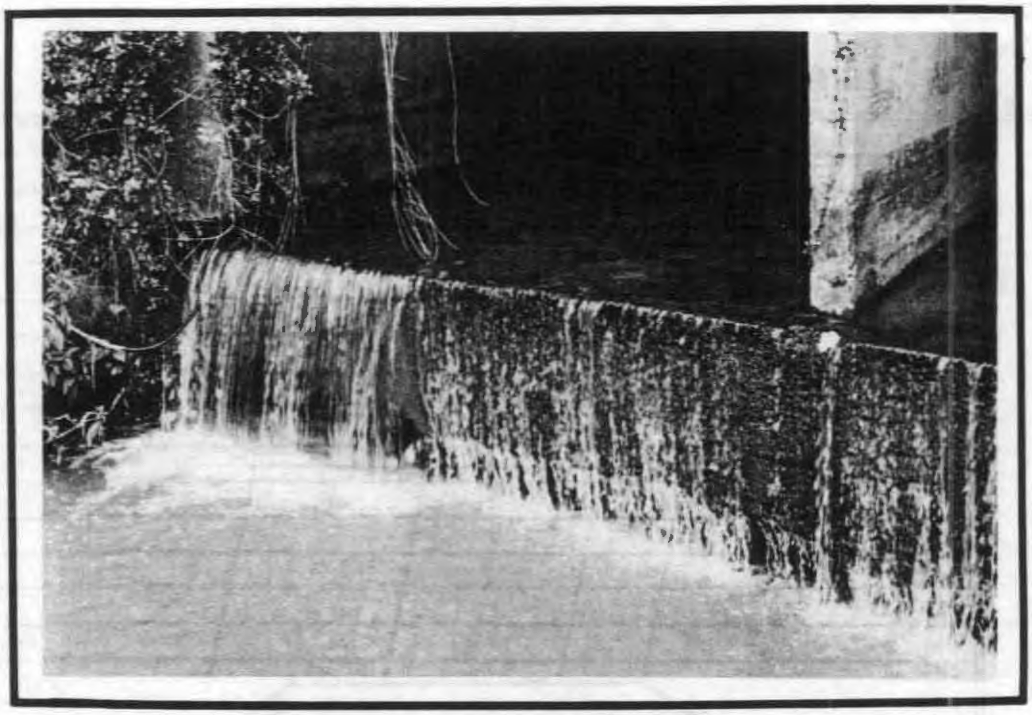


Exhibit 37. Undermined toe-wall.

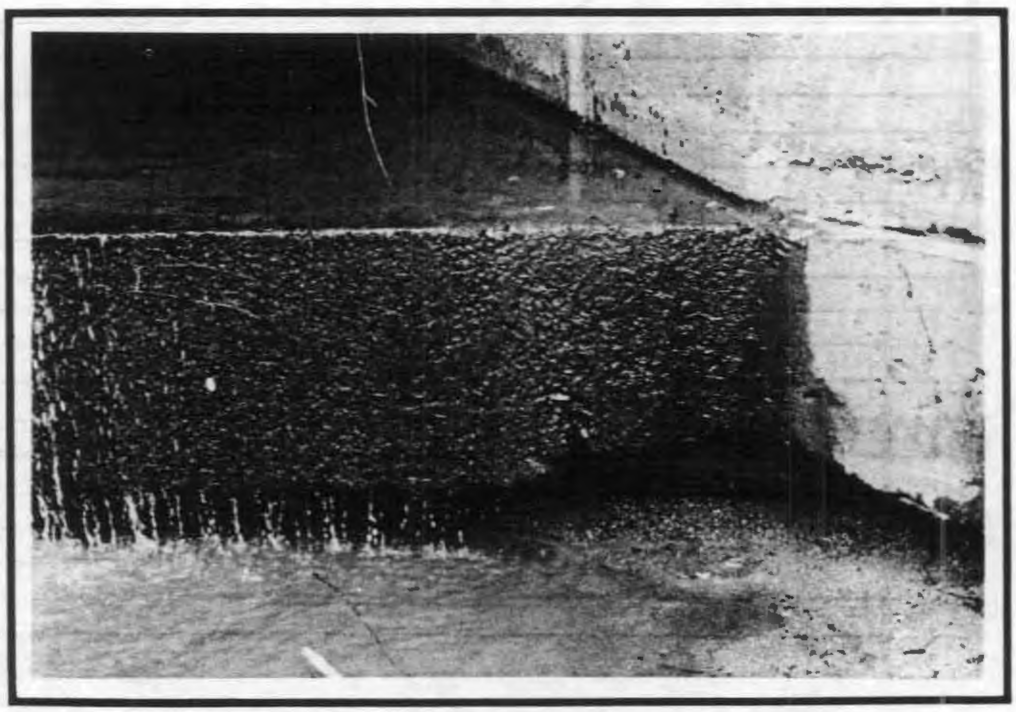


Exhibit 38. Undermined toe-wall.

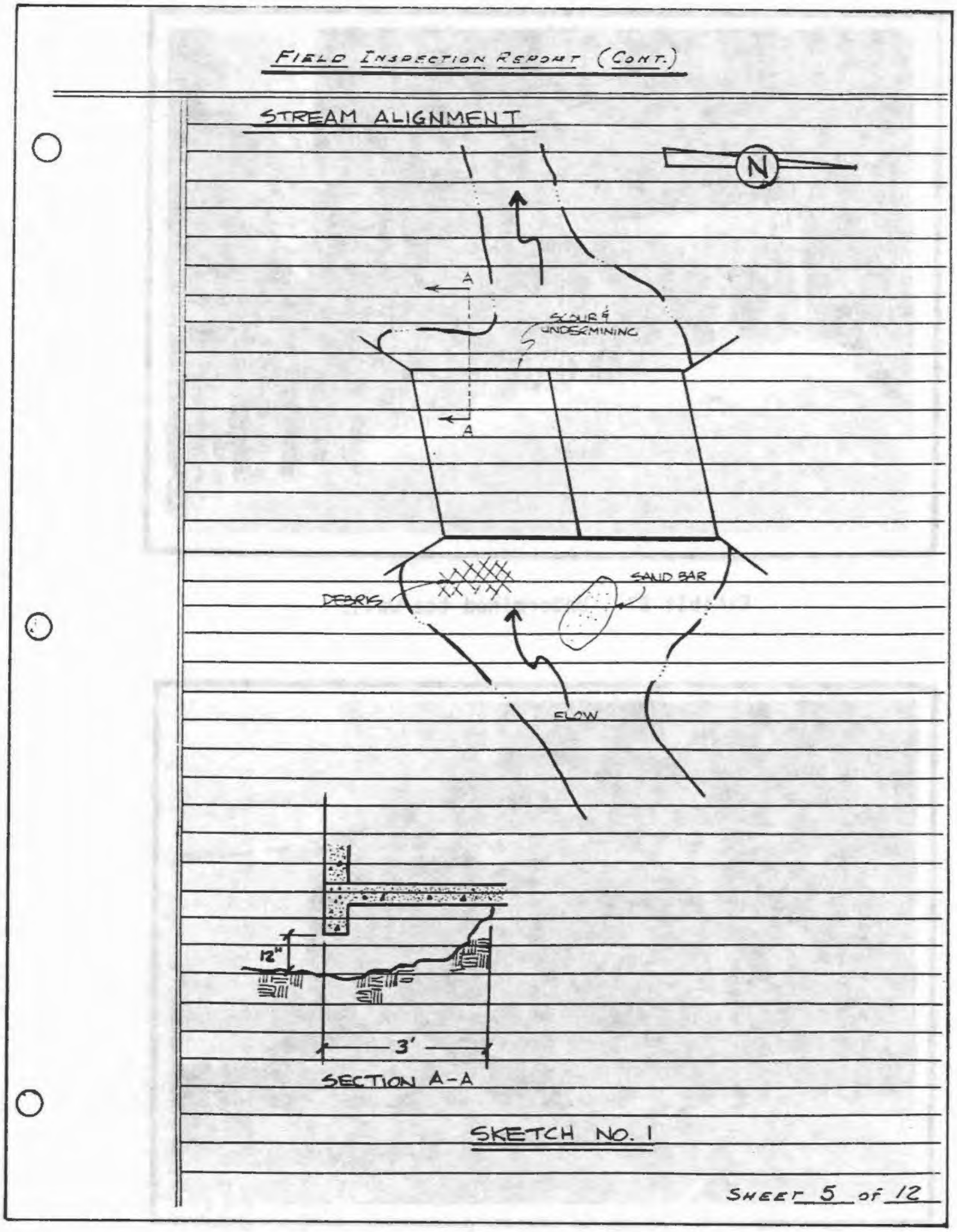


Exhibit 39. Sketch of undermined toe-wall.

g. Summary--A brief summary of the structure's condition should generally be included in the report. The summary should identify any significant problems found and include a brief comment on type of defect andlocation of the problem on the structure. The reviewer can then refer to appropriate sections of the inspection report for details.

h. Recommendations--The inspector should list any maintenance or repairs that are needed to maintain structural integrity, insure public safety, preserve the investment represented by the culvert, and extend the service life.

4-2.6 Updating Inventory Records.

The usefulness of information collected during field inspections depends upon its availability for use. Records must be maintained in an orderly system so that specific records can be easily located by authorized personnel for updating or review.

a. Updating Files--The structure files, previously described, should be used to retain copies of available information on each structure. They should be updated each time the structure is inspected or maintenance is performed. After an initial inspection report has been completed, subsequent inspections will usually not require the same amount of documentation as a new report. However, all inspections should be recorded even if they are cursory and no changes were found. When a culvert is significantly modified, a revised report should be prepared. The original report should be retained but clearly marked to indicate that it has been superseded by a new report.

b. File Access--The use of computerized inventory records can greatly improve the speed at which data can be located and retrieved. Even when culvert inventory records are manually indexed, it is likely that some form of tabulation or cross indexing will be required. Typical file access requirements may include access by:

(1) structure number
(2) roadway data--route number, road classification, roadway width
(3) location
(4) area, district, county, coordinates
(5) structure type
(6) age
(7) size--span of each barrel and total opening length
(8) material
(9) date of last inspection
(10) condition
(11) load capacity
(12) drainage data--drainage area, design discharge, design variables, allowable headwater elevation
(13) end section--type, cut-off wall depth
(14) traffic safety features--guardrail, Jersey barrier

Section 3. RATING SYSTEMS

4-3.1 Numerical Evaluation.

Numerical rating systems are useful methods for summarizing the condition of bridge and culvert components. When the conditions associated with a specific numerical value are well-defined and the rating system is clearly understood by both raters and reviewers, valuable information can be quickly extracted from the inspection reports.

To achieve accurate and consistent results, clear definitions are needed on how the ratings are to be applied. For example, is an item rating based on average condition or on the worst condition found? Ideally the answer should depend upon the type and location of the defects found. Questions the inspector should ask when rating an item are: Is the item functioning as originally intended? Could it pose a threat to public safety and private property? Could it cause extensive damage if it is not repaired? Can the problem be repaired by maintenance action or will it require rehabilitation?

4-3.2 SI&A Ratings

The results of all bridge and culvert inspections performed as part of the National Bridge Inspection Program are reported to the FHWA on Standard Inventory and Appraisal (SI&A) forms as previously illustrated in exhibit __. The information reported includes inventory data, condition ratings, and appraisal ratings. As noted earlier, FHWA publishes instructions and guidelines for recording each item on the standard SI&A form.

a. Condition Ratings--Condition ratings are based on a comparison of the existing condition of the item being evaluated with the "as-built" condition. The following condition items are applicable to culverts:

(1) Item 61--channel and channel protection
(2) Item 62--culvert and retaining walls
(3) Item 63--estimated remaining life
(4) Item 64--operating rating (maximum permissible load)
(5) Item 65--approach roadway alignment
(6) Item 66--inventory rating

A description of each of these six items is included in the Coding Guide previously mentioned. With the exception of items 63, 64, and 66, SI&A condition items are rated using a numerical scale that ranges from "0" for closed and beyond repair to "9" for new condition. General descriptions of the conditions that apply to each number of the rating scale are provided in the Coding Guide.

b. Appraisal Ratings--Appraisal ratings are an evaluation of how the structure as a whole functions as an element of the highway network. Appraisal ratings also use a "0" to "9" numerical scale but are based on a comparison with current standards as opposed to "as-built" standards. General descriptions of each number on the appraisal rating scale as well as a description of each item are provided in the Coding Guide. The following SI&A appraisal items apply to culverts:

(1) Item 67--structural condition
(2) Item 68--deck geometry
(3) Item 70--safe load capacity
(4) Item 71--waterway adequacy
(5) Item 72--approach roadway alignment

4-3.3 Maintenance Rating Systems.

It is usually necessary to evaluate the condition of more items than those rated on the SI&A forms because the SI&A condition items cover such broad components. For example SI&A item 62 covers all structural components of a culvert. Additionally, the SI&A numerical rating system is not well suited for evaluating minor items. Minor items are essentially limited to ratings of "N","9", "8", or "7" since the other rating numbers imply a significant impact on the overall integrity or safety of the structure. Therefore, a modified rating system should be used for rating the condition of items added to supplement the SI&A items. Since items are added primarily to identify potential maintenance problems, the modified rating scale should be oriented toward maintenance.

A sample maintenance rating system is shown in exhibit 40. The rating system shown provides a numerical scale that is related to the urgency of maintenance action required as well as the action which should be taken by the inspector.

It is important to note that the inspector basically has three courses of action depending on the severity of conditions found. Each of these actions involves noting the condition of the culvert components in the inspection report. When no immediate maintenance actions are required, the note in the report is all that is necessary. When a high priority should be assigned for correcting problems found during the inspection, some type of special notification to maintenance personnel is recommended. When immediate action is required to address a hazardous situation or preserve the integrity of the structure, maintenance personnel should be notified on an emergency basis.

Care must be exercised when using different rating systems, particularly when combining the ratings given to supplemental items to arrive at ratings for SI&A items. SI&A item ratings usually represent a composite rating of a group or broad category of supplemental items. The SI&A ratings should not merely be an average of the ratings assigned to the supplemental items but should be based on the inspector's judgment. A low rating in one supplemental item will usually control the composite rating. The inspector should ask the same questions discussed in section 4-3.1.

Maintenance Urgency Index	Maintenance Immediacy of Action	Inspection Course of Action
9	No repairs needed.	Note in inspection report only.
8	No repairs needed. List specific items for special inspection during next regular inspection.	
7	No immediate plans for repair. Examine possibility of increased level of inspection.	
6	By end of next season - add to scheduled work.	
5	Place in current schedule - current season - first reasonable opportunity.	Special notification to superior is warranted.
4	Priority - current season - review work plan for relative priority - adjust schedule if possible.	
3	High priority - current season as soon as can be scheduled.	
2	Highest priority - discontinue other work if required - emergency basis or emergency subsidiary actions if needed (post, one lane traffic, no trucks, reduced speed, etc.)	Notify superiors verbally as soon as possible and confirm in writing.
1	Emergency actions required - reroute traffic and close.	
0	Facility is closed for repairs.	

Source: NCHRP Report 251

Exhibit 40. Maintenance rating scale.

Section 4. ELEMENTS OF INSPECTION

4-4.1 Inspection Sequence.

A logical sequence for inspecting culverts helps insure that a thorough and complete inspection will be conducted. More than just the components of a culvert should be evaluated; look also for high water marks, changes in the drainage area, settlement of the roadway, and other indications of potential problems. A general plan is therefore useful to avoid oversights.

For typical culvert installations it is usually convenient to begin the field inspection with general observations of the overall condition of the structure and an inspection of the approach roadway. The inspector should select one end of the culvert and inspect the embankment, waterway, headwalls, wingwalls, and culvert barrel. The inspector should then move to the other end of the culvert. Detailed inspection guidelines are provided in the Culvert Component Inspection Guide, found in chaper 5 of this manual; and the following general elements of inspection are discussed briefly in this section.

a. Review of available information

b. Observation of overall condition

c. Approach roadway and embankment

d. Waterway

e. Headwalls and wingwalls

f. Culvert barrel

4-4.2 Review of Available Information.

Previous inspection reports and plans, when available, should be reviewed prior to, and possibly during, the field inspection. A review of previous reports will familiarize the inspector with the structure and make detection of changed conditions easier. A review will also indicate critical areas that need special attention and the possible need for special equipment.

4-4.3 Observation of Overall Condition.

General observations of the condition of the culvert should be made while approaching the culvert area. The purpose of these initial observations is similar to the plan review as it familiarizes the inspector with the structure, may point out a need to modify the inspection sequence, or indicate areas requiring special attention. The inspector should also be alert for changes in the drainage area that might affect runoff characteristics. For example, a change in land use from agricultural to commercial could result in increased runoff and sedimentation. When the inspector observes extensive land development activities, an inspection of downstream culverts should be conducted. The inspector should also look for new construction within flood hazard zones, the addition of guardrail or Jersey barrier that would increase the upstream flood hazard from ponding, unexpected or new directions of runoff, and blockages downstream.

4-4.4 Approach Roadway.

Inspection of the approach roadway and embankment includes an evaluation of the roadway condition and functional adequacy. The condition rating is recorded under item 65 on the standard SI&A sheet (see exhibit 31). The functional assessment is recorded under SI&A items 68 and 72. Collection and validation of inventory data needed for the standard SI&A sheet may also be performed as part of the approach roadway inspection. The inspection is performed by visual observation and should be documented by a brief narrative to support the ratings assigned, a sketch of the alignment, and photographs.

Defects in the approach roadway and embankment may be indicators of possible structural or hydraulic problems in the culvert as shown in exhibit 41. The approach roadway and embankment should be inspected for the following:

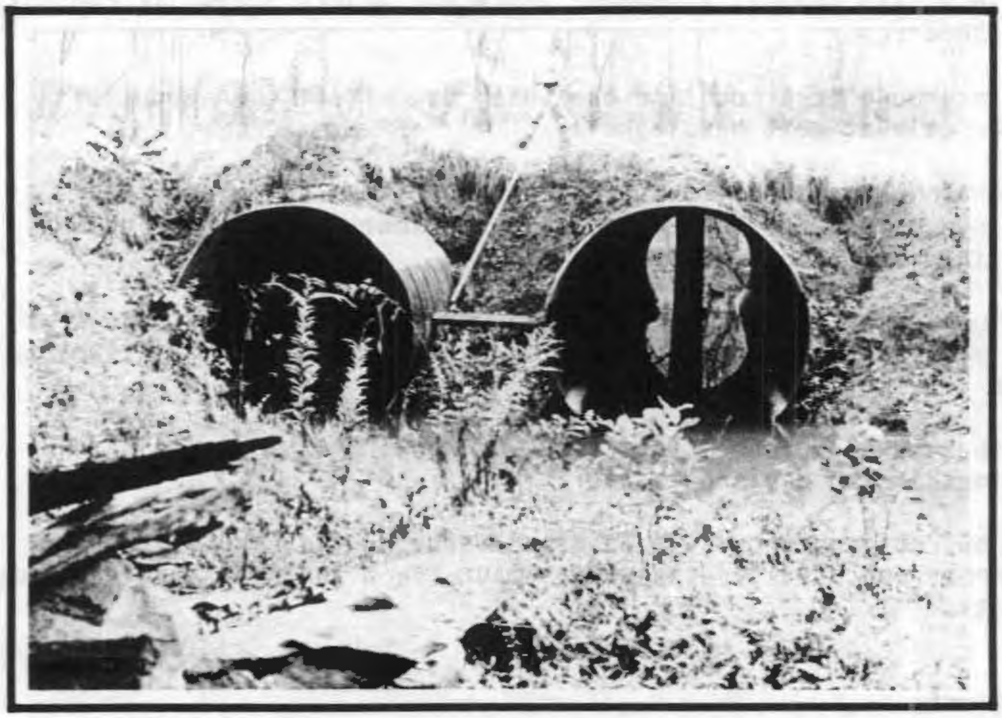
a. Condition of embankment and roadway
  (1) sag in roadway or guardrail
  (2) cracks in pavement
  (3) pavement patches or evidence that roadway has been built-up
  (4) erosion or failure of side slope

b. Functional requirements
  (1) signing
  (2) alignment
  (3) clearances
  (4) adequate shoulder profile
  (5) safety features

4-4.5 Waterways

The SI&A sheet requires a condition rating for the stream channel (SI&A item 61) and a functional rating of the waterway adequacy (SI&A item 71). These items are inspected visually and should be documented by a brief narrative description supporting the ratings along with sketches and photographs showing the stream alignment and location of problems such as scour or sediment deposits. Vertical distance between the streambed and the culvert invert should also be measured when a significant difference in elevation exists.

Extensive roadway patching due to settlement of the embankment.



Pipes at same location as top photo require bracing to prevent excessive deflection. Bracing is a temporary measure until permanent repairs can be made.

Exhibit 41. Roadway defect may be an indication of distress in the culvert.

The inspection of hydraulic components is a key part of culvert inspection. The condition of the stream channel should be visually inspected for the following:

a. Horizontal alignment of the culvert with the stream channel--The inspector should be aware that this may change during high or low flows and that poor alignment may reduce the hydraulic capacity of the culvert.

b. Vertical alignment of the culvert--This may cause problems with sedimentation or scour.

c. Erosion and scour--These may be related to vertical (steep gradient), horizontal alignment, or to more frequent flows of higher magnitudes resulting from changes in the watershed.

d. Accumulations of debris and sediment--These may be caused by a number of factors including a culvert opening too small, installation of the culvert with its invert below the streambed, obstructions downstream, or development upstream.

Evaluation of the waterway adequacy involves checking for indications of an inadequate opening. The stream channel and drainage area should be evaluated for the following:

a. Changes in stream channel alignment which may reduce hydraulic capacity or cause scour.

b. Changes in ground cover or land use which may affect the amount of runoff the culvert must handle.

c. Changes in the amount and type of channel erosion. Excessive bank erosion, stream channel aggradation/degradation, or head cutting may indicate increased runoff.

d. Changes in high water marks. High water marks may indicate that culverts are inadequately sized, increasing the potential for flooding damage or roadway overtopping.

e. Changes in flow from intermittent to continuous which may indicate changes in the drainage area.

f. Channel obstructions such as deposits of debris, mud slides, beaver dams, fences, and utility pipes which may affect the hydraulic capacity of culverts.

4-4.6 End Treatments

End treatments such as headwalls, wingwalls, slope protections, and energy dissipators are used to protect the culvert barrel from hydraulic forces, retain the embankment, and improve hydraulic efficiency. Headwall and wingwall end treatments are shown in exhibit 42. The SI&A inspection form does not specifically address end treatments in terms of inventory data or condition. The condition rating of end treatments is included in SI&A item 62, Culvert and Retaining Walls. The appraisal rating should be included in SI&A item 67, Structural Condition.

Exhibit 42. Headwall and wingwall end treatment.

Inspections of end treatments primarily involve visual inspection although hand tools should be used such as a plumb bob to check for misalignment, a hammer to sound for defects, and a probing bar to check for scour and undermining. The inspection should be documented by a narrative description of the type and condition of end treatment used, and photographs or sketches of any significant problems found. The defects to look for during an inspection will depend upon the type of end treatment being inspected. In general, headwalls should be inspected for movement or settlement, cracks, deterioration, and traffic safety. All ends should be checked for undermining, scour, and evidence of piping. Piping is the removal of soil by water seeping along the outside of the pipe. This process is called piping because a pipe-shaped tube is often formed in the soil. Exhibit 43 illustrates a culvert with undermining at the outlet and evidence of piping.

Exhibit 43. Corrugated metal pipe arch with undermining and scour.

4-4.7 Culvert Barrel.

When the size of the barrel and flow of water permits, the full length of the culvert should be inspected from the inside. Culverts with small diameters can be inspected by looking through the culvert from both ends. The condition of the culvert barrel is rated under SI&A items 62 and 67, which cover all structural components of a culvert. The severity, extent, and location of significant defects should be documented by narrative description, sketches, and photographs, when possible.

It is very important to clearly identify problem locations in the inspection report. Accurate comparisons of condition cannot be made on follow-up inspections unless the locations of problems are documented. Locations in sectional pipe can be referenced by using pipe joints as stations to establish the stationing of specific cross-sections. Stations should start with number 1 at the outlet and increase going upstream to the inlet. The location of points on a circular cross section can be referenced like hours on a clock. The clock should be oriented looking upstream. On structural plate corrugated metal culverts points can be referenced to bolted circumferential and longitudinal seams.

The types of defects to look for when inspecting the culvert barrel will depend upon the type of culvert being inspected. Culvert barrel defects are described in detail in the Structural Components Inspection Guide found in chapter 5 of this manual. In general, corrugated metal culvert barrels should be inspected for cross-sectional-shape and barrel defects such as joint defects, seam defects, durability, and localized construction damage. Concrete culvert barrels should be inspected primarily for barrel defects such as misalignment, joint defects, cracking, spalling, and durability.

4-4.8 Summary.

A good inspection program requires procedures for

a. planning, scheduling, and conducting field inspections;

b. collecting and reporting the findings of the field inspection;

c. updating the information to provide accurate and complete records; and

d. recommending corrective actions.

CHAPTER 5

CULVERT COMPONENTS INSPECTION GUIDE

Chapters 1 to 4 have covered the terminology and basic principles of culvert design and construction, the tools and equipment to be used, and the safety precautions that must be taken during culvert inspections. Planning and reporting requirements needed for culvert inspections have also been discussed.

The primary objective of this chapter is to serve as a guide that will enable the culvert inspector to detect and identify common types of culvert distress or deficiencies, and recognize the severity and significance of defects found. The chapter concentrates on the most common types of culverts, including corrugated metal pipe culverts, corrugated metal long-span culverts, precast concrete culverts, and cast-in-place concrete culverts. Additional information is also provided on the approach roadways, the waterways, and the end treatments.

The following culvert components included in this chapter are covered in the order given:

a. Approach Roadway

b. Waterways

c. End Treatments and Appurtenances

d. Corrugated Metal Culverts

e. Shape Inspection of Corrugated Metal Culvert Barrels

f. Shape Inspection of Corrugated Metal Long-Span Structures

g. Concrete Culverts

h. Precast Concrete Culvert Barrels

i. Cast-in-Place Concrete Culvert Barrels

j. Masonry Culverts

k. Overall Culvert Ratings

Section 1. APPROACHES

5-1.0 General.

Settlement is a common problem with bridge and culvert approaches and is usually due to poorly compacted embankment material. It may result from settlement of the culvert in soft foundation material, displacement of soft material, or piping along the culvert.

Settlement of backfill material and movement of the structure may have serious structural consequences in culverts when it affects the backfill. A stable soil envelope around culverts is necessary to obtain side support that will minimize deflection of flexible culverts and reduce settlement of rigid or flexible culverts.

The inspector should also look for any changes in the approach roadway that might affect the performance of overflow sections. Grade changes or the addition of guardrail or Jersey barrier may increase the hazard to upstream property.

Two items of concern in approaches are the condition (SI&A item 65) of the approach, and an evaluation of how well the approach functions as a part of the highway system (SI&A items 72, 68, and 36).

5-1.1 Inspection of the Approach Roadway Condition

Approach conditions may be inspected visually for sudden dips or sags, cracks, pavement patches, and other indications of settlement. Cracks in pavements will usually be parallel to the culvert barrel. Shoulders and embankments should also be inspected for dips, sags and other depressions, erosion, and slope slippage. Sags can often be detected by sighting along guardrails, as illustrated in exhibit 44. Sighting along the edge of pavement, or along pavement markings can also reveal sags and depressions.

Exhibit 44. A dip in the guardrail or approach roadway may be due to excessive deflection in culvert.

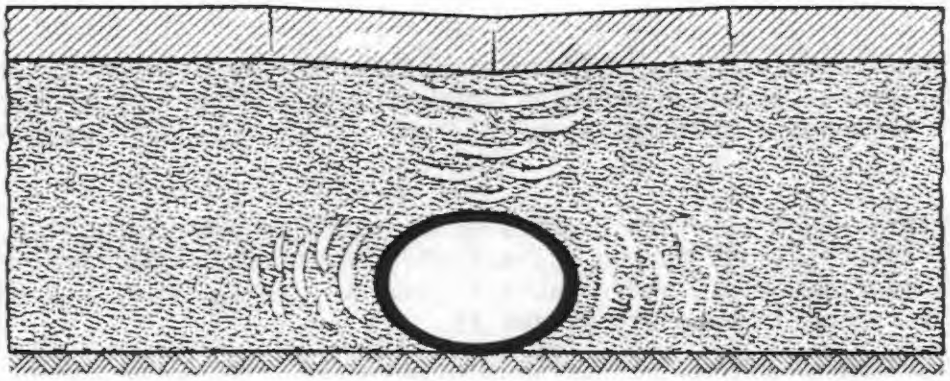
Some defects in approaches may be caused by a number of different factors, some of which may have little or no effect on the culvert. For example, pavement patches may be placed to correct defects in the pavement itself. Similarly, structural problems may exist with little visible effect on the approaches.

The structural significance of approach defects depends upon the other findings of the inspection. Depressions, pavement cracks, and other problems should alert the inspector to the fact that structural problems might exist. The inspector should attempt to determine the cause of approach defects and should note in the inspection report the location and extent of any defects found. Severe dips or sags may present a traffic hazard as well as possible structural problems and should therefore be reported.

In some instances when concrete box culverts are used, the traffic rides directly on the top slab. The top slab then serves as the pavement wearing surface as well as a structural member of the culvert. Cracks and other defects in slabs which support traffic should be evaluated to determine their impact, if any, on the structural capacity of the slab.

The type of defects that are found in the approaches may vary with pavement type, structure type, structure shape, maintenance history, and other factors. These defect types are discussed in the following paragraphs.

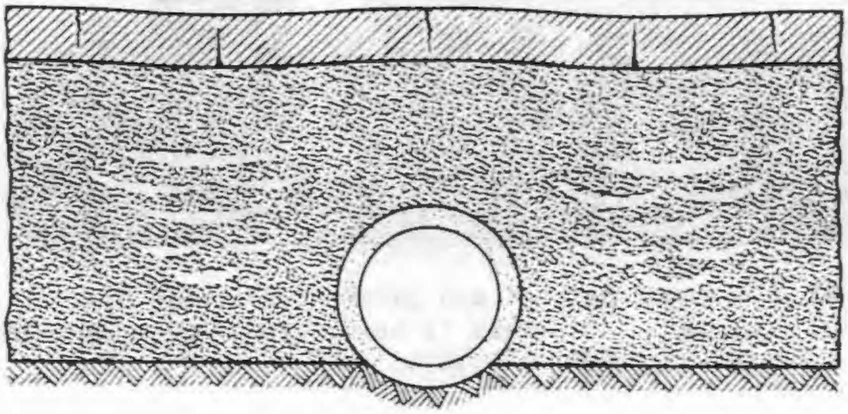
a. Pavement Type--Rigid pavements (concrete) bridge over minor subsurface voids while flexible pavements (asphalt) have little bridging capability. Settlement of material beneath the pavement can lead to cracking in rigid and irregular settlement in flexible pavements as illustrated in exhibit 45.



Source: Effects of Loads on Storm Drains and Culverts, U.S. Army C.O.E.

Exhibit 45. Pavement failure due to inadequate compaction or material quality adjacent to flexible pipe.

b. Structure Type--Flexible culverts will deflect if adequate lateral support is not provided by the surrounding soil. This may result in a loss of support for the approach pavement and usually results in settlement over the culvert. Inadequate compaction of backfill for rigid culverts usually results in settlement beside the culvert as shown in exhibit 46.



Source: Effects of Loads on Storm Drains and Culverts, U.S. Army C.O.E.

Exhibit 46. Pavement failure due to inadequate compaction or material quality adjacent to rigid pipe.

c. Structure Shape--Good performance of flexible culverts is related to symmetry close to the design shape. Culverts may deflect downward and displace material laterally. This may result in roadway settlement. For circular culverts such settlement is mainly directly over the culvert. Vertical ellipses, pear-shaped culverts, and arches may tend to peak or push up in the center resulting in settlement and loss of pavement support beside the culvert.

d. Pavement Maintenance History--Pavement patches may be an indication that progressive settlement, or other problems, have occurred or are occurring, particularly if it appears that the area over the culvert has been patched repeatedly.

e. Other Factors--Several other factors in addition to embankment settlement can cause distress in the culvert and the approach roadway, such as saturated embankment material, poor backfill quality, piping, erosion, and slope failures as shown in exhibits 47 and 48.

Exhibit 47. Pavement patches and pavement distress beside culvert. Distress is being caused by embankment spilling over wingwall.

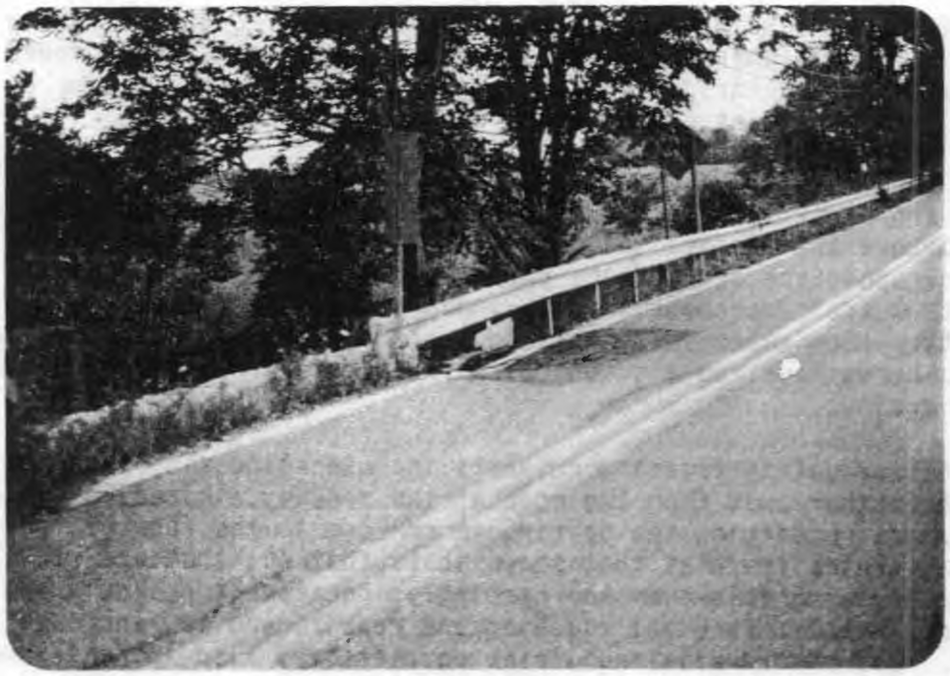


Exhibit 48. Pavement patches and distress same location as exhibit 47.

5-1.2 Functional Evaluation of the Approach Roadway.

The functional evaluation of the approach roadway is an evaluation of how the culvert performs in terms of traffic safety. The evaluation consists of collecting geometric data such as roadway width, evaluation of the roadway alignment and traffic safety features. The signing should also be checked as part of the approach roadway evaluation. The presence or absence of advance warning signs, weight restrictions, or narrow bridge signs should be noted. The SI&A inspection includes several inventory items pertaining to measured clearances and roadway widths. It also includes several items relating to the roadway which require evaluation by the inspector. These are item 72, Roadway Alignment; item 68, Deck Geometry; and item 36, Traffic Safety Features. Items 72 and 68 are rated using the 0 to 9 numerical scale described in the Coding Guide. Item 36 is rated with a 0, 1, or N.

SI&A item 72 is a functional evaluation of the approach roadway alignment. Alignment of the approach roadway is usually not an issue with culverts. However, one method of checking alignment is to determine the sight distance in each direction from the culvert and then compare the actual sight distance to the sight distance required by current standards.

The geometry of a roadway as it passes over a structure is an important element in the functional evaluation of the approach. SI&A item 68, Deck Geometry, should be used to evaluate the roadway geometry over the culvert. Ratings are typically based on the difference in the width of the roadway, surface over the structure, and the width of the traveled surface of roadway approaching the structure. For example, if the width of the roadway on or over the structure is the same or greater than the approach roadway traveled surface, a rating of 4 or higher may be assigned. The rating value assigned should also reflect other factors which affect the flow of traffic. Some of the factors which should be considered are described in the following paragraphs.

Culvert ends that are close to the edge of the roadway may constitute a significant hazard to traffic. Headwalls that protrude above the surface of the roadway or above the face of the embankment may be a fixed object hazard. Culvert openings that are close to the roadway may present a severe drop-off hazard, or have steep embankment that could roll a vehicle over. Depressions around inlets or outlets may also act as a fixed object hazard which a vehicle could impact against.

Common methods for safety treating culverts include relocating the ends so that they are farther away from the edge of the roadway, installing guardrails or other barriers, modifying the opening to conform to the face of the slope, and installing grates (such as that shown in exhibit 49) that are structurally adequate to carry a vehicle over the opening. The inspector should be aware that grates may require frequent cleaning and repair, and may increase upstream flooding. Guardrails and Jersey barriers may also increase upstream hazards.

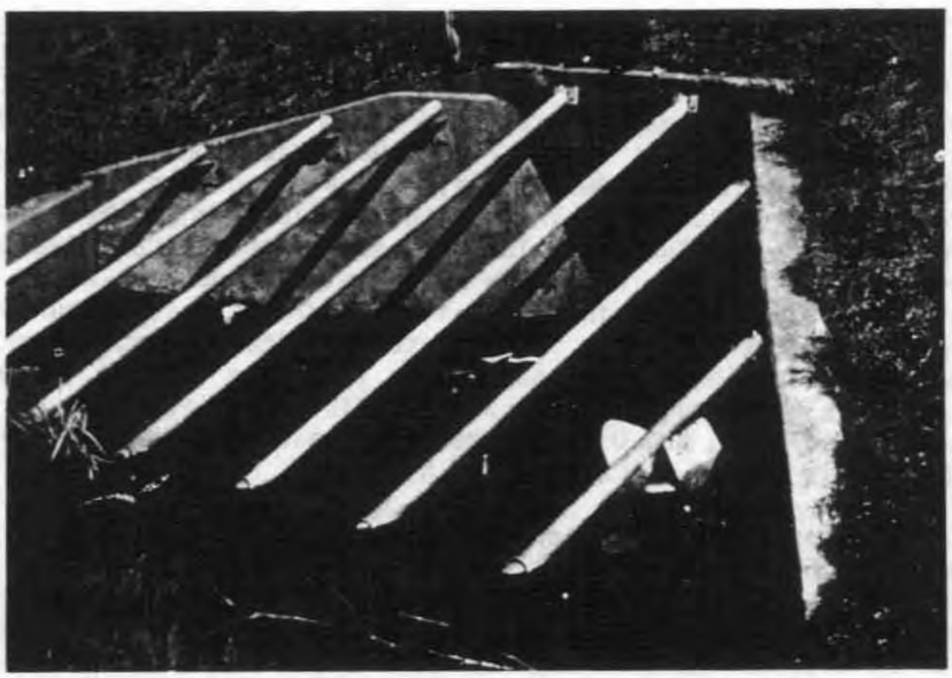


Exhibit 49. Example of vehicle safe grate on safety treated headwall.

SI&A item 36, Traffic Safety Features, is actually an inventory item that deals with the rail system. However, item 36 does involve a comparison of the existing rail system with current standards. The ends, transitions, and rails are rated as either meeting current standards or not meeting current standards. A rail system may also be rated as not applicable if rails are not in place and are not required.

Section 2. END TREATMENT AND APPURTENANT STRUCTURES

5-2.0 General.

Several types of end treatments are commonly used at culvert inlets and outlets ranging from no treatment to a constructed in place end structure. End structures are used to reduce erosion, retain fill material, inhibit seepage, improve hydraulic efficiency when the culvert operates under inlet control, provide structural stability to the culvert ends, and improve the appearence of the culvert. Common end treatments include:

a. Projecting--This type of end treatment has no end structure attached to the ends of the culvert barrel. The barrel simply extends beyond the face of the embankment, as shown in exhibit 50.

Exhibit 50. Projecting end treatment on corrugated metal pipe culvert.

b. Mitered--A mitered end treatment is a culvert end that has been cut to match the embankment slope. Slope paving, as shown in exhibit 51, is generally used with mitered ends particularly with corrugated metal pipe culverts. Some agencies refer to this treatment as a beveled end.

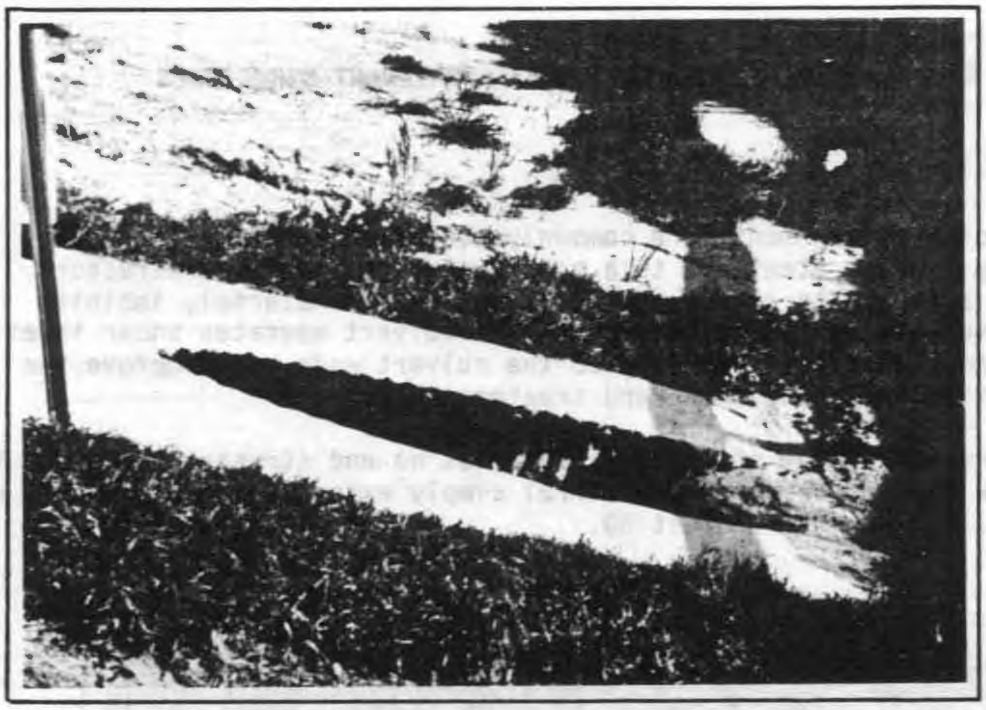


Exhibit 51. Slope paving used to protect mitered end.

c. Skewed--Culverts which are not perpendicular to the centerline of the road are referred to as skewed. If the ends are cut to be parallel to the roadway it may be referred to as a skewed end treatment.

d. Pipe End Sections--This type of end section consists of prefabricated metal or precast concrete pipe sections that may be placed on the ends of the culvert barrel. Pipe end sections are generally used on relatively small culverts.

e. Headwalls--Headwalls and wingwalls may be used to retain the fill, resist erosion, improve hydraulic characteristics, resist uplift, and resist horizontal forces that tend to separate sections of precast culvert pipe. Headwalls are usually cast-in-place concrete but may also be constructed of timber, masonry, or other materials including precast concrete. Metal headwalls are fairly common on metal box culvert shapes.

Appurtenant structures are used with end treatments to improve drainage or reduce erosion. Typical items are listed below and shown in exhibit 52.

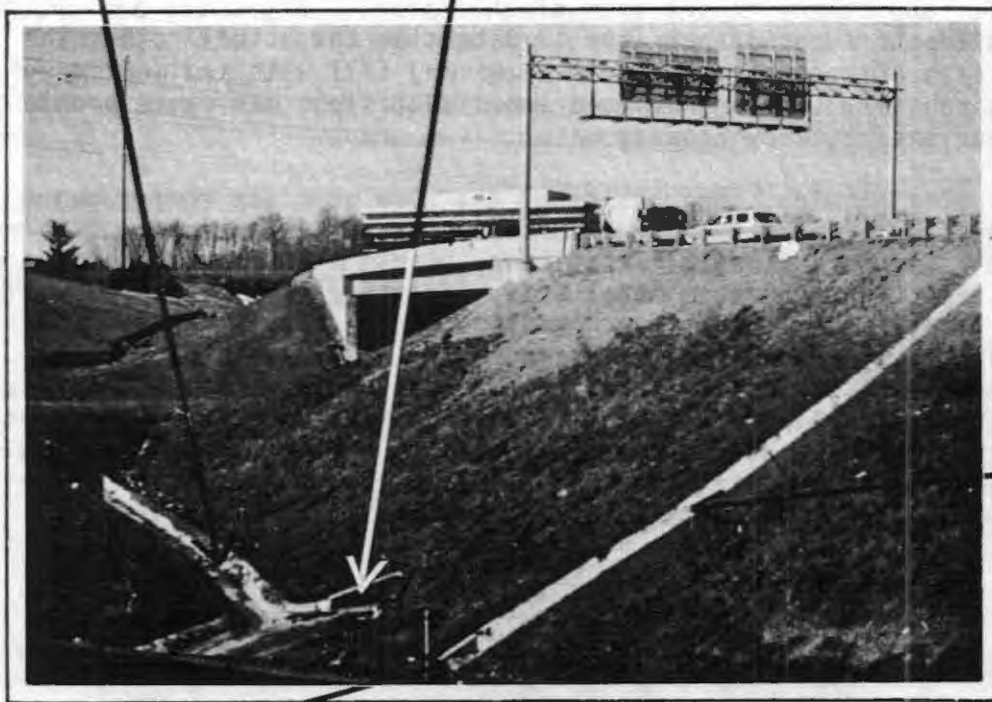


Exhibit 52. Culvert appurtenant structures.

a. Flumes and side ditches which may be used to direct roadside drainage to the stream channel.

b. Aprons are used to reduce erosion at the inlets and outlets of culverts and improve hydraulic efficiency. Aprons may consist of a concrete slab, grouted or ungrouted rip rap, or other material. Most aprons include a cutoff wall to protect against undermining.

c. Energy dissipators are used when outlet velocities are likely to cause stream bed erosion downstream from the culvert. Energy dissipators may consist of stilling basins, rip rap channels, or other devices.

5-2.1 What to Look for During Inspection.

Culvert ends and appurtenant structures perform a variety of functions and therefore may need to be inspected in terms of their structural, hydraulic, and traffic safety characteristics. Structural and hydraulic characteristics may differ considerably with different types of end treatments. What to look for during inspection depends upon the type of end treatment being inspected.

a. Projecting--When inspecting culverts with projecting ends, the inspector should note the extent and location of any erosion or undercutting around the ends of the culvert barrel, deterioration of the fill slope, accumulations of drift and debris, and damage to the ends of the barrel. A probing bar should be used to locate scoured areas and to determine the actual rather than apparent depth of scour, since scour holes may fill with sediment or debris as high flows subside. The unprotected embankment slope may cause problems if it is eroded or saturated by flowing water.

Piping or water flowing along the outside of the pipe can remove supporting material, as shown in exhibit 53. Erosion can cause end-section displacement and drop off in rigid pipe culverts, particularly at the outlet ends, as shown in exhibit 54. In corrugated metal pipe culverts, the pipe may be subject to buoyant forces if the material surrounding the culvert is saturated or eroded. Examples of buoyant damage are illustrated in exhibits 55 and 56. Damage due to buoyant forces usually occurs at the inlet end but may occur at submerged outlets. The capacity of culverts may be reduced by accumulations of drift and debris at the inlet end or by slope failure. Inlet ends may also be damaged by impact from floating debris, and either end can be damaged by mowing equipment and other maintenance vehicles, as shown in exhibit 57.

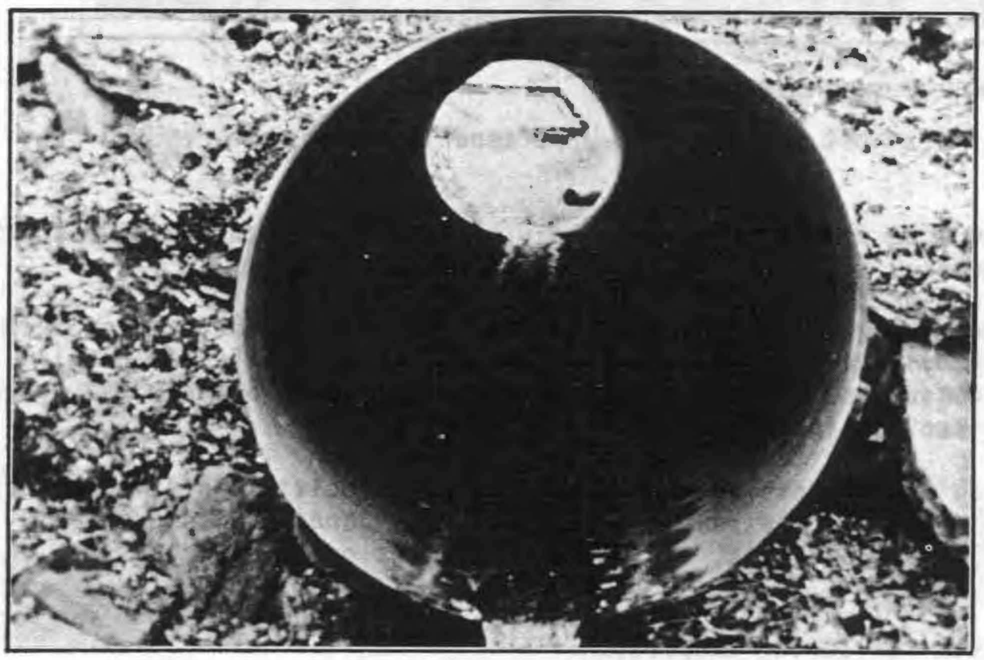


Exhibit 53. Voids around outside of pipe indicate possible piping. Shape distortion has occurred.

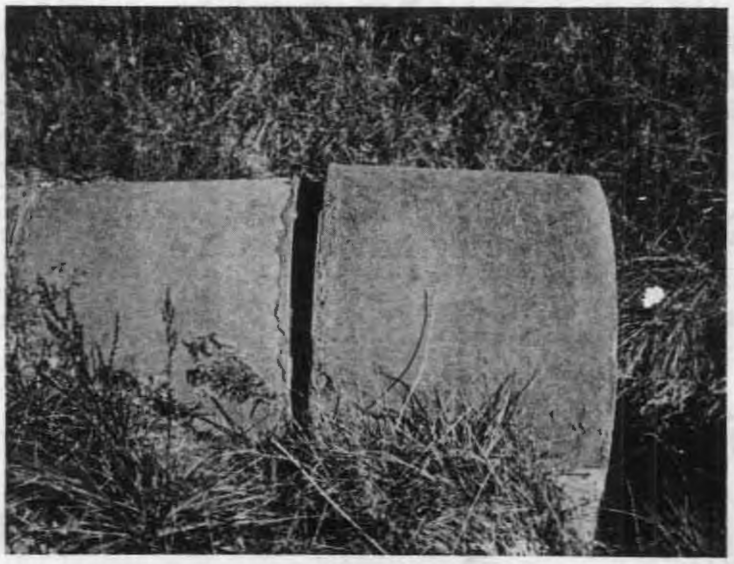
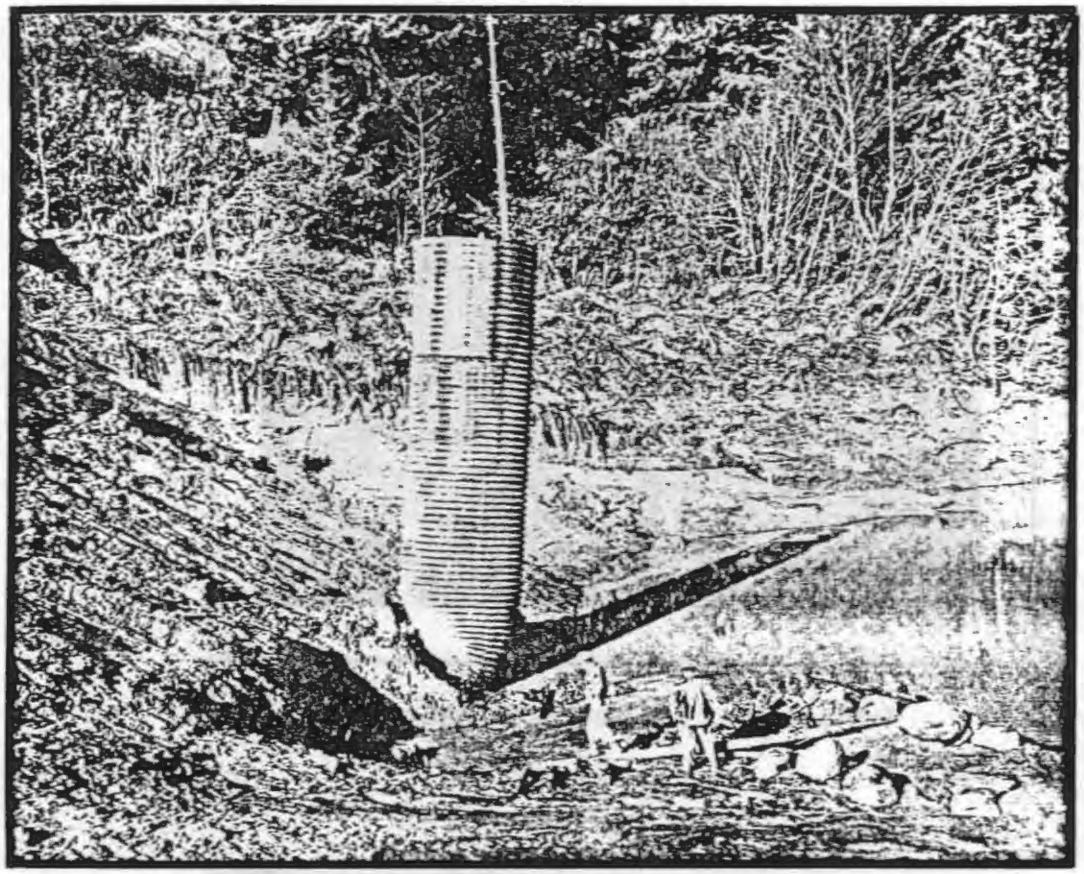


Exhibit 54. End section drop off.

Exhibit 55. Mitered end of culvert turned up due to bouyant forces.



Source: NCHRP Report 286

Exhibit 56. Damage due to bouyant forces.

Exhibit 57. Impact damage to end of concrete pipe.

b. Mitered--Culverts with mitered end treatments and those with pipe end sections should be inspected for the same types of problems as culverts with projecting ends. In addition, metal pipe culverts with either a mitered end or skewed end should be inspected for deformation. Cutting the ends to form a mitered or skewed treatment reduces the structural integrity of the ends of a corrugated metal culvert. The cut ends cannot act as a ring in compression but act essentially as cantilevered retaining walls. If there is no fill slope stabilization or reinforcement of the cut ends, deformation may occur.

While a retaining wall type failure of the cut end may not seriously affect the structural integrity of the culvert barrel it could cause serious hydraulic problems. As previously mentioned, hydraulic forces can destroy or turn up an unstable or distressed pipe end damming the culvert. Damaging ponding or washing out of the fill may result. It is therefore important to check cut ends of culverts for signs of distress including deformation, erosion of the fill slope, and undercutting as shown in exhibit 58. Partial headwalls, cutoff walls, slope paving, anchored tie-backs, and riprap are frequently used to stabilize cut ends. These devices should be inspected for undermining and to insure that pipe ends are firmly anchored.

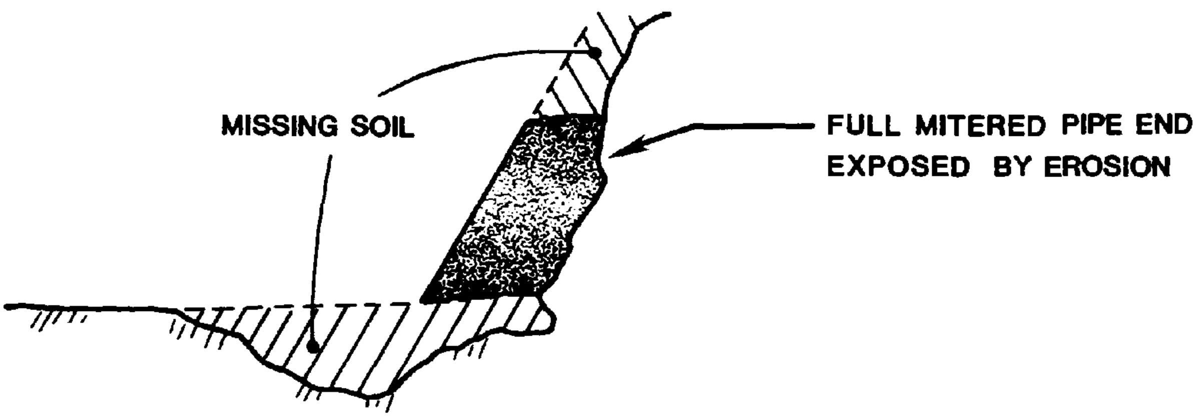


Exhibit 58. Erosion around mitered end.

c. Headwalls and Wingwalls--Headwalls and wingwalls should be inspected for any signs of undermining and settlement such as cracking, tipping, or separation of the culvert barrel from the headwall. Settlement places additional stresses on the ends of the culvert and may cause blockage or end failure. Damaging ponding or washing out of the fill could result. Separations between the barrel and the headwall that expose fill material can be particularly serious and should be reported for special attention. Such separations permit the loss of the supporting soil which could lead to failure anywhere along the length of the culvert. Additionally headwalls should be high enough and long enough to protect the embankment from erosive flows and to keep the embankment from spilling over and blocking the flow. Metal headwall and wingwall inspections should include checking for voids behind the walls which may indicate a loss of backfill, toe out of the base which may indicate scour in front of the wall, and outward movement of the top which may indicate damage to anchor rods.

d. Aprons--Aprons should be checked for signs of undermining settlement or movement. Dry stone or ungrouted rip rap should be inspected for displaced or moving stones. A scour hole with a downstream mound will often form in riprap aprons and should generally not be disturbed by maintenance activities. Additional rock may be needed if the scour has penetrated through the riprap. Wire enclosed riprap should be checked for displaced baskets, partially full baskets, and wire deterioration. Concrete slabs should be checked for undermining and settlement. Undermining is checked by probing along the edge of the apron. Settlement can be detected by checking for cracks and signs of movement at the joint with the headwall. The joints between concrete aprons and headwalls should also be checked to insure that they are watertight.

Section 3. WATERWAYS

5-3.0 General.

The primary function of most culverts is to carry surface water or traffic from one side of a roadway embankment to the other side. The hydraulic design of culverts usually involves the determination of the most economical size and shape of culvert necessary to carry the design discharge without exceeding the headwater depth allowable. It is essential that the culvert be able to handle the design discharge. If the culvert is blocked with debris or the stream changes course near the ends of the culvert, the culvert may be inadequate to handle design flows. This may result in excessive ponding, flooding of nearby properties, and washouts of the roadway and embankment. In addition changes in upstream land use such as clearing, deforestation, and real estate development may change the peak flow rates and stream stability. It is therefore important to inspect the condition of the stream channel, SI&A item 61, and evaluate the ability of the culvert to handle peak flows, SI&A item 71.

5-3.1 Stream Channel--What to Look for During Inspection.

The stream channel should be inspected to determine whether conditions exist that would cause damage to the culvert or surrounding properties. Factors to be checked include culvert location (horizontal and vertical alignment), scour, and accumulation of sediment and debris. These factors are closely related to each other. Poor culvert location can result in reduced hydraulic efficiency, increased erosion and sedimentation of the stream channel, and increased damage to the embankment and surrounding properties. A brief discussion of each of these factors is provided. Exhibit 59 presents guidelines for rating SI&A item 61.

RATING GUIDELINES FOR SI&A ITEM 61 - CHANNEL AND CHANNEL PROTECTION			
RATING	**CONDITION**	**RATING**	**CONDITION**
9	• Alignment: good • Scour: no indication of bed scour or bank erosion • Obstructions: no obstructions	4	• Alignment: alignment causing embankment erosion and undercutting of structure • Scour: protection required due to bed scour or bank erosion • Obstruction: partial blockage of channel or culvert
8	• Alignment: alignment adequate • Scour: no indication of bed scour or bank erosion • Obstruction: no obstruction	3	• Alignment: scour due to alignment threatening structure or approach embankment • Scour: the structure has been displaced or settled due to bank erosion or scour • Obstruction: mass drift accumulation has severely restricted channel or culvert opening
7	• Alignment: alignment fair • Scour: mild bank erosion or bed scour • Obstruction: minor debris accumulation		
6	• Alignment: alignment not desirable • Scour: moderate bed scour or bank erosion occurring • Obstruction: minor sedimentation and debris	2	• Alignment: structure or approach weakened by scour due to poor alignment • Scour: structure or roadway weakened by bank erosion or bed scour, danger of collapse with next flood • Obstruction: culvert blocked by mass drift accumulation
5	• Alignment: channel alignment beginning to change • Scour: significant bed scour or bank erosion requiring investigation to determine need and nature of corrective measures • Obstruction: waterway moderately restricted by trees, shrubs, or sedimentation	1	• Alignment: channel directed at embankment causing severe scour of approach embankment • Scour: structure or approach weakened, danger of immediate collapse • Roadway: closed to traffic
		0	• Structure: washed out by flood action • Roadway: closed to traffic

NOTES: 1. See Coding Guide for description of Rating Scale.

2. As a starting point, select the lowest rating which matches actual conditions.

Exhibit 59. Condition rating guidelines.

a. Horizontal Alignment--The inspector should check the condition of the stream banks and any bank protection at both ends of the culvert. He should also check for erosion and indications of changes in the direction of the stream channel. Sketches and photographs should be used to document the condition and alignment at the time of inspection. Abrupt stream alignment changes retard flow and may require a larger culvert; they cause increased erosion along the outside of the curve, damage to the culvert, and increased sedimentation along the inside of the curve. Where sharp channel curves exist at either the entrance or exit of a culvert, the inspector should check for sedimentation and erosion.

b. Vertical Alignment--Vertical alignment problems are usually indicated by scour or accumulation of sediment. Culverts on grades that differ significantly from the natural gradient may present problems. Culverts on flat grades may have problems with sediment build up at the entrance or within the barrel. Culverts on moderate and steep grades generally have higher flow velocities than the natural stream and may have problems with outlet scour. Scour and sediment problems may also occur if the culvert barrel is higher or lower than the stream bed.

c. Scour--Erosion generally refers to loss of bank material and a lateral movement of the channel. Scour is more related to a lowering of the stream bed due to the removal and transporting of stream bed material by flowing water. Scour may be classified into two types: local scour and general scour.

(1) Local scour is located at and usually caused by a specific flow obstruction or object which causes a constriction of the flow. Local scour occurs primarily at the culvert outlet.

(2) General scour extends farther along the stream and is not localized around a particular obstruction. General scour can involve a gradual, fairly uniform degradation or lowering of the stream channel. It can also result in abrupt drops in the channel that move upstream during peak flows. This type of scour is referred to as head cutting. Head cutting may be a serious problem if it is occurring in the channel downstream from the culvert, since it may threaten the culvert as it moves upstream. Head cutting may also occur in the stream channel immediately upstream from depressed inlets. Where upstream head cutting is usually not as serious a problem for the culvert, it can affect upstream structures and properties.

The upstream channel should be checked for scour that may undermine the culvert or erode the embankment as shown in exhibit 60. Scour that is undermining trees or producing sediment that could block or reduce the culvert opening should also be noted. The stream channel below the culvert should be checked for local scour caused by the culvert's discharge and for general scour that could eventually threaten the culvert as shown in exhibit 61.

Exhibit 60. Scour at outlet of masonry culvert.

Exhibit 61. Embankment erosion.

d. Accumulation of Sediment and Debris--Deposits of debris or sediment that could block the culvert or cause local scour in the stream channel should be noted. Accumulations of debris sediment in the stream may cause scour of the streambanks and roadway embankment, or could cause changes in the channel alignment. Debris and sediment accumulations at the culvert inlets or within the culvert barrel reduce the culvert's capacity and may result in excessive ponding. It also increases the chances for damage due to buoyant forces. Downstream obstructions which cause water to pond at the culvert's outlet may also reduce the culvert's capacity. Debris collectors are used in some culverts so that the opening is not blocked by floating materials.

5-3.2 Waterway Adequacy--What to Look for During Inspection.

The preceding paragraphs dealt with evaluating the condition of the stream channel and identifying conditions that could cause damage to the culvert or reduce the hydraulic efficiency of the culvert. A closely related condition that must be evaluated is the waterway adequacy or ability of the culvert to handle peak flows including high water marks, changes in the watershed, and changes in the stream channel which might affect the hydraulic performance. Guidelines for rating SI&A item 71, Waterway Adequacy, are presented in exhibit 62.

a. High Water Marks--The high water elevation will vary with each flood but should still be checked to evaluate waterway adequacy. Ideally, culverts should be checked during or immediately after peak flows to determine whether water is being ponded to excessive depths, flooding adjoining properties, or overflowing the roadway, as shown in exhibit 63. High water marks are needed to define the upstream pond elevation and the downstream tailwater elevation. Several high water marks should be obtained, if possible, to insure consistency. High water marks in the culvert barrel, in the drain down area near the inlet, or near turbulent areas at the outlet are generally misleading. An inspection can also determine high water levels for peak flows by looking for debris caught on fences, lodged in trees, or deposited on the embankment. Information may also be obtained by interviewing area residents. Indications of excessive ponding, flooding, or overtopping of the roadway should be investigated to determine the cause. If the cause is apparent, such as a blocked inlet, it should be reported for scheduling of appropriate maintenance. If the cause is not apparent, the culvert should be reported for evaluation by a hydraulic specialist.

RATING GUIDELINES FOR SI&A ITEM 71 - WATERWAY ADEQUACY

RATING	CONDITION
9	• Opening and Alignment: good • Scour: no indication of bed scour or bank erosion
8	• Opening: waterway opening is adequate • Alignment: stream aligned with culvert centerline • Scour: no indication of bed scour or bank erosion
7	• Opening: opening is adequate • Alignment: stream at slight angle to culvert centerline • Scour: mild bank erosion or bed scour
6	• Opening: occasional drift or sediment removal required • Alignment: stream enters or exits at moderate angle • Scour: moderate bed scour or bed erosion occurring
5	• Opening: evidence of extensive ponding due to inadequate size opening, partial blockage or poor alignment • Alignment: alignment causing ponding or erosion • Scour: significant bed scour or bank erosion requiring investigation to determine need and nature of corrective measures
4	• Opening: marginally adequate, allowable headwater, depths may be exceeded during peak flows due to inadequate size opening, partial blockage or poor alignment • Alignment: misalignment causing erosion of embankment, or undercutting structure • Scour: protection required due to bed scour or bank erosion
3	• Opening: evidence that roadway is topped during high flows, or that ponding area is excessive due to inadequate size opening, partial blockage or poor alignment • Alignment: stream approaches or exits on small angle, channel is in the process of changing • Scour: the structure has displaced or settled due to bank erosion or scour
2	• Opening: road/or adjacent properties frequently flooded due to inadequate size opening, partial blockage or poor alignment • Alignment: channel directed at embankment, collapse possible with next storm • Scour: structure or roadway weakened by bank erosion or bed scour, danger of collapse with next flood
1	• Opening: flood action has closed structure • Alignment: channel directed at embankment with threat of immediate collapse • Scour: structure weakened with threat of collapse • Roadway: closed to traffic
0	• Opening: structure collapsed or washed out • Roadway: closed to traffic

NOTES: 1. See Coding Guide for description of Rating Scale.
2. As a starting point, select the lowest rating which matches actual conditions.

Exhibit 62. Condition rating guidelines.

Exhibit 63. Culvert failure due to overtopping.

b. Drainage Area - The inspector should be aware that changes in the drainage may have an effect on the discharge that culverts must handle. Replacement of an upstream culvert with a larger structure may eliminate upstream ponding, causing more water to reach the culvert sooner. Land clearing construction, channel improvements, or removal of upstream dams or sediment basins may also affect discharge rates. Similarly, changes in land use may increase or decrease the amount of rainfall that infiltrates the ground and the amount that runs off. The inspector should note in the inspection report any apparent changes that are observed and be aware that changes a considerable distance upstream may affect the performance of downstream structures. Obstructions downstream from a culvert that back water up to the culvert may also affect the performance of the culvert.

c. Scour--As previously discussed, scour which changes the stream alignment at the ends of the culvert can reduce the hydraulic efficiency.

d. Sedimentation and Debris--Accumulation of debris and sediment at the inlet or within the culvert barrel reduces both the size of the opening and the culvert's capability to handle peak flows. Severe drift and sediment accumulations are illustrated in exhibits 64 and 65. However, culverts are occasionally designed with fill in the bottom to create a more natural stream bed for fish.

Exhibit 64. Culvert almost completely blocked by sediment accumulation.

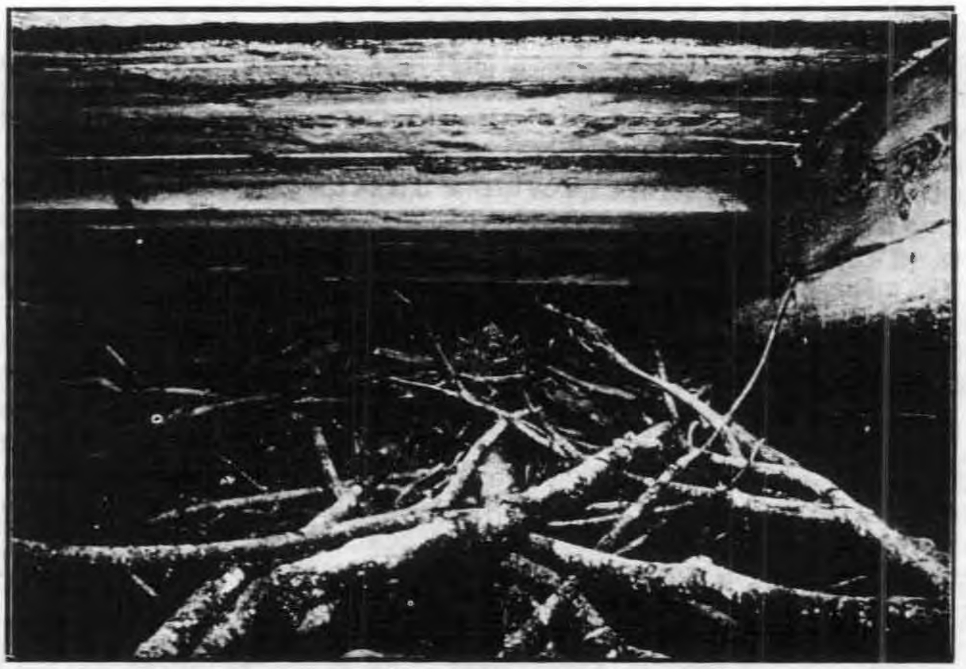


Exhibit 65. Drift and debris inside timber box culvert.

Section 4. CORRUGATED METAL CULVERTS

5-4.0 General.

Corrugated aluminum and corrugated steel culverts are classified as flexible structures because they respond to and depend upon the soil backfill to provide structural stability and support to the culvert. The flexible corrugated metal acts essentially as a liner. The liner acts mainly in compression and can carry large ring compression thrust, but very little bending or moment force. (Rib reinforced box culverts are exceptions.) Inspection of the culvert determines whether the soil envelope provides adequate structural stability for the culvert and verifies that the "liner" is capable of carrying the compressive forces and protecting the soil backfill from water flowing through the culvert. Verification of the stability of the soil envelope is accomplished by checking culvert shape. Verification of the integrity of the "liner" is accomplished by checking for pipe and plate culvert barrel defects.

This section contains discussions on inspecting corrugated metal structures for shape and barrel defects. Because shape inspection requirements do vary somewhat for different shapes, separate sections with detailed guidelines are provided for corrugated metal pipe culvert shapes and long-span culvert shapes. Section 5 of this chapter addresses corrugated metal pipe culverts, and section 6 covers long-span corrugated metal culverts.

5-4.1 Shape Inspections

The single most important feature to observe and measure when inspecting corrugated metal culverts is the cross-sectional shape of the culvert barrel. The corrugated metal culvert barrel depends on the backfill or embankment to maintain its proper shape and stability. When the backfill does not provide the required support, the culvert will deflect, settle, or distort. Shape changes in the culvert therefore provide a direct indication of the adequacy and stability of the supporting soil envelope. By periodic observation and measurement of the culvert's shape, it is possible to verify the adequacy of the backfill. The design or theoretical cross-section of the culvert should be the standard against which field measurements and visual observations are compared. If the design cross section is unknown, a comparison can be made between the unloaded culvert ends and the loaded sections beneath the roadway or deep fills. This can often provide an indication of structure deflection or settlement. Symmetrical shape and uniform curvature around the perimeter are generally the critical factors. If the curvature around the structure becomes too flat, and/or the soil continues to yield under load, the culvert wall may not be able to carry the ring thrust without either buckling inward or deflecting excessively to the point of reverse curvature. Either of these events leads to partial or total failure.

As explained in chapter 3, an arc of a circular pipe or other shape structure will be stable and perform as long as the soil pressure on the outside of the pipe is resisted by the compression force in the pipe at each end of the arc.

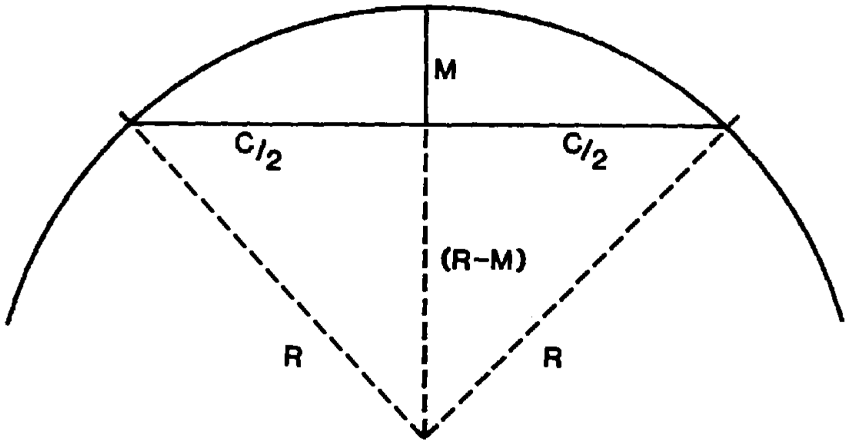
Corrugated metal pipes can change shape safely within reasonable limits as long as there is adequate exterior soil pressure to balance the ring compression. Therefore, size and shape measurements taken at any one time do not provide conclusive data on backfill instability even when there is significant deviation from the design shape. Current backfill stability cannot be reliably determined unless changes in shape are measured over time. It is therefore necessary to identify current or recent shape changes to reliably check backfill stability. If there is instability of the backfill, the pipe will continue to change shape.

In general, the inspection process for checking shape will include visual observations for symmetrical shape and uniform curvature as well as measurements of important dimensions. The specific measurements to be obtained depend upon factors such as the size, shape, and condition of the structure. If shape changes are observed, more measurements may be necessary. For small structures in good condition, one or two simple measurements may be sufficient, for example, measuring the horizontal diameter on round pipe. For larger structures such as long span culverts, key measurements may be difficult to obtain. Horizontal diameters may be both high and large. The inspection process for long span culverts generally requires that elevations be established for key points on the structure. Although some direct measurements may also be required for long-span structures, elevations are needed to check for settlement and for calculating vertical distances such as the middle ordinate of the top arc. For structures with shallow cover, observations of the culvert with a few live loads passing over are recommended. Discernible movement in the structure may indicate possible instability and a need for more in-depth investigation.

The number of measurement locations depends upon the size and condition of the structure. Long-span culverts should normally be measured at the end and at 25 foot intervals. Measurements may be required at more frequent intervals if significant shape changes are observed. The smaller pipe culverts can usually be measured at longer intervals than long-span culverts.

It is extremely important to tie down exact locations of measurement points. Unless the same point is checked on each inspection, changes cannot be accurately monitored. The inspection report must, therefore, include precise descriptions of reference point locations. It is safest to use the joints, seams, and plates as the reference grid for measurement points. Exact point locations can then be easily described in the report as well as physically marked on the structures. This guards against loss of paint or scribe marks and makes points easy to find or reestablish. All dimensions in structures should be measured to the inside crest of corrugation. When possible, measurement points on structural plate should be located at the center of a longitudinal seam. However, some measurement points are not on a seam.

When distortion or curve flattening is apparent, the extent of the flattened area, in terms of arc length, length of culvert affected, and the location of the flattened area should be described in the inspection report. The length of the chord across the flattened area and the middle ordinate of the chord should be measured and recorded. The chord and middle ordinate measurements can be used to calculate the curvature of the flattened area using the formula shown in exhibit 66.



C = MEASURED CHORD

M = MEASURED MIDDLE ORDINATE

SOLVE FOR R_A = ACTUAL RADIUS

$$R_A = \frac{4M^2 + C^2}{8M}$$

IF R_A IS > R_D (DESIGN RADIUS) THEN
ACTUAL CURVE IS FLATTER THAN DESIGN

Exhibit 66. Checking curvature by curve and middle ordinate.

5-4.2 Inspecting Barrel Defects.

The structural integrity of corrugated metal culverts and long-span structures is dependent upon their ability to perform in ring compression and their interaction with the surrounding soil envelope. Defects in the culvert barrel itself, which can influence the culvert's structural and hydraulic performance, are discussed in the following paragraphs. Rating guidelines are provided in the sections dealing with specific shapes.

a. Misalignment--The inspector should check the vertical and horizontal alignment of the culvert. The vertical alignment should be checked visually for sags and deflection at joints. Poor vertical alignment may indicate problems with the subgrade beneath the pipe bedding. Sags trap debris and sediment and may impede flow. Since most highway culverts do not have watertight joints, sags which pocket water could saturate the soil beneath and around the culvert, reducing the soil's stability. The horizontal alignment should be checked by sighting along the sides for straightness. Vertical alignment can be checked by sighting along bolt lines. Minor horizontal and vertical misalignment is generally not a significant problem in corrugated metal structures unless it causes shape or joint problems. Occasionally culverts are intentionally installed with a change in gradient.

b. Joint Defects--Field joints are generally only found with factory manufactured pipe. There are ordinarily no joints in structural plate culverts, only seams. (In a few cases, preassembled lengths of structural plate pipe have been coupled or banded together like facto.y pipe.)

Field joints in factory pipe serve to maintain the water conveyance of the culvert from section to section, to keep the pipe sections in alignment, keep the backfill soil from infiltrating, and to help prevent sections from pulling apart. Joint separation may indicate a lack of slope stability as described in section 5-4.2 e., circumferential seams. Key factors to look for in the inspection of joints are indications of backfill infiltration and water exfiltration. Excessive seepage through an open joint can cause soil infiltration or erosion of the surrounding backfill material reducing lateral support. Open joints may be probed with a small rod or flat rule to check for voids. Indications of joint defects include open joints, deflection, seepage at the joints, and surface sinkholes over the culvert as illustrated in exhibits 67 and 68. Any evidence of joint defects should be recorded. Culverts in good condition should have no open joints, those in fair condition may have a few open joints but no evidence of soil infiltration, and those in marginal to poor condition will show evidence of soil infiltration.

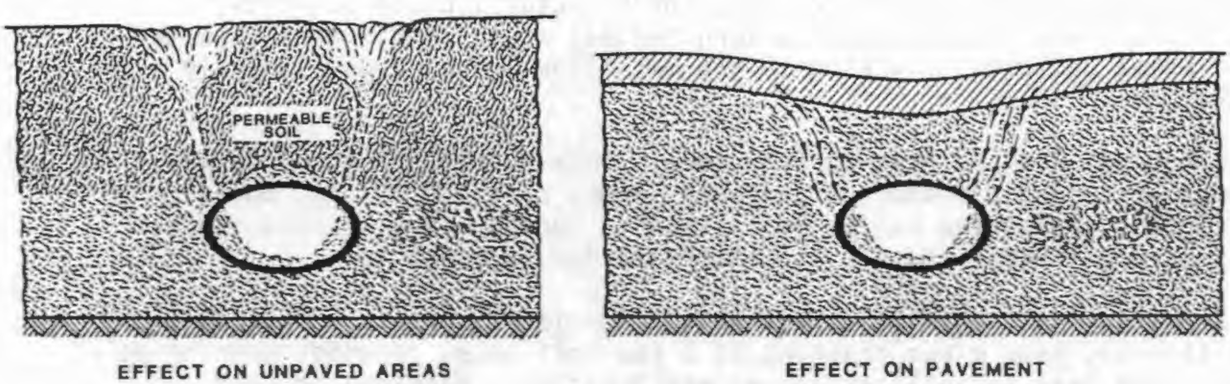


Exhibit 67. Surface indications of infiltration.

Exhibit 68. Surface hole above open joint.

c. Seam Defects in Fabricated Pipe--Pipe seams in helical pipe do not carry a significant amount of the ring compression thrust in the pipe. That is the reason that a lock seam is an acceptable seam. Helical seams should be inspected for cracking and separation. An open seam could result in a loss of backfill into the pipe, or exfiltration of water. Either condition could reduce the stability of the surrounding soil.

In riveted or spot welded pipes, the seams are longitudinal and carry the full ring compression in the pipe. These seams, then, must be sound and capable of handling high compression forces. They should be inspected for the same types of defects as those described in the text for structural plate culverts, section 3-1.4 b. When inspecting the longitudinal seams of bituminous-coated corrugated metal culverts, cracking in the bituminous coating may indicate seam separation.

d. Longitudinal Seam Defects in Structural Plate Culverts - Longitudinal seams should be visually inspected for open seams, cracking at bolt holes, plate distortion around the bolts, bolt tipping, cocked seams, cusped seams, and for significant metal loss in the fasteners due to corrosion.

Culverts in good condition should have only minor joint defects. Those in fair condition may have minor cracking at a few bolt holes or minor opening at seams that could lead to infiltration or exfiltration. Marginal to poor culvert barrel conditions are indicated by significant cracking at bolt holes, or deflection of the structure due to infiltration of backfill through an open seam. Cracks 3 inches long on each side of the bolts indicate very poor to critical conditions.

(1) Loose Fasteners--Seams should be checked for loose or missing fasteners as shown in exhibit 69. For steel structures the longitudinal seams are bolted together with high-strength bolts in two rows; one row in the crests and one row in the valleys of the corrugations. These are bearing type connections and are not dependent on a minimum clamping force of bolt tension to develop interface friction between the plates. Fasteners in steel structural plate may be checked for tightness by tapping lightly with a hammer and checking for movement.

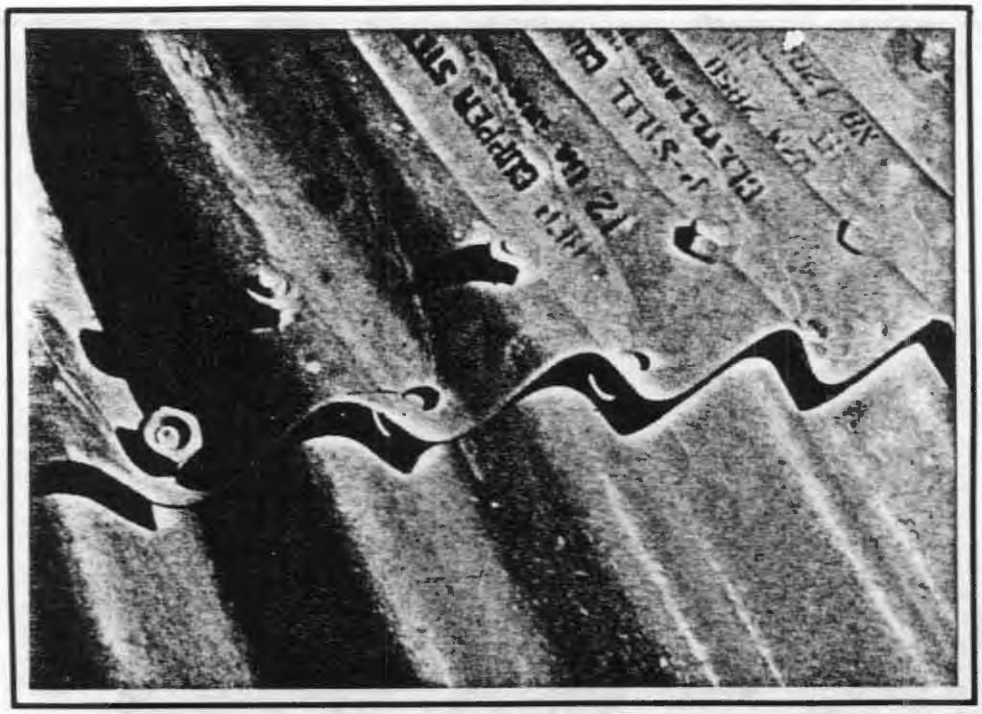


Exhibit 69. Close-up of loose and missing bolts at a cusped seam. Loose fasteners are usually detected by tapping the nuts with a hammer.

For aluminum structural plate the longitudinal seams are bolted together with normal strength bolts in two rows with bolts in the crests and valleys of both rows. These seams function as bearing connections, utilizing bearing of the bolts on the edges of holes and friction between the plates. The seams in aluminum structural plate should be checked with a torque wrench (125 ft-lbs minimum to 150 ft-lbs maximum). If a torque wrench is not available fasteners can be checked for tightness with a hammer as described for steel plates.

(2) Cocked and Cusped Seams--The longitudinal seams of structural plate are the principal difference from factory pipe. The shape and curvature of the structure is affected by the lapped, bolted longitudinal seam. Improper erection or fabrication can result in cocked seams or cusped effects in the structure at the seam, as

illustrated in exhibit 70. Slight cases of these conditions are fairly common and frequently not significant. However, severe cases can result in failure of the seam or structure. When a cusped seam is significant the structure's shape appearance and key dimensions will differ significantly from the design shape and dimensions. The cusp effect should cause the structure to receive very low ratings on the shape inspection if it is a serious problem. A cocked seam can result in loss of backfill and may reduce the ultimate ring compression strength of the seam.

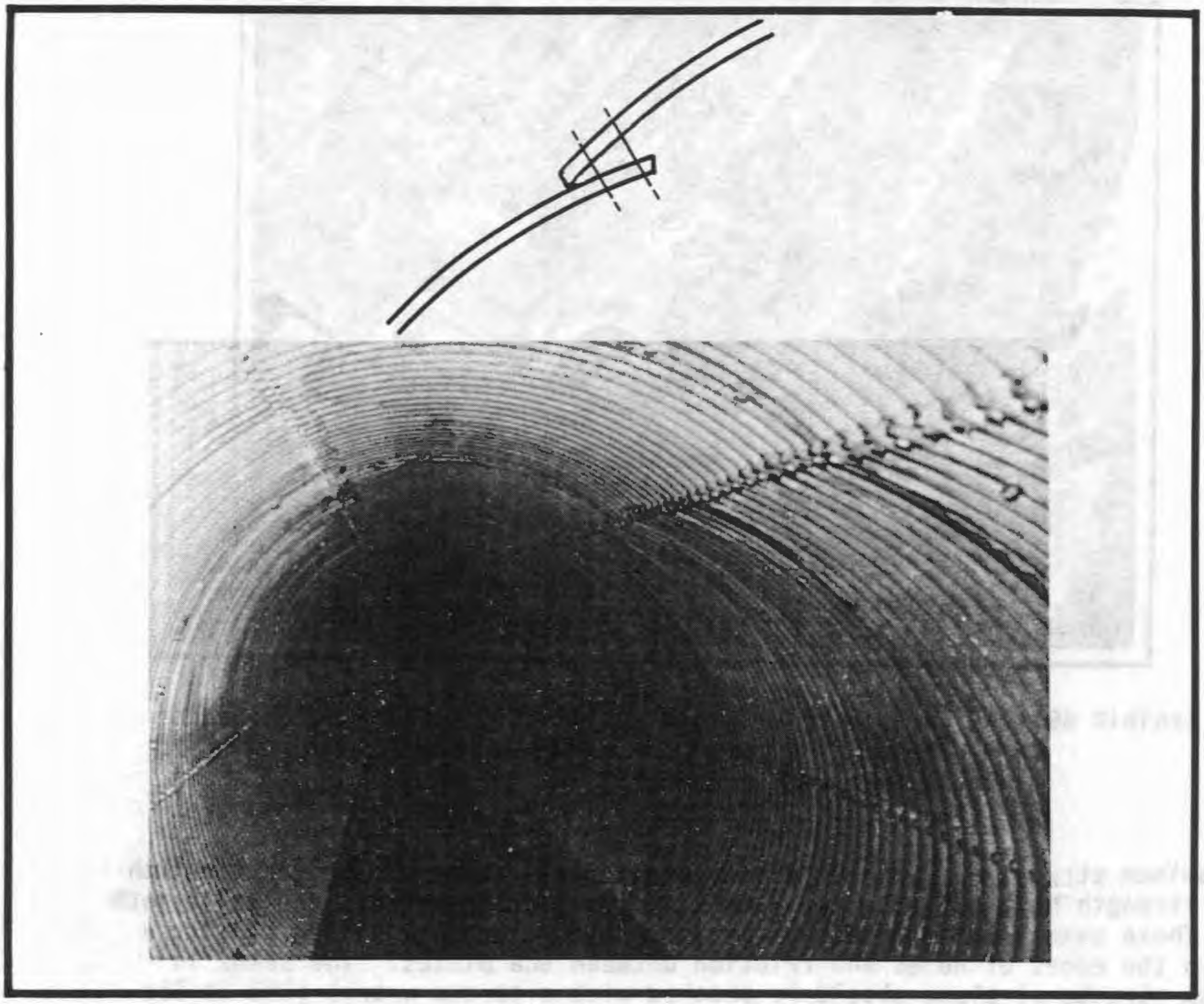


Exhibit 70. Cocked seam with cusp effect.

(3) Seam Cracking--Cracking along the bolt holes of longitudinal seams can be serious if allowed to progress. As cracking progresses, the plate may be completely severed and the ring compression capability of the seam lost. This could result in deformation or possible

failure of the structure. Longitudinal cracks are most serious when accompanied by significant deflection, distortion, and other conditions indicative of backfill or soil problems. Longitudinal cracks are caused by excessive bending strain, usually the result of deflection, exhibit 71. Cracking may occasionally be caused by improper erection practices such as using bolting force to "lay down" a badly cocked seam.

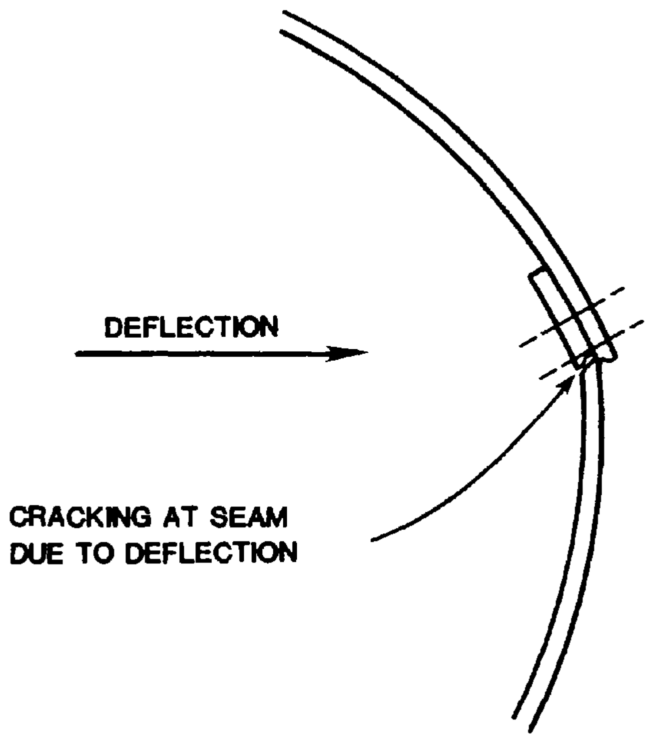


Exhibit 71. Cracking due to deflection.

(4) Bolt Tipping--The bolted seams in structural plate culverts only develop their ultimate strength under compression. Bolt tipping occurs when the plates slip. As the plates begin to slip, the bolts tip, and the bolt holes are plastically elongated by the bolt shank. High compressive stress is required to cause bolt tipping. Structures have rarely been designed with loads high enough to produce a ring compression that will cause bolt tip. However, seams should be examined for bolt tip particularly in structures under higher fills. Excessive compression on a seam could result in plate deformations around the tipped bolts and failure is reached when the bolts are eventually pulled through the plates.

e. Circumferential Seams - The circumferential seams, like joints in factory pipe, do not carry ring compression. They do make the conduit one continuous structure. Distress in these seams is rare and will ordinarily be a result of a severe differential deflection or distortion problem or some other manifestation of soil failure. For example, a steep sloping structure through an embankment may be pulled apart longitudinally if the embankment moves down as shown in exhibit 72. Plates should be installed with the upstream plate overlapping the downstream plate to provide a "shingle" effect in the direction of flow.

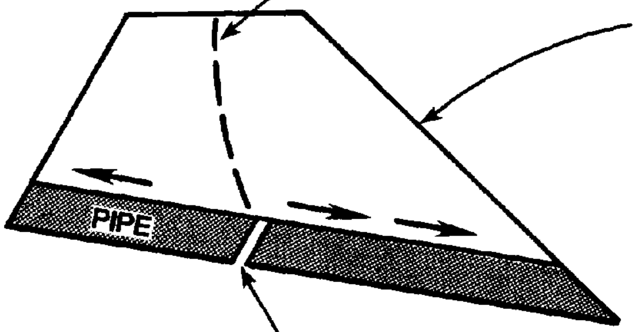


Exhibit 72. Circumferential seam failure due to embankment slippage.

The circumferential seam at one or more locations would be distressed by the movement of the fill. Such distress is important to note during inspections since it would indicate a basic problem of stability in the fill. Circumferential seam distress can also be a result of foundation failure, but in such cases should be clearly evident by the vertical alignment.

f. Dents and Localized Damage--All corrugated metal culverts should be inspected for localized damage. Pipe wall damage such as dents, bulges, creases, cracks, and tears can be serious if the defects are extensive and can impair either the integrity of the barrel in ring compression or permit infiltration of backfill. Small, localized examples are not ordinarily critical. When the deformation type damages are critical, they will usually result in a poorly shaped cross section. The inspector should document the type, extent, and location of all significant wall damage defects. When examining dents in corrugated steel culverts, the opposite side of the plate should be checked, if possible, for cracking or disbonding of the protective coating.

g. Durability (Wall Deterioration)--Durability refers to the ability of a material to resist corrosion and abrasion. Corrosion is the deterioration of metal due to electrochemical or chemical reactions. Abrasion is the wearing away of culvert materials by the erosive action of bedload carried in the stream.

Abrasion is generally most serious in steep or mountainous areas where high flow rates carry sand and rocks that wear away the culvert invert. Abrasion can also accelerate corrosion by wearing away protective coatings.

As discussed in chapter 3, metal culverts are subject to corrosion in certain aggressive environments. For example, steel rapidly corrodes in salt water and in environments with highly acidic (low pH) conditions in the soil and water. Aluminum is fairly resistant to salt water but will corrode rapidly in highly alkaline (high pH) environments, particularly if metals such as iron or copper and their salts are present. The electrical resistivity of soil and water also provide an indication of the likelihood of corrosion. Many agencies have established guidelines in terms of pH and resistivity that are based on local performance. The FHWA has also published guidelines for aluminum and steel culverts including various protective coatings.

Corrosion and abrasion of corrugated metal culverts can be a serious problem with adverse effects on structural performance. Damage due to corrosion and abrasion is the most common cause for culvert replacement. The inspection should include visual observations of metal corrosion and abrasion. As steel corrodes it expands considerably. Relatively shallow corrosion can produce thick deposits of scale. A geologist's pick-hammer can be used to scrape off heavy deposits of rust and scale permitting better observation of the metal. A hammer can also be used to locate unsound areas of exterior corrosion by striking the culvert wall with the pick end of the hammer. When severe corrosion is present, the pick will deform the wall or break through it. Protective coatings should be examined for abrasion damage, tearing, cracking, and removal. The inspector should document the extent and location of surface deterioration problems.

When heavy corrosion is found by observation or sounding, special inspection methods such as pH testing, electrical resistivity measurement, and obtaining cores from the pipe wall are recommended. A routine program for testing pH and electrical resistivity should be considered since it is relatively easy to perform and provides valuable information.

Durability problems are the most common cause for the replacement of pipe culverts. The condition of the metal in corrugated metal culverts and any coatings, if used, should be considered when assigning a rating to the culvert barrel. Suggested rating guidelines for metal culverts with metallic coatings are shown in exhibit 73. Modification of these guidelines may be required when inspecting culverts with non-metallic coatings. Aluminum culvert barrels may be rated as being in good condition if there is superficial corrosion. Steel culverts rated as in good condition may have superficial rust with no pitting. Perforation of the invert as shown in exhibit 74 would indicate poor condition. Complete deterioration of the invert in all or part of the culvert barrel would indicate a critical condition as shown in exhibit 75. Culverts with deteriorated inverts may function as an arch structurally, but are highly susceptible to failure due to erosion of the bedding.

Rating Value	General Description	Corrugated Steel	Corrugated Aluminum
9	New	Near original condition	Near original condition
8	Good	Superficial rust, no pitting	Superficial corrosion slight pitting
7	Generally Good	Moderate rust, slight pitting	Moderate corrosion no attack of core alloy
6	Fair	Fairly heavy rust, moderate pitting, slight thinning	Significant corrosion minor attack of core alloy
5	Generally Fair	Extensive heavy rust, deep pitting, moderate thinning	Significant corrosion moderate attack of core alloy
4	Marginal	Pronounced thinning (some deflection or penetration when struck with pick hammer)	Extensive corrosion significant attack of core alloy
3	Poor	Extensive heavy rust, deep pitting scattered perforations	Extensive corrosion attack of core alloy scattered perforations
2	Critical	Extensive perforations due to rust	Extensive perforations due to corrosion
1	Critical	Invert completely deteriorated	Invert completely deteriorated
0	Critical	Partial or complete collapse	Partial or complete collapse

Exhibit 73. Suggested rating criteria for condition of corrugated metal.

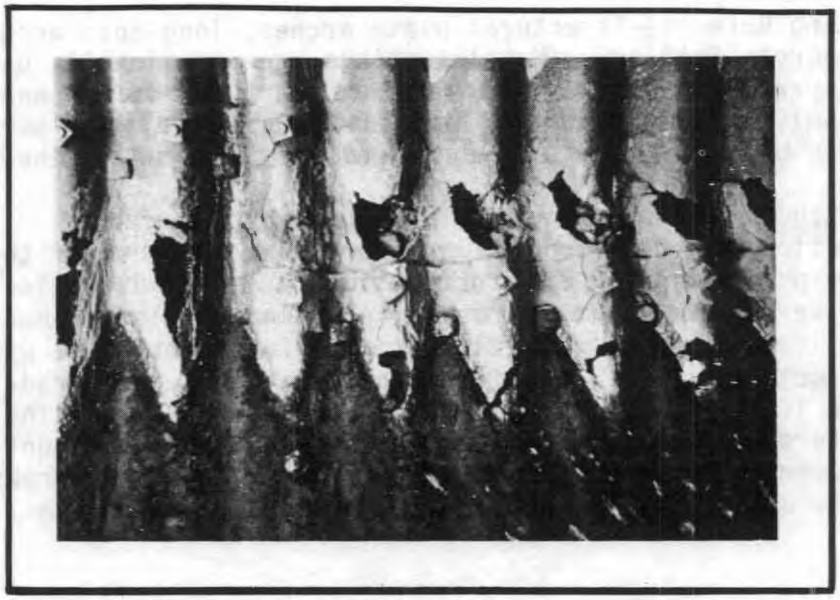


Exhibit 74. Perforation of the invert due to corrosion.

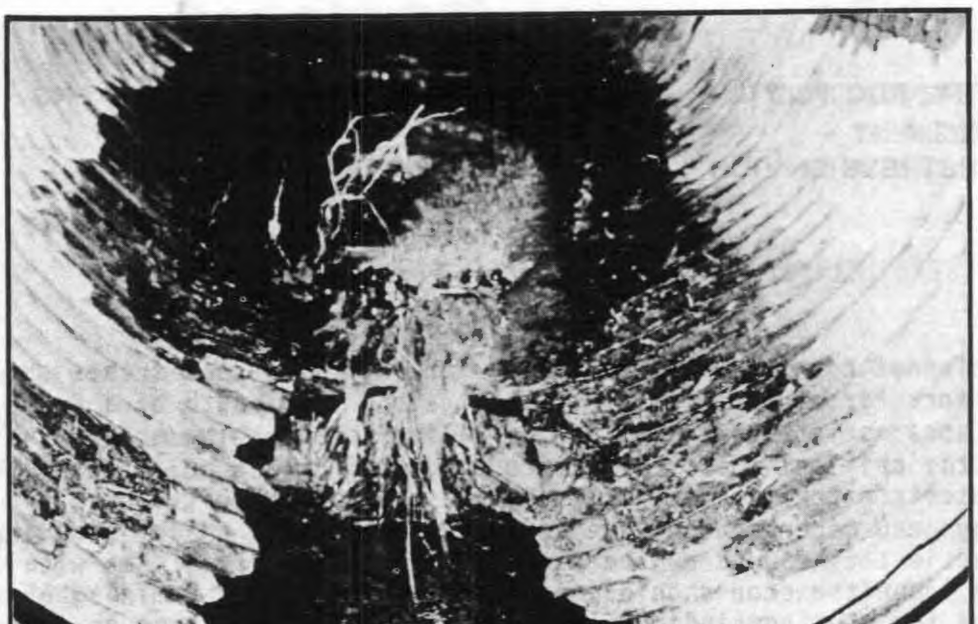


Exhibit 75. Invert deterioration.

h. Concrete Footing Defects--Structural plate arches, long-span arches, and box culverts use concrete footings. Metal footings are occasionally used for the arch and box culvert shapes. The metal "superstructure" is dependent upon the footing to transmit the vertical load into the foundation. The structural plate arch is usually bolted in a base channel which is secured in the footing.

The most probable structural defect in the footing is differential settlement. One section of a footing settling more than the rest of the footing can cause wrinkling or other distortion in the arch. Flexible corrugated metal culverts can tolerate some differential settlement but will be damaged by excessive differential settlement. Uniform settlement will not ordinarily affect a metal arch but can affect the clearances in a grade separation structure if the footings settle and the road does not. The significance of differential footing settlement increases as the amount of the difference in settlement increases, the length it is spread over decreases, and the height of the arch decreases. This concept is illustrated in exhibit 76.

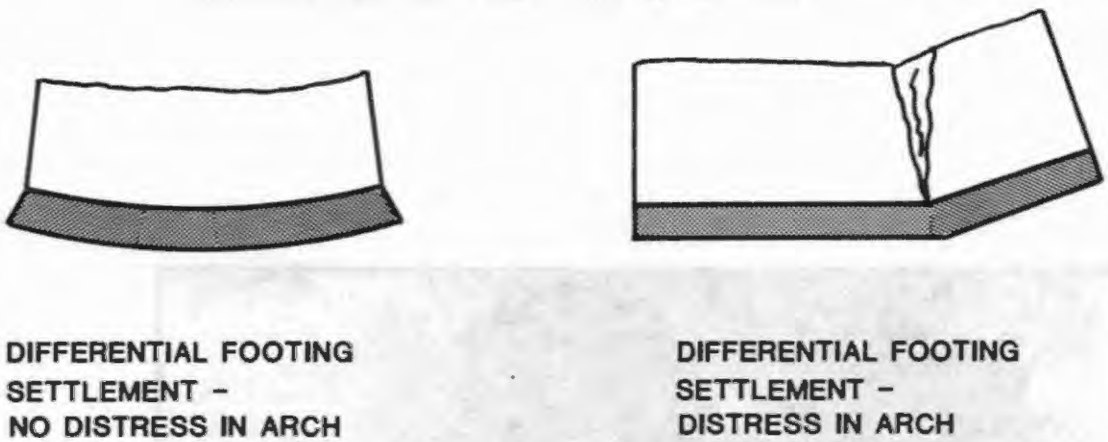


Exhibit 76. Differential footing settlement.

The inspection of footings in structural plate and long-span arches should include a check for differential settlement along the length of a footing. This might show up in severe cracking, spalling, or crushing across the footing at the critical spot. If severe enough, it might be evidenced by a compression or stretching of the corrugations in the culvert barrel. Deterioration may occur in concrete and masonry footings which is not related to settlement but is caused by the concrete or mortar. In arches with no invert slab, the inspector should check for erosion and undermining of the footings and look for any indication of rotation of the footing as illustrated in exhibits 77 and 78.

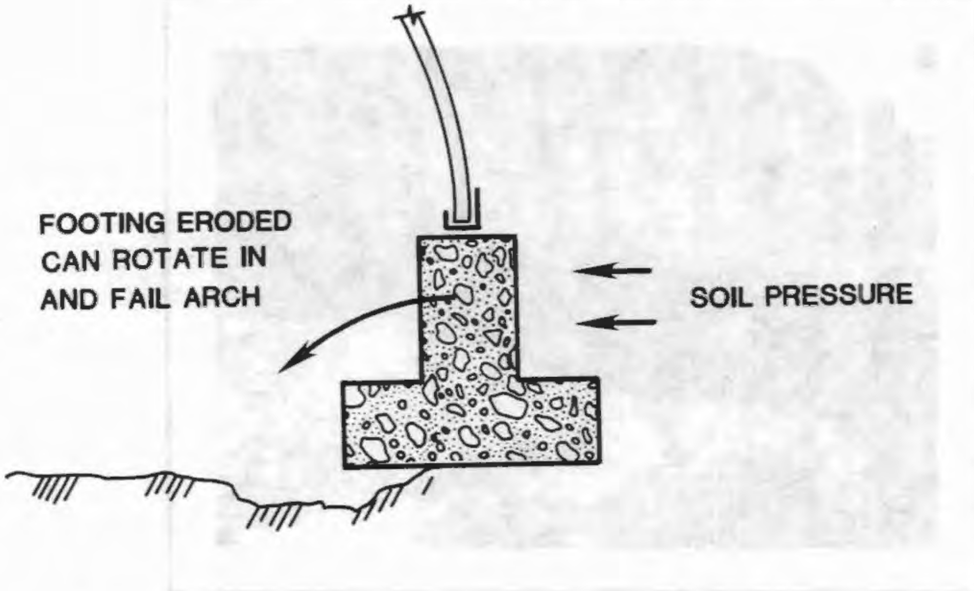


Exhibit 77. Footing rotation due to undermining.

Exhibit 78. Erosion of invert undermining footing of arch.

Culverts rated in good condition may have minor footing damage. Poor to critical condition would be indicated by severe footing undermining, damage, or rotation, or by differential settlement causing distortion and circumferential kinking in the corrugated metal as shown in exhibit 79.

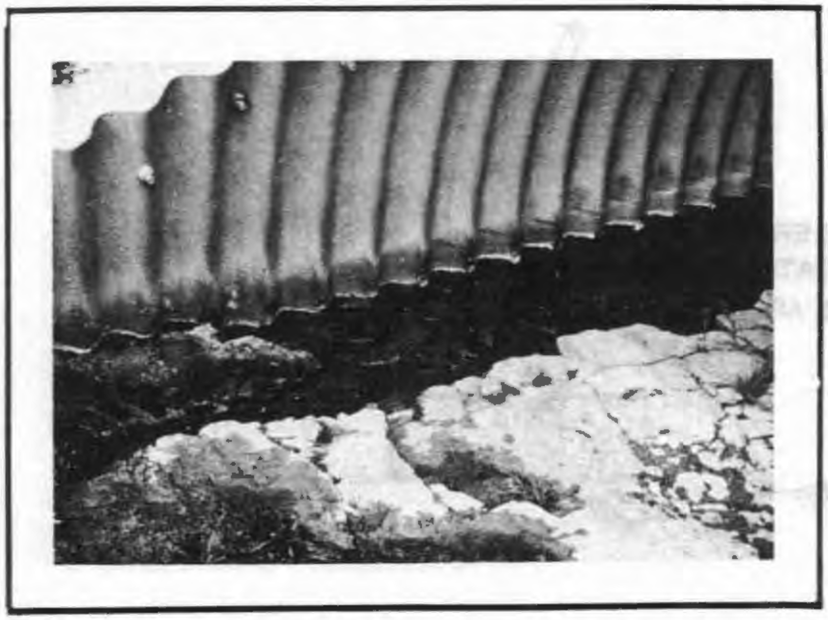


Exhibit 79. Erosion damage to concrete invert.

i. Defects in Concrete Inverts--Concrete inverts in arches are usually floating slabs used to carry water or traffic. Invert slabs provide protection against erosion and undercutting, and are also used to improve hydraulic efficiency. Concrete inverts are sometimes used in circular, as well as other culvert shapes, to protect the metal from severe abrasive or severe corrosive action. Concrete invert slabs in arches should be checked for undermining and damage such as spalls, open cracks, and missing portions. The significance of damage will depend upon its effect on the footings and corrugated metal.

Section 5. SHAPE INSPECTION OF CORRUGATED METAL CULVERT BARRELS

5-5.0 General.

This section deals with shape inspections of common culvert shapes including round and vertical elongated, pipe arches, arches, and box culvert shapes. Specific guidelines for recommended measurements to be taken for each location are provided for each typical culvert shape. Additional measurements are also recommended when field measurements differ from the design dimensions or when significant shape changes are observed. Rating guidelines are also provided for each shape. The guidelines include condition descriptions with shape and barrel defects defined for each rating.

5-5.1 Using the Rating Guidelines.

When using the rating guidelines, the inspector should keep the following factors in mind:

a. The inspector should select the lowest rating which best describes either the shape condition or the barrel condition. Structure shape is the most critical factor in flexible culverts, and this should be kept in mind when selecting the rating.

b. The shape criteria described for each numerical rating should be considered as a group rather than as separate criteria for each measurement check listed. As discussed in section 3 of this chapter, good curvature and the rate of change are critical. Significant changes in shape since the last inspection should be carefully evaluated even if the structure is still in fairly good condition.

c. The guidelines merely offer a starting point for the inspector. The inspector must still use judgment in assigning the appropriate numerical rating. The numerical rating should be related to the actions required. The inspector may wish to refer to chapter 4, section 3 and exhibit 40.

5-5.2 Round and Vertical Elongated Pipe.

Round and vertically elongated pipes are expected to deflect vertically during construction resulting in a slightly increased horizontal span. Round pipes are sometimes vertically elongated five percent to compensate for settlement during construction. It is frequently difficult to determine in the field if a pipe was round or elongated when installed. Large round pipes may appear to be elongated if they were subjected to minor flattening of the sides during backfill.

Vehicular underpasses sometimes use 10 percent vertically elongated very large pipe which is susceptible to side flattening during installation. In shallow cover situations, adequate curvature in the sides is the important factor. The soil pressures on the sides may be greater than the weight of the shallow fill over the pipe. The result is a tendency to push the sides inward rather than outward as in deeper buried or round pipes. Side flattening, such as that shown in exhibit 80, can be caused by unstable backfill. A deteriorated invert may have contributed to the problem by reducing the pipe's ability to transmit compressive forces.

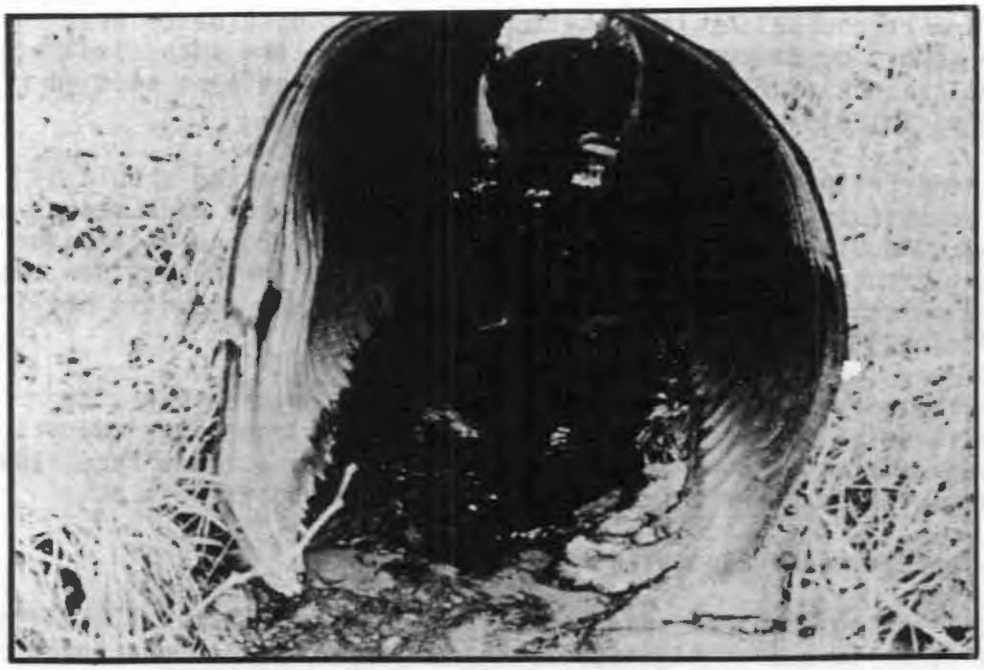


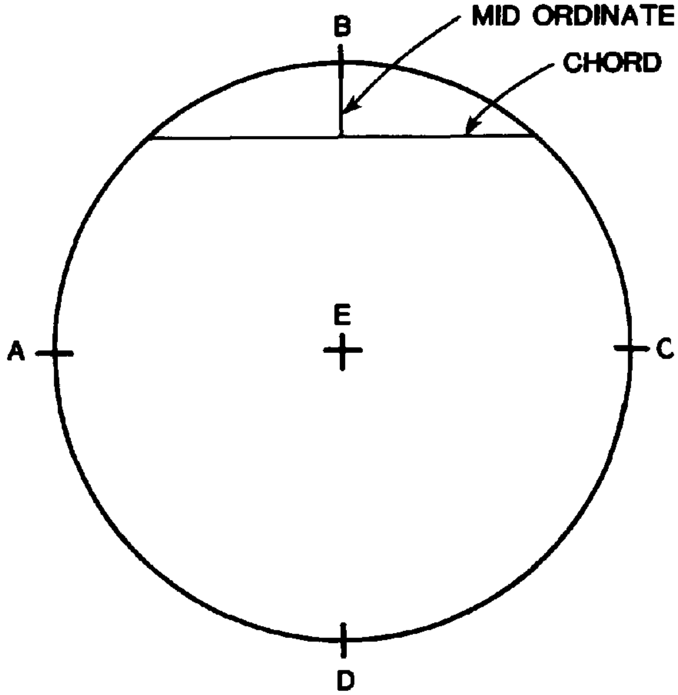
Exhibit 80. Excessive side deflection.

Flattening of the top arc is an indication of possible distress. Flattening of the invert is not as serious. Pipes not installed on shaped bedding will often exhibit minor flattening of the invert arc. However, severe flattening of the bottom arc would indicate possible distress.

The inspector should note the visual appearance of the culvert's shape and measure the horizontal span as shown in exhibit 81. Almost all round or vertical elongated pipe can be directly measured and will not require elevations. Exceptions are large vertical elongated grade separation structures. On such structures, elevations should be obtained similar to those recommended for the long-span pear shape.

If the visual appearance or measured horizontal diameter differ significantly from the design specifications, additional measurement, such as vertical diameter, should be taken. Flattened areas should be checked by measuring a chord and the mid ordinate of the chord. The chord length and ordinate measurement should be noted in the report with a description of the location and extent of the flattened area.

Round and vertically elongated pipe with good to fair shape will have a generally good shape appearance. Good shape appearance means that the culvert's shape appears to match the design shape, with smooth, symmetrical curvature and no visible deformations. The horizontal span should be within 10 percent of the design span. Pipe with marginal shape will be indicated by characteristics such as a fair or marginal general shape appearance, distortion in the upper half of the pipe, severe flattening in the lower half of the pipe, or horizontal spans 10 to 15 percent greater than design.



1. MINIMUM MEASUREMENTS REQUIRED:
   - HORIZONTAL DIAMETER = AC

2. IF FLATTENING OBSERVED MEASURE:
   - CHORD AND MID ORDINATE OF FLATTENED AREA

3. IF HORIZONTAL DIAMETER EXCEEDS DESIGN BY MORE THAN 10% MEASURE:
   - VERTICAL DIAMETER = BD

Exhibit 81. Shape inspection circular and vertical elongated pipe.

Pipe with poor to critical shape will have a poor shape appearance that does not match the design shape, does not have smooth or symmetrical curvature, and may have obvious deformations. Severe distortion in the upper half of the pipe, a horizontal diameter more than 15 percent to 20 percent greater than the design diameter, or flattening of the crown to an arc with a radius of 20 to 30 feet or more would indicate poor to critical condition. It should be noted that pipes with deflection of less than 15 to 20 percent may be rated as critical based on poor shape appearance. Guidelines for rating round corrugated metal culvert are presented in exhibit 82.

RATING GUIDELINES FOR ROUND OR VERTICAL ELONGATED CORRUGATED METAL PIPE BARRELS

RATING	CONDITION
9	• New condition
8	• Shape: good, smooth curvature in barrel - Horizontal: within 10 percent of design • Seams and Joints: tight, no openings • Metal: - Aluminum: superficial corrosion, slight pitting - Steel: superficial rust, no pitting
7	• Shape: generally good, top half of pipe smooth but minor flattening of bottom - Horizontal Diameter: within 10 percent of design • Seams or Joints: minor cracking at a few bolt holes, minor joint or seam openings, potential for backfill infiltration • Metal: - Aluminum: moderate corrosion, no attack of core alloy - Steel: moderate rust, slight pitting
6	• Shape: fair, top half has smooth curvature but bottom half has flattened significantly - Horizontal Diameter: within 10 percent of design • Seams or Joints: minor cracking at bolts is prevalent in one seam in lower half of pipe. Evidence of backfill infiltration through seams or joints • Metal: - Aluminum: significant corrosion, minor attack of core alloy - Steel: fairly heavy rust, moderate pitting
5	• Shape: generally fair, significant distortion at isolated locations in top half and extreme flattening of invert - Horizontal Diameter: 10 percent to 15 percent greater than design • Seams or Joints: moderate cracking at bolt holes along one seam near bottom of pipe, deflection of pipe caused by backfill infiltration through seams or joints • Metal: - Aluminum: significant corrosion, moderate attack of core alloy - Steel: scattered heavy rust, deep pitting
4	• Shape: marginal significant distortion throughout length of pipe, lower third may be kinked - Horizontal Diameter: 10 percent to 15 percent greater than design • Seams or Joints: Moderate cracking at bolt holes on one seam near top of pipe, deflection caused by loss of backfill through open joints • Metal: - Aluminum: extensive corrosion, significant attack of core alloy - Steel: extensive heavy rust, deep pitting
3	• Shape: poor with extreme deflection at isolated locations, flattening of crown, crown radius 20 to 30 feet - Horizontal Diameter: in excess if 15 percent greater than design • Seams: 3 in. long cracks at bolt holes on one seam • Metal: - Aluminum: extensive corrosion, attack of core alloy, scattered perforations - Steel: extensive heavy rust, deep pitting, scattered perforations
2	• Shape: critical, extreme distortion and deflection throughout pipe, flattening of crown, crown radius over 30 feet - Horizontal Diameter: More than 20 percent greater than design • Seams: plate cracked from bolt to bolt on one seam • Metal: - Aluminum: extensive perforations due to corrosion - Steel: extensive perforations due to rust
1	• Shape: partially collapsed with crown in reverse curve • Seams: failed • Road: closed to traffic
0	• Pipe: totally failed • Road: closed to traffic

NOTES: 1. See Coding Guide for description of Rating Scale.

2. As a starting point, select the lowest rating which matches actual conditions.

Exhibit 82. Condition rating guidelines.

5-5.3 Pipe Arch.

The pipe arch is a completely closed structure but is essentially an arch. The load is transmitted to the foundation principally at the corners. The corners are much like footings of an arch. There is relatively little force or pressure on the large radius bottom plate. The principal type of distress in a pipe arch is a result of inadequate soil support at the corners where the pressure is relatively high. The corner may push down or out into the soil while the bottom stays in place. The effect will appear as if the bottom pushed up. This problem is illustrated in exhibits 83 and 84.

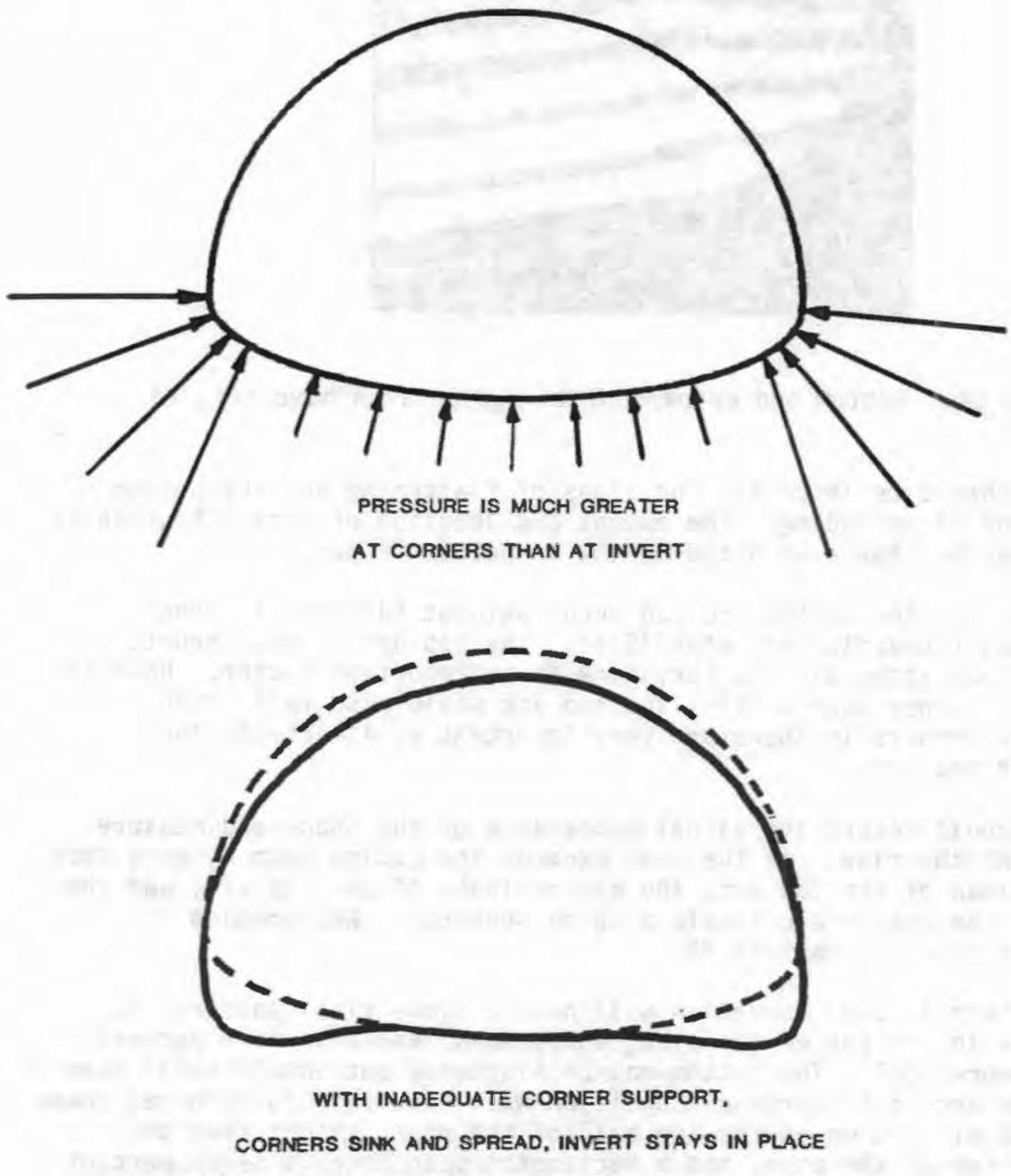


Exhibit 83. Bottom distortion in pipe arches.

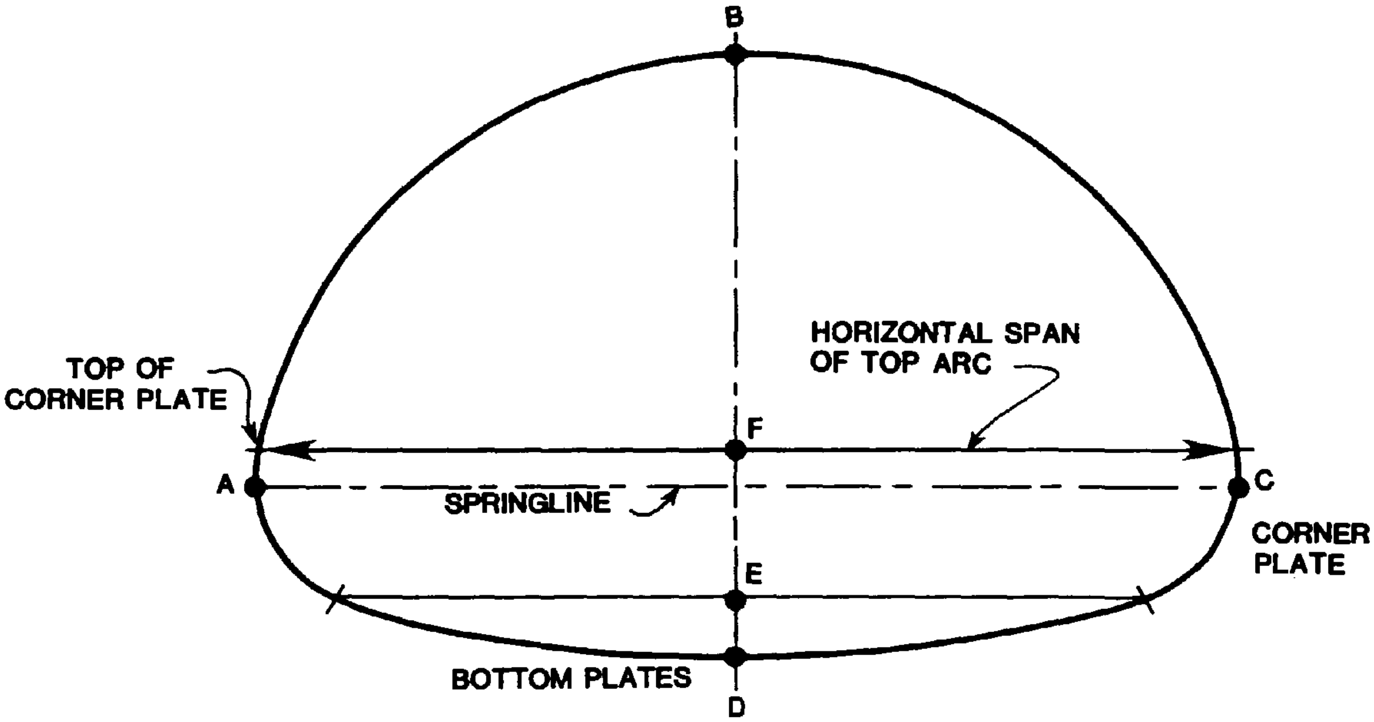
Exhibit 84. Bottom and corners of this pipe arch have settled.

The bottom arc should be inspected for signs of flattening and the bottom corners for signs of spreading. The extent and location of bottom flattening and corner spreading should be noted in the inspection report.

Complete reversal of the bottom arc can occur without failure if corner movement into the foundation has stabilized. The top arc of the structure is supporting the load above and its curvature is an important factor. However, if the "footing" corner should fail, the top arc would also fail. The spreading of the corners is therefore very important as it affects the curvature of the top arc.

The inspector should record the visual appearance of the shape and measure both the span and the rise. If the span exceeds the design span by more than 3 percent, the span of the top arc, the mid ordinate of the top arc, and the mid ordinate of the bottom arc should also be measured. Recommended measurements are shown in exhibit 85.

Pipe arches in fair to good condition will have a symmetrical appearance, smooth curvature in the top of the pipe, and a span less than five percent greater than theoretical. The bottom may be flattened but should still have curvature. Pipe arches in marginal condition will have fair to marginal shape appearance, with distortion in the top half of the pipe, slight reverse curvature in bottom of the pipe, and a horizontal span five to seven percent greater than theoretical. Pipe in poor to critical condition will have



1. MINIMUM REQUIRED MEASUREMENTS - AC, BD
   - SPAN = AC
   - RISE = BD

2. IF AC EXCEEDS DESIGN BY 3% OR MORE MEASURE BF, ED, AND HORIZONTAL SPAN OF TOP ARC

Exhibit 85. Shape inspection structural plate pipe arch.

characteristics such as a poor shape appearance, severe deflection or distortion in the top half of the pipe, severe reverse curvature in the bottom of the pipe, flattening of one side, flattening of the crown to an arc with a radius of 20 to 30 feet, or a horizontal span more than seven percent greater than theoretical. Guidelines for rating pipe arches are shown in exhibit 86.

5-5.4 Arches.

Arches are fixed on concrete footings, usually below or at the springline. The springline is a line connecting the outermost points on the sides of a culvert. This difference between pipes and arches means that an arch tends to deflect differently during backfill. Backfill forces tend to flatten the arch sides and peak its top because the springline cannot move inward like the wall of a round pipe as shown in exhibit 87. As a result, important shape factors to look for in an arch are flattened sides, peaked crown, and flattened top arc.

Another important shape factor in arches is symmetrical shape. If the arch was erected with the base channels not square to the centerline, it causes a racking of the cross section. A racked cross-section is one that is not symmetrical about the centerline of the culvert. One side tends to flatten, the other side tends to curve more while the crown moves laterally and possibly upward. If these distortions are not corrected before backfilling the arch, they usually get worse during backfill. Exhibit 88 illustrates racked or peaked arches.

Visual observation of the shape should involve looking for flattening of the sides, peaking or flattening of the crown, or racking to one side. The measurements to be recorded are illustrated in exhibit 89. Minimum measurements include the vertical distance from the crown to the bottom of the base channels and the horizontal distances from each of the base channels to a vertical line from the highest point on the crown. These horizontal distances should be equal. When they differ by more than 10 inches or 5 percent of the span, whichever is less, racking has occurred and the curvature on the flatter side of the arch should be checked by recording chord and midordinate measurements. Racking can occur when the rise checks with the design rise. When the rise is more than 5 percent less than the design rise, the curvature of the top arc should be checked.

Arches in fair to good condition will have the following characteristics: a good shape appearance with smooth and symetrical curvature, and a rise within three to four percent of theoretical. Marginal condition would be indicated when the arch is significantly non-symetrical, when arch height is five to seven percent less or greater than theoretical, or when side or top plate flattening has occurred such that the plate radius is 50 to 100 percent greater than theoretical. Arches in poor to critical condition will have a poor shape appearance including significant distortion and deflection, extremely non-symetrical shape, severe flattening (radius more than 100 percent greater than theoretical) of sides or top plates, or a rise more than eight percent greater or less than the theoretical rise. Guidelines for rating structural plate arches are shown in exhibit 90.

RATING GUIDELINES FOR CORRUGATED METAL PIPE-ARCH BARRELS

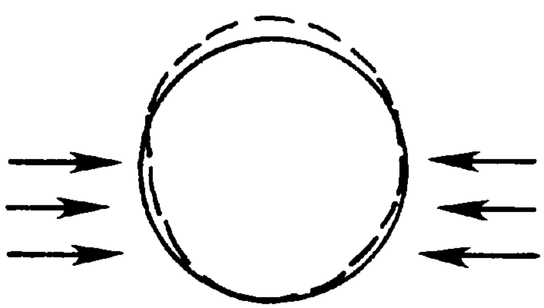
RATING	CONDITION	RATING	CONDITION
9	• New condition	4	• Shape: marginal, significant distortion all along top of arch, bottom has reverse curve - Horizontal Span: more than 7 percent greater than design • Joints and Seams: moderate cracking all along one seam; backfill infiltration causing major deflection • Metal: - Aluminum: extensive corrosion, significant attack of core alloy - Steel: extensive heavy rust, deep pitting
8	• Shape: good with smooth curvature - Horizontal Span: less than 3 percent greater than design • Joints or Seams: good condition • Metal: minor construction defects, protective coatings intact - Aluminum: superficial corrosion, slight pitting - Steel: superficial rust, no pitting	3	• Shape: poor, extreme deflection in top arch in one section; bottom has reverse curvature throughout - Horizontal Span: more than 7 percent greater than design • Seams: seam cracked 3 in. on each side of bolt holes • Metal: - Aluminum: extensive corrosion, attack of core alloy, scattered perforations - Steel: extensive heavy rust, deep pitting, scattered perforations
7	• Shape: generally good, smooth curvature in top half, bottom flattened but still curved - Horizontal Span: within 3 to 5 percent greater than design • Joints or Seams: minor cracking at a few bolt holes; minor joint or seam openings, infiltration of backfill possible • Metal: protective coating ineffective - Aluminum: moderate corrosion, no attack of core alloy - Steel: moderate rust, slight pitting	2	• Shape: critical, extreme deflection along top of pipe - Horizontal Span: more than 7 percent greater than design • Seams: seam cracked from bolt to bolt down one seam • Metal: - Aluminum: extensive perforations due to corrosion - Steel: extensive perforations due to rust
6	• Shape: fair, smooth curvature in top half, bottom flat - Horizontal Span: 5 percent greater than design • Joints or Seams: minor cracking all along one seam; minor joint openings with evidence of infiltration • Metal: - Aluminum: significant corrosion, minor attack of core alloy - Steel: fairly heavy rust, moderate pitting	1	• Shape: structure partially collapsed • Seams: seam failed • Road: closed to traffic
5	• Shape: generally fair, significant distortion in top in one location; bottom has slight reverse curvature in one location - Horizontal Span: within 5 to 7 percent greater than design • Joints and Seams: moderate cracking at bolt holes along a seam in one section, backfill being lost through seam or joint causing slight deflection • Metal: - Aluminum: significant corrosion, moderate attack of core alloy - Steel: scattered heavy rust, deep pitting	0	• Shape: structure collapsed • Road: closed to traffic

NOTES: 1. See Coding Guide for description of Rating Scale.

2. As a starting point, select the lowest rating which matches actual conditions.

Exhibit 86. Condition rating guidelines.

BACKFILL TENDS TO PEAK
ARCHES (DOTTED LINE)



ROUND PIPES CAN DEFLECT
MORE UNIFORMLY

Exhibit 87. Arch deflection during installation.

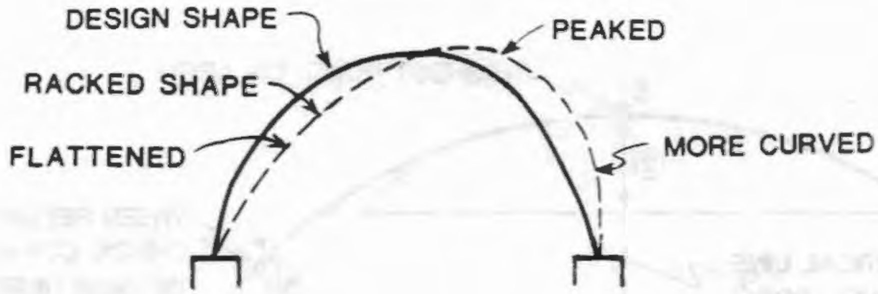
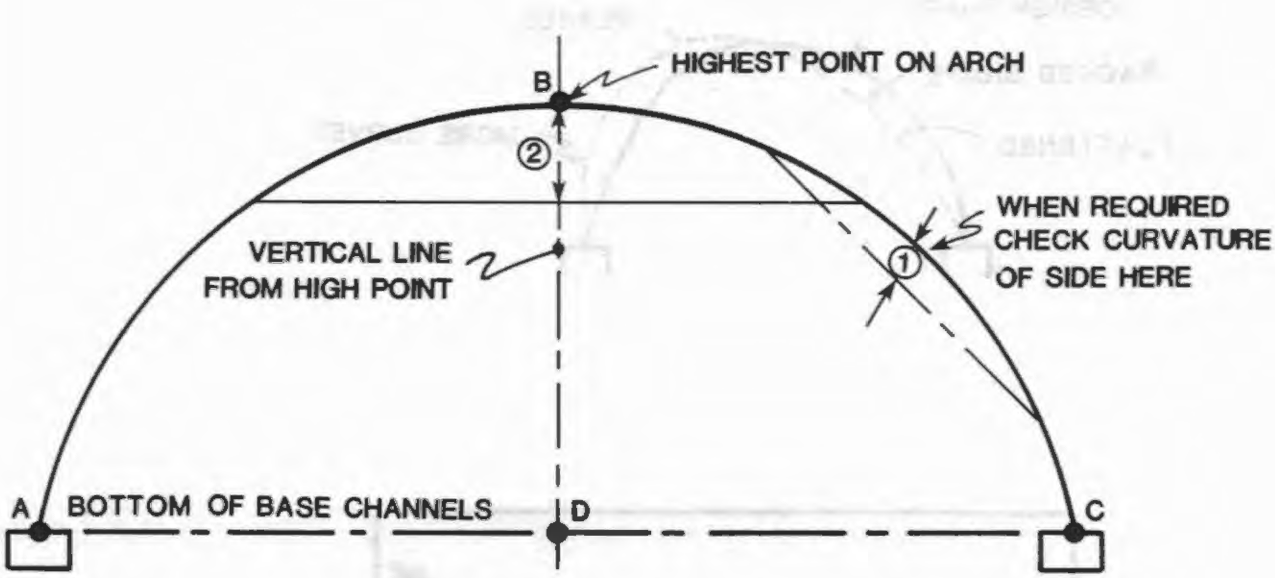


Exhibit 88. Racked and peaked arch.



1. MINIMUM REQUIRED MEASUREMENTS
   - SPAN = AD + DC
   - RISE = BD

2. MINIMUM REQUIRED ELEVATIONS - B

3. IF BD GREATER THAN DESIGN BY 5% OR MORE
   CHECK SIDE CURVATURE

4. IF AD AND DC NOT EQUAL CHECK SIDE CURVATURE ①

5. IF BD LESS THAN DESIGN BY 5% OR MORE
   CHECK TOP CURVATURE ②

Exhibit 89. Shape inspection structural plate arch.

RATING GUIDELINES FOR STRUCTURAL PLATE ARCH BARREL

RATING	CONDITION
9	• New condition
8	• Shape: good, smooth symmetrical curvature • Rise: within ± 3 percent of design • Seams: properly made and tight • Metal: minor defects and damage due to contraction - Aluminum: superficial corrosion, slight pitting - Steel: superficial rust, no pitting • Footings: good with no erosion
7	• Shape: generally good with smooth curvature, symmetrical; slight flattening of top or sides in one section • Rise: within 3 to 4 percent of design • Seams: minor cracking at a few bolt holes; minor seam opening, possibility of soil infiltration • Metal: - Aluminum: moderate corrosion, no attack of core alloy - Steel: moderate rust, slight pitting • Footings: moderate erosion causing differential settlement and minor cracking in footing
6	• Shape: fair, smooth curvature but non-symmetrical; slight flattening of top and sides throughout • Rise: within 4 to 5 percent of design • Seams: minor cracking of bolt holes along one or more seams; evidence of backfill infiltration • Metal: - Aluminum: significant corrosion, minor attack of core alloy - Steel: fairly heavy rust, moderate pitting • Footings: moderate cracking and differential settlement of footing due to extensive erosion
5	• Shape: generally fair, significant distortion and deflection in one section; sides beginning to flattend; non-symmetrical • Rise: within 5 to 7 percent of design • Seams: moderate cracking of one seam near footing; infiltration of soil causing slight deflection • Metal: - Aluminum: significant corrosion, moderate attack of core alloy - Steel: scattered heavy rust, deep pitting • Footings: significant undercutting of footing and extreme differential settlement; major cracking in footing
4	• Shape: marginal, significant distortion and deflection throughout; sides flattened with radius 100 percent greater than design • Rise: within 7 to 8 percent of design • Seams: major cracking of seam near crown; infiltration of soil causing major deflection • Metal: - Aluminum: extensive corrosion, significant attack of core alloy - Steel: extensive heavy rust, deep pitting • Footings: rotated due to erosion and undercutting; settlement has caused damage to metal arch
3	• Shape: poor, extreme distortion and deflection in one section; sides virtually flattened; extremely non-symmetrical • Rise: within 8 to 10 percent of design • Seams: cracked 3" to either side of bolts • Metal: - Aluminum: extensive corrosion, attack of core alloy, scattered perforations - Steel: extensive heavy rust, deep pitting, scattered perforations • Footing: rotated, severely undercut; major cracking and spalling
2	• Shape: critical, extreme deflection, throughout; sides flattened; extremely non-symetrical • Rise: greater than 10 percent of design • Seams: cracked from bolt to bolt; significant amounts of backfill infiltration • Metal: - Aluminum: extensive perforations due to corrosion - Steel: extensive perforations due to rust • Footing: severe differential settlement has caused distortion and kinking of metal arch
1	• Shape: severe due to partial collapse; local reverse curve of crown and sides • Seams: failed, backfill pushing in • Road: closed to traffic
0	• Structure: completely collapsed • Road: closed to traffic

NOTES: 1. See Coding Guide for description of Rating Scale.

2. As a starting point, select the lowest rating which matches actual conditions.

Exhibit 90. Condition rating guidelines.

5-5.5 Corrugated Metal Box Culverts.

The box culvert is not like the other flexible buried metal structures. It behaves as a combination of ring compression action and conventional structure action. The sides are straight, not curved and the plates are heavily reinforced and have moment or bending strength that is quite significant in relation to the loads carried.

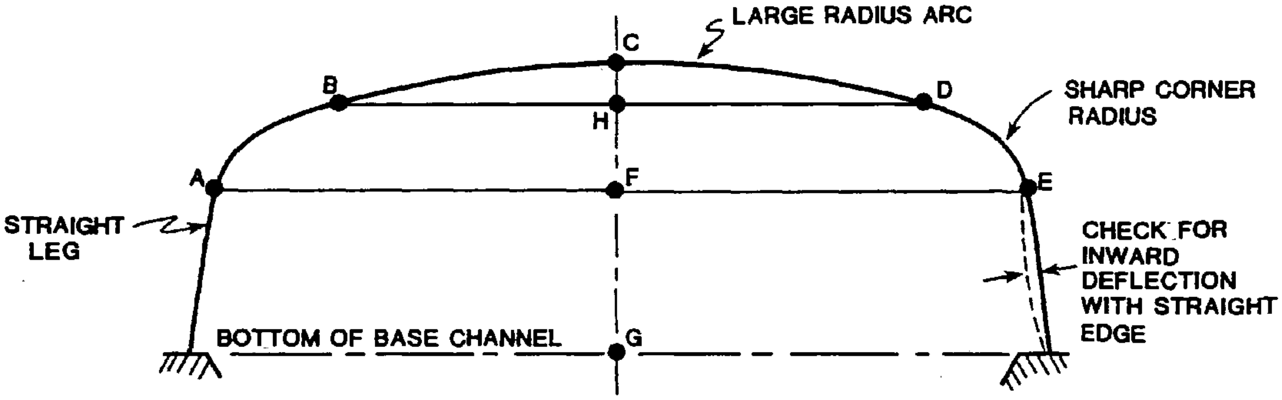
The key shape factor in a box culvert is the top arc. The design geometry is clearly very "flat" to begin with and therefore cannot be allowed to deflect much. The span at the top is also important and cannot be a'lowed to increase much.

The side plates often deflect slightly inward or outward. Generally an inward deflection would be the more critical as an outward movement would be restrained by soil.

Shape factors to be checked visually include flattening of top arc, outward movement of sides, or inward deflection of the sides. The inspector should note the visual appearance of the shape and should measure and record the rise and the horizontal span at the top of the straight legs as shown in exhibit 91. If the rise is more or less than 1 1/2 percent of the design rise, the curvature of the large top radius should be checked.

The radius points are not necessarily located at the longitudinal seams. Many box culverts use double radius plates and the points where the radius changes must be estimated by the inspector or can be determined from the manufacturer's literature. These points can still be referenced to the bolt pattern to describe exactly where they are. Since these are all low structures, the spots should also be marked and painted for convenient repeat inspection.

Box culverts in fair to good condition will appear to be symetrical with smooth curves, slight or no deflection of the straight legs, a horizontal span length within five percent of the design span and the middle ordinate of the tops are within ten percent of the design. Culverts in marginal condition may appear to be non-symetrical, have noticeable deflection in the straight legs, have spans that differ from design by five percent, or have a middle ordinate of the top arc that differ from design by 20 to 30 percent. Poor to critical conditions exist when the culvert shape appears poor, the culvert has severe deflections of the straight legs, a horizontal span that differs from design by more than five percent, or a middle ordinate of the top arc that differs from the theoretical by more than 40 to 50 percent. Guidelines for rating structural plate box culverts are shown in exhibit 92.



1. MINIMUM REQUIRED MEASUREMENTS
   - RISE = CG
   - SPAN = AE

2. IF NOT POSSIBLE TO MEASURE CG, MEASURE BD AND CH

3. IF CG DIFFERS BY MORE THAN 1½% OF DESIGN OR AE DIFFERS BY MORE THAN ±3% OF DESIGN MEASURE
   - CHORD OF TOP ARC = BD
   - MIDDLE ORDINATE OF TOP ARC = CH

Exhibit 91. Shape inspection structural plate box culverts.

RATING GUIDELINES FOR CORRUGATED METAL BOX CULVERT BARREL

RATING	CONDITION
9	• New condition
8	• Shape: good appearance, smooth symmetrical curvature – Top Arc Mid-Ordinate: within 11 percent of design – Horizontal Span: within 5 percent of design • Sides: straight leg very slightly deflected inward or outward and curvature smooth • Seams: properly made and tight • Metal: minor defects and damage due to construction – Aluminum: superficial corrosion, slight pitting – Steel: superficial rust, no pitting • Footings: good with no erosion
7	• Shape: generally good; curvature is smooth and symmetrical – Top Arc Mid-Ordinate: within 11 percent to 15 percent of design – Horizontal Span: within 5 percent of design • Sides: straight leg slightly deflected inward or moderately deflected outward, curvature smooth • Seams: minor cracking at a few bolt holes; minor seam openings, possibility of backfill infiltration exists • Metal: – Aluminum: moderate corrosion, no attack of core alloy – Steel: moderate rust, slight pitting • Footings: minor differential settlement due to erosion; minor hairline cracking in footing
6	• Shape: smooth curvature, shape is non-symetrical – Top Arc Mid-Ordinate: within 15 percent of design – Horizontal Span: more than + or – 5 percent of design • Sides: straight leg moderately deflected inward or extremely deflected outward, curvature smooth • Seams: minor cracking at bolt holes along one seam; evidence of backfill infiltration • Metal: – Aluminum: significant corrosion, minor attack of core alloy – Steel: fairly heavy rust, moderate pitting • Footing: differential settlement due to extensive erosion; moderate cracking of footing
5	• Shape: generally fair; significant distortion and deflection in one section;half top arcs beginning to flatten; mid-ordinate of half top arc 30 percent less than design – Top Arc Mid-Ordinate: within 15 to 20 percent of design – Horizontal Span: more than + or – 5 percent of design – Sides: straight leg bowed inward significantly or extremely bowed outward for distance of less than 1/4 span length • Seams: major cracking in one location; infiltration of soil causing slight deflection • Metal: – Aluminum: significant corrosion, moderate attack of core alloy – Steel: scattered heavy rust, deep pitting • Footings: significant undercutting of footing and extreme differential settlement; major cracking of footing
4	• Shape: marginal, significant distortion and deflection throughout; mid-ordinate of half top arc less than 50 percent of design – Top Arc Mid-Ordinate: within 20 to 30 percent of design – Hozizontal Span: more than + or – 5 percent of design – Sides: straight leg bowed inward significantly or extremely bowed outward for distance between 1/4 and 1/2 span length, curvature irregular • Seams: significant seam cracking all along seam; infiltration of soil causing major deflection • Metal: – Aluminum: extensive corrosion, significant attack of core alloy – Steel: extensive heavy rust, deep pitting • Footings: rotated due erosion and undercutting; settlement has caused damage to metal arch
3	• Shape: poor extreme distortion and deflection in one section and ordinate of half top arc 50 to 70 percent less than design – Top Arc Mid-Ordinate: 30 to 40 percent less than design – Horizontal Span: more than + or – 6 percent of design Sides: straight leg extremely bowed inward for distance less than 1/2 span length or leg bowed outward severely causing bulges in metal • Seams: cracked 3" or more to either side of bolt; infiltration of backfill causing severe deflection locally • Metal: – Aluminum: extensive corrosion, attack of core alloy, scattered perforations – Steel: extensive heavy rust, deep pitting, scattered perforations • Footing: rotated, severely undercut, major cracking and spalling of footing, significant demege to structure
2	• Shape: critical, extreme distortion and deflection throughout; mid-ordinate of half top arc more than 70 percent less than design – Top Arc Mid-Ordinate: more than 40 percent less than design – Horizontal Span: more then + or – 8 percent of design – Sides: straight leg extremely bowed inward for a distance of 1/2 to 1 span length, or leg bowed outward severely causing bulges or kinking in metal • Seams: cracked from bolt to bolt; significant amounts of backfill infiltration throughout • Metal: – Aluminum: extensive perforations due to corrosion – Steel: extensive perforations due to rust • Footing: severe differential settlement has caused distortion and kinking of metal arch
1	• Shape: severe due to partial collapse; top arc curvature flat or reverse curved • Seams: failed, backfill pushing in • Road closed to traffic
0	• Structure: completely collapsed • Road: closed to traffic

NOTES: 1. See Coding Guide for description of Rating Scale.
2. As a starting point, select the lowest rating which matches actual conditions.

Exhibit 92. Condition rating guidelines.

Section 6. CORRUGATED METAL LONG-SPAN CULVERTS

5-6.0 General.

This section describes procedures for conducting shape inspections of long-span structures. The long-span structures addressed include four typical shapes: low profile arch, horizontal ellipse, high profile arch, and pear. These shapes are illustrated in exhibit 93. The evaluation of shape characteristics of long-spans will vary somewhat depending upon the typical shape being inspected. However, the top or crown sections of all long-span structures have very similar geometry. The crown sections on all long-span structures can be inspected using the same criteria. This section therefore includes separate discussions on the crown section and on each of the typical long-span shapes. Guidelines are also provided for rating the condition of each shape in terms of shape characteristics and barrel defects. The procedures for using the rating guidelines are the same as those described in section 5-5.1.

Shape inspections of long-span structures will generally consist of 1) visual observations of shape characteristics such as smooth or distorted curvature and symmetrical or non-symmetrical shape, 2) measurements of key dimensions, and 3) elevations of key points. Additional measurements may be necessary if measurements or observed shape differ significantly from design.

The visual observations are extremely important to evaluate the shape of the total cross section. Simple measurements such as rise and span do not describe curvature, yet adequate curvature is essential, as shown in exhibit 94. However, measurements and elevations are also needed to document the current shape so that the rate change, if any, can be monitored.

Many long-spans will be too large to allow simple direct measuring. Vertical heights may be as large as 20 to 30 feet and horizontal spans may be large and as high as 12 to 15 feet above inverts. Culverts may have flowing water obscuring the invert and any reference points there. It is, therefore, in general desirable to have instrument survey points which can be quickly checked for elevation. When direct measuring is practical a 25 foot telescoping extension rod can be used for measuring. Such rods can also serve as level rods for taking elevations.

5-6.1 Long-Span Crown Section--Shape Inspection.

As previously mentioned, the section above the springline is essentially the same for most long-span shapes. With the exception of pear shapes, the standard top geometry uses a large radius top arc of approximately 80 degrees with a radius of 15 to 25 feet. The adjacent corner or side plates are from one-half to one-fifth the top arc radius. The most important part of a long-span shape is the standard top arch geometry. Adequate curvature of the large radius top arc is critical. Inspection of the crown section should consist of a visual inspection of the general shape for smooth curvature (no distortion, flattening, peaks, or cusps) and symetrical shape (no racking).

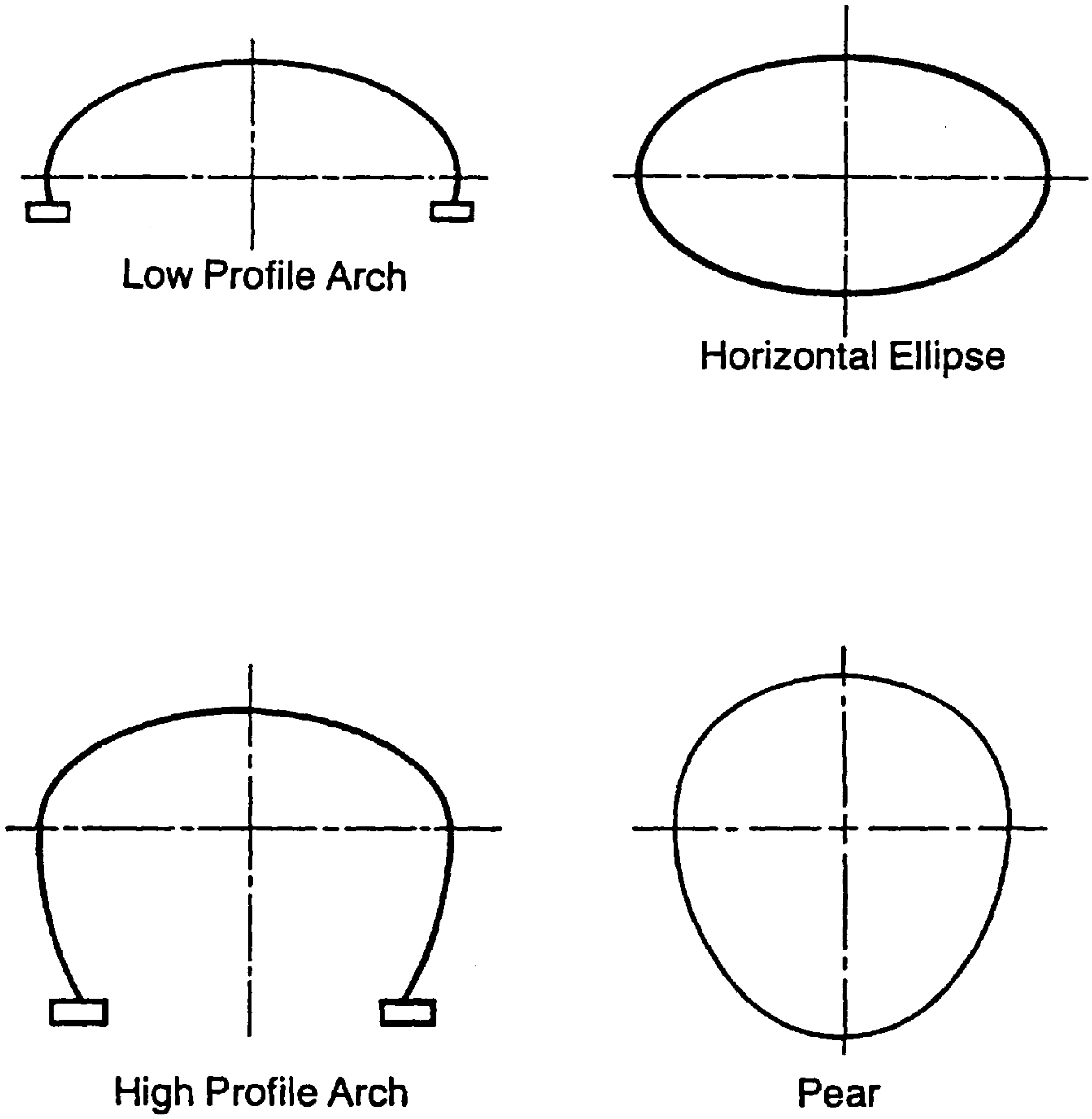
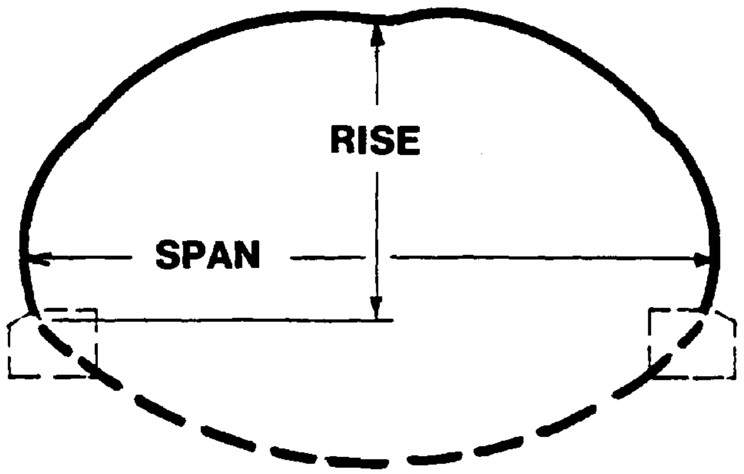
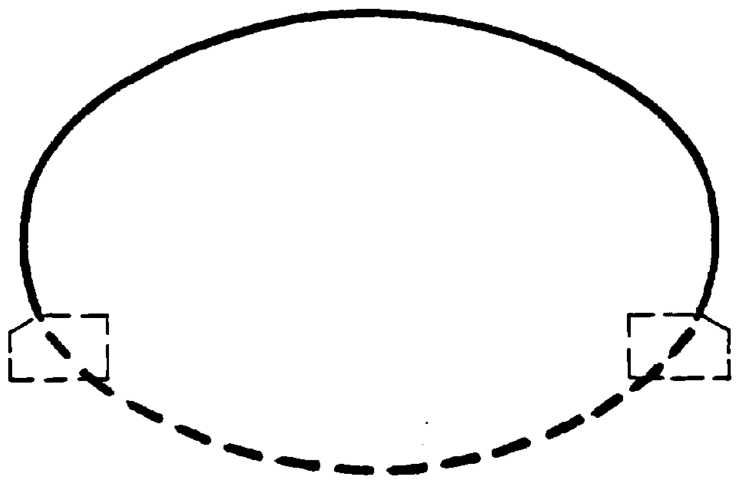


Exhibit 93. Typical long-span shapes.



THE RISE AND SPAN ON THIS STRUCTURE ARE EQUAL TO THE DESIGN RISE AND SPAN, YET IT IS A VERY POOR SHAPE



THE RISE AND SPAN ON THIS STRUCTURE ARE CONSIDERABLY DIFFERENT FROM THE DESIGN RISE AND SPAN, YET IT IS IN EXCELLENT SHAPE

Exhibit 94. Simple linear measurements may not describe the structural shape.

An inspection should also include key measurements such as the middle ordinate of the top arc. Recommended measurements and elevations are shown in exhibit 95.

The initial inspection should establish elevations for the radius points and the top of the crown. From these elevations the middle ordinate for the top arc can be calculated. If the actual middle ordinate is 10 percent more or less than the theoretical design mid-ordinate the horizontal span for the top arc should also be measured. For standard 80 degree arcs the theoretical middle ordinate is equal to 0.234 times the theoretical radius of the top arc. This span is not easy to measure on many long-span structures and need not be measured if the top arc mid-ordinate is within 10 percent of theoretical. Even if it is convenient and practical to direct measure the vertical heights of the points on the top arc from the bottom of the structure, it is wise to also establish their elevations from a reliable benchmark. Bottom reference points can be wiped out by erosion, covered with debris, or covered by water. When direct vertical measuring is practical, the shape may be checked on subsequent inspections with direct measurement. However, it is still important to establish elevations in case bottom reference points are lost or inaccessible.

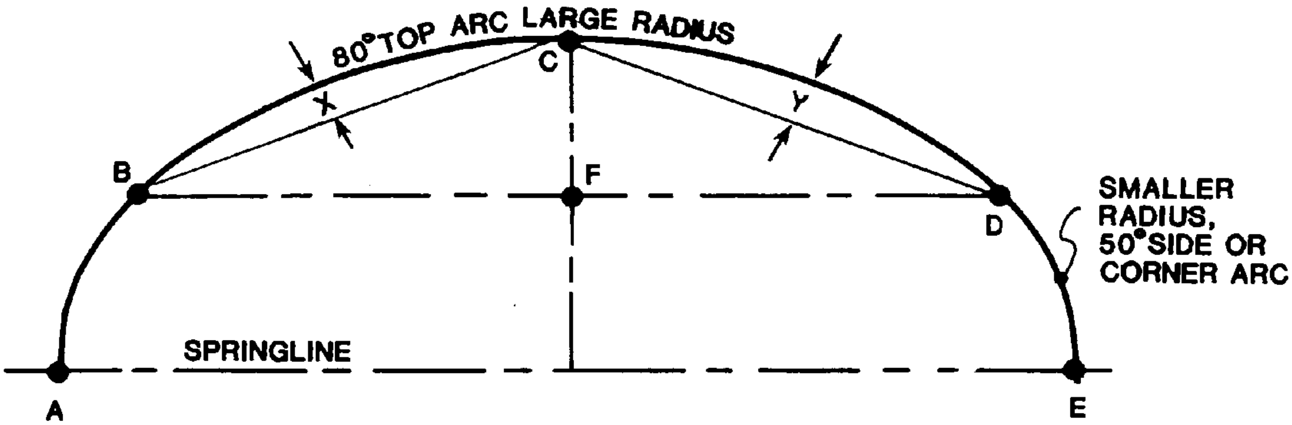
Crown sections in good condition will have a shape appearance that is good, with smooth and symmetrical curvature. The actual middle ordinate should be within 10 percent of the theoretical, and the horizontal span (if measured) should be within five percent of theoretical. Crown sections in fair condition will have a fair to good shape appearance, smooth curvature but possibly slightly non-symetrical. Middle ordinates of the top arc may be within 11 to 15 percent of theoretical and the horizontal span may differ by more than 5 percent of theoretical.

Crown sections in marginal condition will have measurements similar to those described for fair shape. However, the shape appearance will be only fair to marginal with noticeable distortion, deflection, or non-symmetrical curvature. When the curvature is noticeably distorted or non-symmetrical, the sides should be checked for flattening by measuring the middle ordinates of the halves of the top arc. Crown sections with marginal shape may have middle ordinates for top half arcs that are 30 to 50 percent less than theoretical.

Crown sections in poor to critical condition will have a poor to critical shape appearance with severe distortion or deflection. The middle ordinate of the top arc may be as much as 20 percent less than theoretical, while middle ordinates of the top arc halves may be 50 to 70 percent less than theoretical.

5-6.2 Low Profile Long-Span Arch--Shape Inspection.

The low profile arch is essentially the same as the crown section except that the sides are carried about 10 degrees below the springline to the footing. These structures are low and can be measured more easily than other long-span shapes. Recommended measurements and elevations are shown in exhibit 96. Rating guidelines are listed in exhibit 97.



1. MINIMUM REQUIRED ELEVATIONS - B, C, D

   MINIMUM REQUIRED MEASUREMENTS -

   - TOP SPAN = AE

   CALCULATE CF = $\text{ELEV C} - \dfrac{\text{ELEV B} + \text{ELEV D}}{2}$

2. IF CF IS GREATER THAN OR LESS THAN DESIGN BY 10% MEASURE:

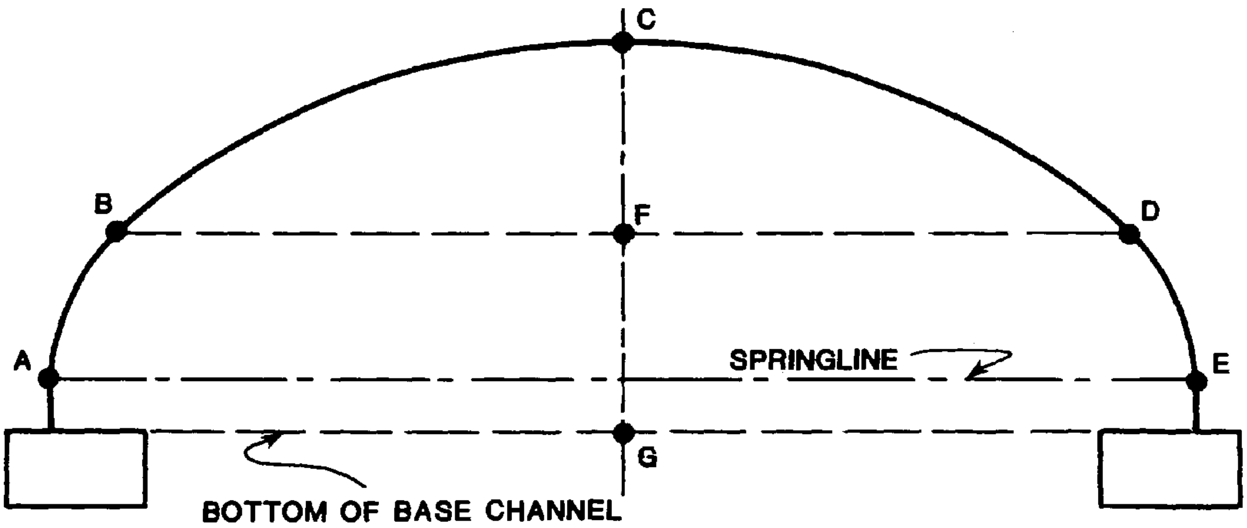
   - TOP ARC CHORD = BD

3. IF BD DIFFERS BY MORE THAN 3% FROM DESIGN MEASURE FOR EACH HALF OF TOP ARC

   - HALF TOP ARC MID ORDINATES = X & Y

Note: These measurements and elevations should be obtained on all long span inspections (see exhibits 96, 98, 100 and 103).

Exhibit 95. Shape inspection crown section of long span structures.



AE = SPAN, CG = RISE OR HEIGHT

1. MINIMUM REQUIRED MEASUREMENTS -
   - SPAN = AE
   - TOP ARC CHORD = BD
   - RISE = CG

2. MINIMUM REQUIRED ELEVATIONS B, C, D
3. CALCULATE CF FROM ELEVATIONS

$$CF = ELEV.\ C - \frac{ELEV.\ B + ELEV.\ D}{2}$$

Note: Use with exhibit 95, crown inspection.

Exhibit 96. Shape inspection low profile long span arch.

RATING GUIDELINES FOR LOW PROFILE ARCH LONG-SPAN CULVERT BARREL

RATING	CONDITION	RATING	CONDITION
9	• New condition	4	• Shape: marginal, significant distortion and deflection throughout; mid-ordinate of half top arc less than 50 percent of design - Top Arc Mid-Ordinate: within 15 to 20 percent of design - Horizontal Span: more than + or - 5 percent of design • Seams: significant seam cracking all along seam; infiltration of soil causing major deflection • Metal: - Aluminum: extensive corrosion, significant attack of core alloy, - Steel: extensive heavy rust, deep pitting • Footings: rotated due erosion and undercutting; settlement has caused damage to metal arch
8	• Shape: good appearance, smooth symmetrical curvature - Top Arc Mid-Ordinate: within 11 percent of design - Horizontal Span: within 5 percent of design • Seams: properly made and tight • Metal: minor defects and damage due to construction - Aluminum: superficial corrosin, slight pitting - Steel: superficial rust, no pitting • Footings: good with no erosion	3	• Shape: poor extreme distortion and deflection in one section and ordinate of half top arc 50 to 70 percent less than design - Top Arc Mid-Ordinate: 20 to 30 percent less than design - Horizontal Span: more than + or - 6 percent of design • Seams: cracked 3" or more to either side of bolt; infiltration of backfill causing severe deflection locally • Metal: - Aluminum: extensive corrosion, attack of core alloy, scattered perforations - Steel: extensive heavy rust, deep pitting, scattered perforations • Footing: rotated, severely undercut, major cracking and spalling of footing, significant damage to structure
7	• Shape: generally good; curvature is smooth and symmetrical - Top Arc Mid-Ordinate: within 11 percent to 15 percent of design - Horizontal Span: within 5 percent of design • Seams: minor cracking at a few bolt holes; minor seam openings, possibility of backfill infiltration exists • Metal: - Aluminum: moderate corrosion, no attack of core alloy - Steel: moderate rust, slight pitting • Footings: minor differential settlement due to erosion; minor hairline cracking in footing	2	• Shape: critical, extreme distortion and deflection throughout; mid-ordinate of half top arc more than 70 percent less than design - Top Arc Mid-Ordinate: more than 30 percent less than design - Horizontal Span: more then + or - 8 percent of design • Seams: cracked from bolt to bolt; significant amounts of backfill infiltration throughout • Metal: - Aluminum: extensive perforations due to corrosion - Steel: extensive perforations due to rust • Footing: severe differential settlement has caused distortion and kinking of metal arch
6	• Shape: smooth curvature, shape is non-symetrical - Top Arc Mid-Ordinate: within 15 percent of design - Horizontal Span: more than + or - 5 percent of design • Seams: minor cracking at bolt holes along one seam; evidence of backfill infiltration • Metal: - Aluminum: significant corrosion, minor attack of core allow - Steel: fairly heavy rust, moderate pitting • Footing: differential settlement due to extensive erosion; moderate cracking of footing	1	• Shape: severe due to partial collapse; top arc curvature flat or reverse curved • Seams: failed, backfill pushing in • Road closed to traffic
5	• Shape: generally fair; significant distortion and deflection in one section;half top arcs beginning to flatten; mid-ordinate of half top arc 30 percent less than design - Top Arc Mid-Ordinate: within 15 to 20 percent of design - Horizontal Span: more than + or - 5 percent of design • Seams: major cracking in one location; infiltration of soil causing slight deflection • Metal: - Aluminum: significant corrosion, moderate attack of core alloy - Steel: scattered heavy rust, deep pitting • Footings: significant undercutting of footing and extreme differential settlement; major cracking of footing	0	• Structure: completely collapsed • Road: closed to traffic

NOTES: 1. See Coding Guide for description of Rating Scale.

2. As a starting point, select the lowest rating which matches actual conditions.

Exhibit 97. Condition rating guidelines.

Because arches are fixed on concrete footings, backfill pressures will try to flatten the sides and peak the top. Another important shape factor is symmetry. If the base channels are not square to the centerline of the structure racking may occur during erection. In racked structures, the crown moves laterally and the curvature in one side becomes flatter while the curvature in the other side increases. Backfill pressures may cause this condition to worsen.

5-6.3 High Profile Long-Span Arch--Shape Inspection.

High profile arches have a standard crown section geometry but have high large radius side walls below the springline. Curvature in these side plates is important. In shallow fills or minimum covers, the lateral soil pressures may approach or exceed the loads over the culvert. Excessive lateral forces could cause the sidewalls to flatten or buckle inward.

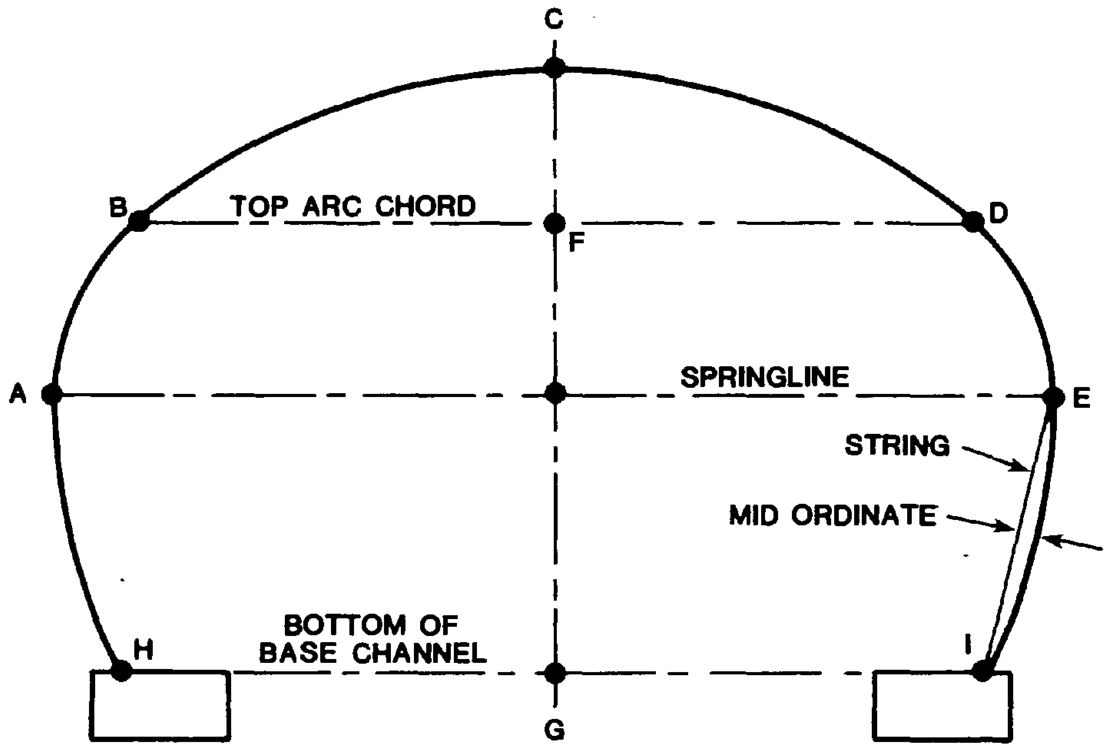
Inspectors should visually inspect high profile arches for flattening of the side plates. Additionally, high profile arches have the same tendencies as regular arches for peaking and racking, so inspectors must also look for peaked top arcs and non-symmetrical or racked arches.

Recommended measurements and elevations are shown in exhibit 98. The shape of the crown section is the most important shape factor. It can be measured and evaluated using the same criteria as that described for the standard crown section. If flattening is observed in the high sidewalls the curvature of the sides should be checked by measuring the middle ordinate of the side walls. If the sidewall middle ordinate is no more than 50 to 70 percent less than the theoretical middle ordinate and no other shape problems are found the arch's shape may be considered fair. When the middle ordinate approaches 75 to 80 percent less than theoretical, the shape should be considered marginal. If the middle ordinate is more than 80 to 90 percent less than theoretical the shape should be considered poor to critical. Rating guidelines are provided in exhibit 99.

5-6.4 Pear Shape Long-Span--Shape Inspection.

The crown section of the pear shape differs from the standard top arch in that smaller radius corner arcs stop short of the horizontal springline. The large radius sides extend above the plane of the horizontal span. In checking curvature of the sides, the entire arc should be checked. Side flattening, particularly in shallow fills, is the most critical shape factor.

The pear shape behaves similarly to the high profile arch. It is essentially a high profile with a metal bottom instead of concrete footings. Pears may be inspected using the criteria for a high profile arch. The recommended measurements and elevations are shown in exhibit 100. Rating guidelines are provided in exhibit 101.



AE = SPAN, CG = RISE

1. MINIMUM REQUIRED MEASUREMENTS
   - SPAN = AE

2. MINIMUM REQUIRED ELEVATIONS - B, C, D, H, I

3. CALCULATE CF FROM ELEVATIONS

Note: Use with exhibit 95, crown inspection.

Exhibit 98. Shape inspection high profile long-span arch.

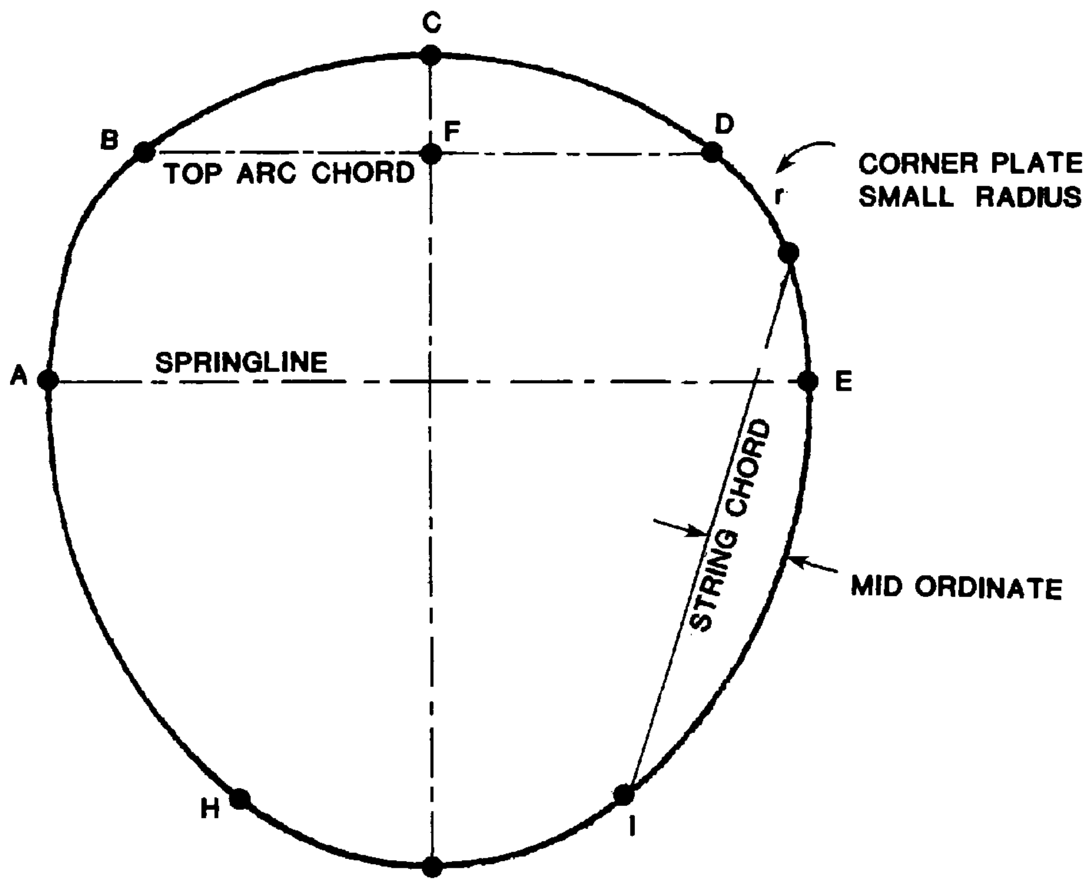
RATING GUIDELINES FOR HIGH PROFILE ARCH LONG-SPAN CULVERT BARREL

RATING	CONDITION
9	• New condition
8	• Shape: good appearance, smooth symmetrical curvature - Top Arc Mid-Ordinate: within 11 percent of design - Horizontal Span: within 5 percent of design - Side Plates: smooth curvature • Seams: properly made and tight • Metal: minor defects and damage due to construction - Aluminum: superficial corrosion, slight pitting - Steel: superficial rust, no pitting • Footings: good with no erosion
7	• Shape: generally good; curvature is smooth and symmetrical - Top Arc Mid-Ordinate: within 11 percent to 15 percent of design - Horizontal Span: within 5 percent of design - Side Plates: side flattened, mid-ordinate less than 50 percent of design • Seams: minor cracking at a few bolt holes; minor seam openings, possibility of backfill infiltration exists • Metal: - Aluminum: moderate corrosion, no attack of core alloy - Steel: moderate rust, slight pitting • Footings: minor differential settlement due to erosion; minor hairline cracking in footing
6	• Shape: smooth curvature, shape is non-symetrical - Top Arc Mid-Ordinate: within 15 percent of design - Horizontal Span: more than + or - 5 percent of design - Side Plates: side flattened, mid-ordinate less than 35 percent of design • Seams: minor cracking at bolt holes along one seam; evidence of backfill infiltration • Metal: - Aluminum: significant corrosion, minor attack of core alloy - Steel: fairly heavy rust, moderate pitting • Footing: differential settlement due to extensive erosion; moderate cracking of footing
5	• Shape: generally fair; significant distortion and deflection in one section;half top arcs beginning to flatten; mid-ordinate of half top arc 30 percent less than design - Top Arc Mid-Ordinate: within 15 to 20 percent of design - Horizontal Span: more than + or - 5 percent of design - Side Plates: side flattened, mid-ordinate less than 25 percent of design • Seams: major cracking in one location; infiltration of soil causing slight deflection • Metal: - Aluminum: significant corrosion, moderate attack of core alloy - Steel: scattered heavy rust, deep pitting • Footings: significant undercutting of footing and extreme differential settlement; major cracking of footing
4	• Shape: marginal, significant distortion and deflection throughout; mid-ordinate of half top arc less than 50 percent of design - Top Arc Mid-Ordinate: within 15 to 20 percent of design - Horizontal Span: more than + or - 5 percent of design - Side Plates: side flattened, mid-ordinate less than 20 percent of design • Seams: significant seam cracking all along seam; infiltration of soil causing major deflection • Metal: - Aluminum: extensive corrosion, significant attack of core alloy - Steel: extensive heavy rust, deep pitting • Footings: rotated due erosion and undercutting; settlement has caused damage to metal arch
3	• Shape: poor extreme distortion and deflection in one section and ordinate of half top arc 50 to 70 percent less than design - Top Arc Mid-Ordinate: 20 to 30 percent less than design - Horizontal Span: more than + or - 6 percent of design - Side Plates: side flattened, mid-ordinate less than 12 percent of design • Seams: cracked 3" or more to either side of bolt; infiltration of backfill causing severe deflection locally • Metal: - Aluminum: extensive corrosion, attack of core alloy, scattered perforations - Steel: extensive heavy rust, deep pitting, scattered perforations • Footing: rotated, severely undercut, major cracking and spalling of footing, significant damage to structure
2	• Shape: critical, extreme distortion and deflection throughout; mid-ordinate of half top arc more than 70 percent less than design - Top Arc Mid-Ordinate: more than 30 percent less than design - Horizontal Span: more then + or - 8 percent of design - Side Plates: side flattened, mid-ordinate less than10percent of design • Seams: cracked from bolt to bolt; significant amounts of backfill infiltration throughout • Metal: - Aluminum: extensive perforations due to corrosion - Steel: extensive perforations due to rust • Footing: severe differential settlement has caused distortion and kinking of metal arch
1	• Shape: severe due to partial collapse; top arc curvature flat or reverse curved - Side Plates: side flat or reversed curved • Seams: failed, backfill pushing in • Road closed to traffic
0	• Structure: completely collapsed • Road: closed to traffic

NOTES: 1. See Coding Guide for description of Rating Scale.

2. As a starting point, select the lowest rating which matches actual conditions.

Exhibit 99. Condition rating guidelines.



AE = SPAN, CG = RISE

1. MINIMUM REQUIRED MEASUREMENT - AE
   - SPAN = AE

2. MINIMUM REQUIRED ELEVATIONS B, C, D

3. WHEN FLATTENING OBSERVED IN SIDE, CHECK MID ORDINATE (RECORD CHORD LENGTH USED)

Note: Use with exhibit 95, crown inspection.

Exhibit 100. Shape inspection long span pear-shape.

RATING GUIDELINES FOR PEAR SHAPED LONG-SPAN CULVERT BARREL

RATING	CONDITION
9	• New condition
8	• Shape: good appearance, smooth symmetrical curvature - Top Arc Mid-Ordinate: within 11 percent of design - Horizontal Span: within 5 percent of design - Side Plates: smooth curvature • Seams: properly made and tight • Metal: minor defects and damage due to construction; superficial corrosion with no pitting - Aluminum: superficial corrosion, slight pitting - Steel: superficial rust, no pitting
7	• Shape: generally good; curvature is smooth and symmetrical - Top Arc Mid-Ordinate: within 11 percent to 15 percent of design - Horizontal Span: within 5 percent of design - Side Plates: side flattened, mid-ordinate less than 50 percent of design • Seams: minor cracking at a few bolt holes; minor seam openings, possibility of backfill infiltration exists • Metal: - Aluminum: moderate corrosion, no attack of core alloy - Steel: moderate rust, slight pitting
6	• Shape: smooth curvature, shape is non-symetrical - Top Arc Mid-Ordinate: within 15 percent of design - Horizontal Span: more than + or - 5 percent of design - Side Plates: side flattened, mid-ordinate less than 35 percent of design • Seams: minor cracking at bolt holes along one seam; evidence of backfill infiltration • Metal: - Aluminum: significant corrosion, minor attack of core alloy - Steel: fairly heavy rust, moderate pitting
5	• Shape: generally fair; significant distortion and deflection in one section;half top arcs beginning to flatten; mid-ordinate of half top arc 30 percent less than design - Top Arc Mid-Ordinate: within 15 to 20 percent of design - Horizontal Span: more than + or - 5 percent of design - Side Plates: side flattened, mid-ordinate less than 25 percent of design • Seams: major cracking in one location; infiltration of soil causing slight deflection • Metal: corroded locally - Aluminum: significant corrosion, moderate attack of core alloy - Steel: scattered heavy rust, deep pitting
4	• Shape: marginal, significant distortion and deflection throughout; mid-ordinate of half top arc less than 50 percent of design - Top Arc Mid-Ordinate: within 15 to 20 percent of design - Horizontal Span: more than + or - 5 percent of design - Side Plates: side flattened, mid-ordinate less than 20 percent of design • Seams: significant seam cracking all along seam; infiltration of soil causing major deflection • Metal: - Aluminum: extensive corrosion, significant attack of alloy - Steel: extensive heavy rust, deep pitting
3	• Shape: poor extreme distortion and deflection in one section and ordinate of half top arc 50 to 70 percent less than design - Top Arc Mid-Ordinate: 20 to 30 percent less than design - Horizontal Span: more than + or - 6 percent of design - Side Plates: side flattened, mid-ordinate less than 12 percent of design • Seams: cracked 3" or more to either side of bolt; infiltration of backfill causing severe deflection locally • Metal: - Aluminum: extensive corrosion, attack of core alloy, scattered perforations - Steel: extensive heavy rust, deep pitting, scattered perforations
2	• Shape: critical, extreme distortion and deflection throughout; mid-ordinate of half top arc more than 70 percent less than design - Top Arc Mid-Ordinate: more than 30 percent less than design - Horizontal Span: more then + or - 8 percent of design - Side Plates: side flattened, mid-ordinate less than10percent of design • Seams: cracked from bolt to bolt; significant amounts of backfill infiltration throughout • Metal: - Aluminum: extensive perforations due to corrosion - Steel: extensive perforations due to rust
1	• Shape: severe due to partial collapse; top arc curvature flat or reverse curved - Side Plates: side flat or reversed curved - Seams: failed, backfill pushing in • Road closed to traffic
0	• Structure: completely collapsed • Road: closed to traffic

NOTES: 1. See Coding Guide for description of Rating Scale.

2. As a starting point, select the lowest rating which matches actual conditions.

Exhibit 101. Condition rating guidelines.

5-6.5 Horizontal Ellipse--Shape Inspections.

For horizontal ellipses the most important shape factor is adequate curvature in the crown section. The crown section uses the standard long-span crown geometry. The sides and bottom behave similar to the corners and bottom of pipe arches. The invert has relatively minor pressure when compared with the sides, which may have several times the bearing pressure of the invert. As a result the corners and sides have the tendency to push down into the soil while the bottom does not move. The effect is as if the bottom pushed up. Inspectors should look for indications of bottom flattening and differential settlement between the side and bottom sections, as illustrated in exhibit 102.

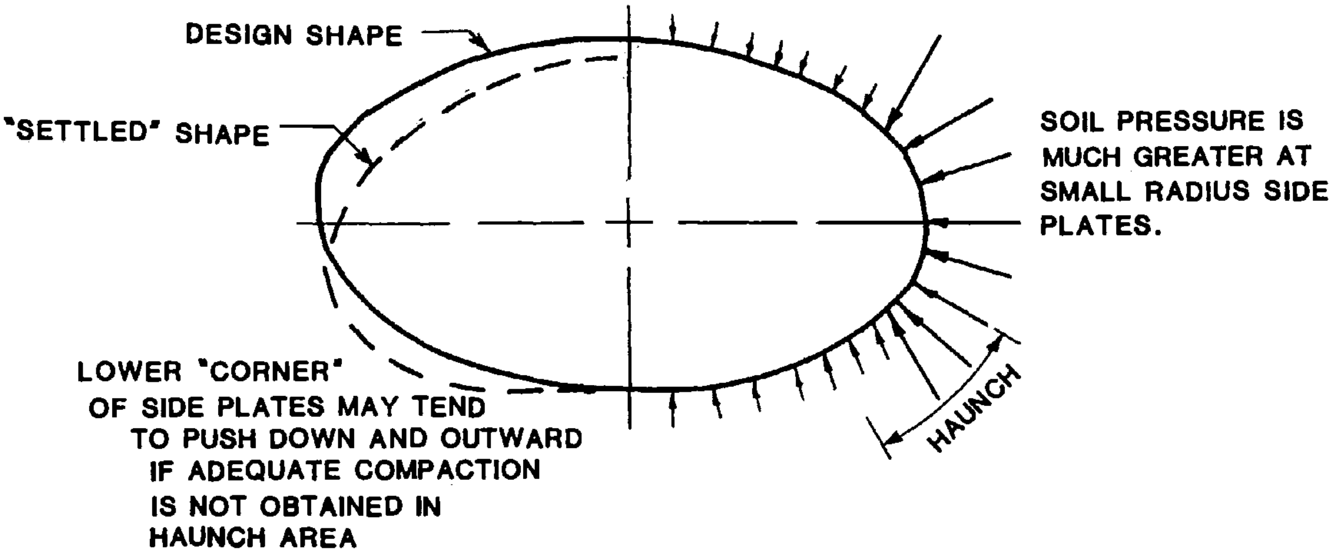
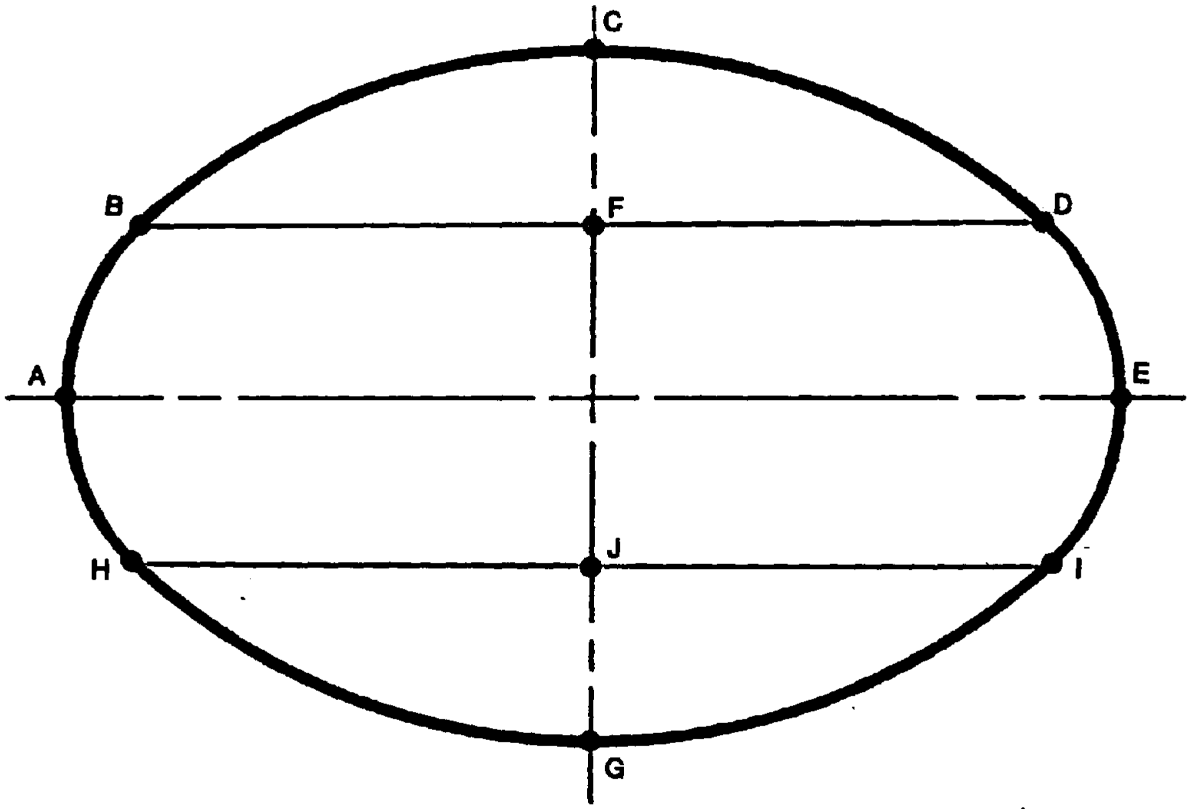


Exhibit 102. Potential for differential settlement in horizontal ellipse.

The recommended measurements and evaluations for a shape inspection of horizontal ellipse are shown in exhibit 103. The measurements are essentially the same as those recommended for a standard crown section. Shape evaluation of an ellipse is also essentially the same as the evaluation of a standard crown section except that the curvature of the bottom should also be evaluated. Marginal shape would be indicated when the bottom is flat in the center and corners are beginning to deflect downward or outward. Critical shape conditions would be indicated by reverse curvature in the bottom arc. Guidelines for rating horizontal ellipse shape culverts are provided in exhibit 104.



1. MINIMUM REQUIRED MEASUREMENTS
   - SPAN = AE

2. MINIMUM REQUIRED ELEVATIONS - B, C, D, G (IF POSSIBLE)

3. WHEN BOTTOM FLATTENING IS OBSERVED, CHECK CURVATURE, MEASURE
   - BOTTOM ARC CHORD = HI
   - BOTTOM ARC MIDDLE ORDINATE = JG

Note: Use with exhibit 95, crown inspection.

Exhibit 103. Shape inspection long-span horizontal ellipse.

RATING GUIDELINES FOR HORIZONTAL ELLIPSE LONG SPAN CULVERT BARREL

RATING	CONDITION
9	• New condition
8	• Shape: good appearance, smooth symmetrical curvature - Top Arc Mid-Ordinate: within 11 percent of design - Horizontal Span: within 5 percent of design - Bottom Arc: smooth curvature, mid-ordinate within 50 percent of design • Seams: properly made and tight • Metal: minor defects and damage due to construction - Aluminum: superficial corrosion, slight pitting - Steel: superficial rust, no pitting • Footings: good with no erosion
7	• Shape: generally good; curvature is smooth and symmetrical - Top Arc Mid-Ordinate: within 11 percent to 15 percent of design - Horizontal Span: within 5 percent of design - Bottom Arc: bottom flattened, mid-ordinate less than 50 percent of design • Seams: minor cracking at a few bolt holes; minor seam openings, possibility of backfill infiltration exists • Metal: - Aluminum: moderate corrosion, no attack of core alloy - Steel: moderate rust, slight pitting • Footings: minor differential settlement due to erosion; minor hairline cracking in footing
6	• Shape: smooth curvature, shape is non-symmetrical - Top Arc Mid-Ordinate: within 15 percent of design - Horizontal Span: more than + or - 5 percent of design - Bottom Arc: bottom flattened and irregular, mid-ordinate less than 50 percent of design • Seams: minor cracking at bolt holes along one seam; evidence of backfill infiltration • Metal: - Aluminum: significant corrosion, minor attack of core alloy - Steel: fairly heavy rust, moderate pitting • Footing: differential settlement due to extensive erosion; moderate cracking of footing
5	• Shape: generally fair; significant distortion and deflection in one section;half top arcs beginning to flatten; mid-ordinate of half top arc 30 percent less than design - Top Arc Mid-Ordinate: within 15 to 20 percent of design - Horizontal Span: more than + or - 5 percent of design - Bottom Arc: bottom virtually flat over center half of arc • Seams: major cracking in one location; infiltration of soil causing slight deflection • Metal: - Aluminum: significant corrosion, moderate attack of core alloy - Steel: scattered heavy rust, deep pitting • Footings: significant undercutting of footing and extreme differential settlement; major cracking of footing
4	• Shape: marginal, significant distortion and deflection throughout; mid-ordinate of half top arc less than 50 percent of design - Top Arc Mid-Ordinate: within 15 to 20 percent of design - Horizontal Span: more than + or - 5 percent of design - Bottom Arc: bottom virtually flat over center half of arc and deflected down at corners • Seams: significant seam cracking all along seam; infiltration of soil causing major deflection • Metal: - Aluminum: extensive corrosion, significant attack of alloy - Steel: extensive heavy rust, deep pitting • Footings: rotated due erosion and undercutting; settlement has caused damage to metal arch
3	• Shape: poor extreme distortion and deflection in one section and ordinate of half top arc 50 to 70 percent less than design - Top Arc Mid-Ordinate: 20 to 30 percent less than design - Horizontal Span: more than + or - 6 percent of design - Bottom Arc: bottom reverse curved in center • Seams: cracked 3" or more to either side of bolt; infiltration of backfill causing severe deflection locally • Metal: - Aluminum: extensive corrosion, attack of core alloy, scattered perforations - Steel: extensive heavy rust, deep pitting, scattered perforations • Footing: rotated, severely undercut, major cracking and spalling of footing, significant damage to structure
2	• Shape: critical, extreme distortion and deflection throughout; mid-ordinate of half top arc more than 70 percent less than design - Top Arc Mid-Ordinate: more than 30 percent less than design - Horizontal Span: more than + or - 8 percent of design - Bottom Arc: bottom reversed curved in center and bulged out at sides • Seams: cracked from bolt to bolt; significant amounts of backfill infiltration throughout • Metal: - Aluminum: extensive perforations due to corrosion - Steel: extensive perforations due to rust • Footing: severe differential settlement has caused distortion and kinking of metal arch
1	• Shape: severe due to partial collapse; top arc curvature flat or reverse curved • Seams: failed, backfill pushing in • Road closed to traffic
0	• Structure: completely collapsed • Road: closed to traffic

NOTES: 1. See Coding Guide for description of Rating Scale.

2. As a starting point, select the lowest rating which matches actual conditions.

Exhibit 104. Condition rating guidelines.

Section 7. PRECAST CONCRETE PIPE CULVERTS

5-7.0 General.

The principal properties of concrete, the factors causing deterioration and common signs of distress and deterioration in reinforced concrete are discussed in the Bridge Inspector's Training Manual 70 in chapter 5, section 1. The discussion in Manual 70 is primarily intended for cast-in-place bridge components and cast-in-place culverts but also applies in general to precast concrete culvert pipe. There are, however, certain important considerations related to concrete used in culverts. Precast concrete pipe is manufactured in a plant rather than in the field. The entire manufacturing process is under controlled conditions enabling the production of a uniform quality, high density concrete. Both cast-in-place and precast concrete culverts are somewhat protected by the soil backfill from rapid fluctuations in surface temperature and direct application chloride (salts) used for deicing. As a result they are generally more resistant to surface deterioration than concrete bridge elements. Concrete culverts are classified as rigid structures because they do not bend or deflect appreciably. Inspections must therefore concentrate on defects in the alignment, joints, and walls of the structure. Section 8 describes the conditions to look for when inspecting precast concrete pipe culverts. Section 9 describes the conditions to look for when inspecting cast-in-place concrete culverts.

Section 8. PRECAST CONCRETE PIPE CULVERT BARRELS

5-8.0 General

Rigid culverts such as precast concrete pipe do not deflect appreciably before cracking or fracturing. As a result shape inspections, while very important in flexible structures, are of little value in inspecting precast concrete culverts.

Although the need for soil stability and side support is obviously important with flexible pipe, it is less important with rigid pipe. However, adequate stability of the surrounding soil is necessary to prevent settlement around the culvert and to achieve load carrying capability. The inspector should therefore look for any indications of a lack of soil stability such as settlement or misalignment as well as signs of structural distress such as cracking. Descriptions of the types of distress to look for during inspection are provided in the following paragraphs. Guidelines for condition ratings of concrete pipe are included at the end of this section.

5-8.1 What to Look for During Inspection.

a. Misalignment--Misalignment may indicate the presence of serious problems in the supporting soil. The vertical and horizontal alignment of the culvert barrel should be checked by sighting along the crown and sides of the culvert and by checking for differential movement or settlement at joints between pipe sections. Vertical alignment should be checked for sags, faulting, and heaving. The inspector should be aware that pipes are occasionally laid with a camber or a grade change (broken back grade) to allow for fill settlement.

Sags which trap water may aggravate settlement problems by saturating the supporting soil. Horizontal alignment should be checked for straightness or smooth curvature for those culverts constructed with a curved alignment. Alignment problems may be caused by improper installation, undermining, or uneven settlement of fill. The inspector should attempt to determine which of those problems is causing the misalignment. If undermining is determined to be the probable cause, maintenance forces should be notified since damage will continue until the problem is corrected. The inspector should also try to determine whether the undermining is due to piping, water exfiltration, or infiltration of backfill material. When the misalignment is due to improper installation or uneven settlement, repeat inspections may be needed to determine if the settlement is still progressing or has stabilized.

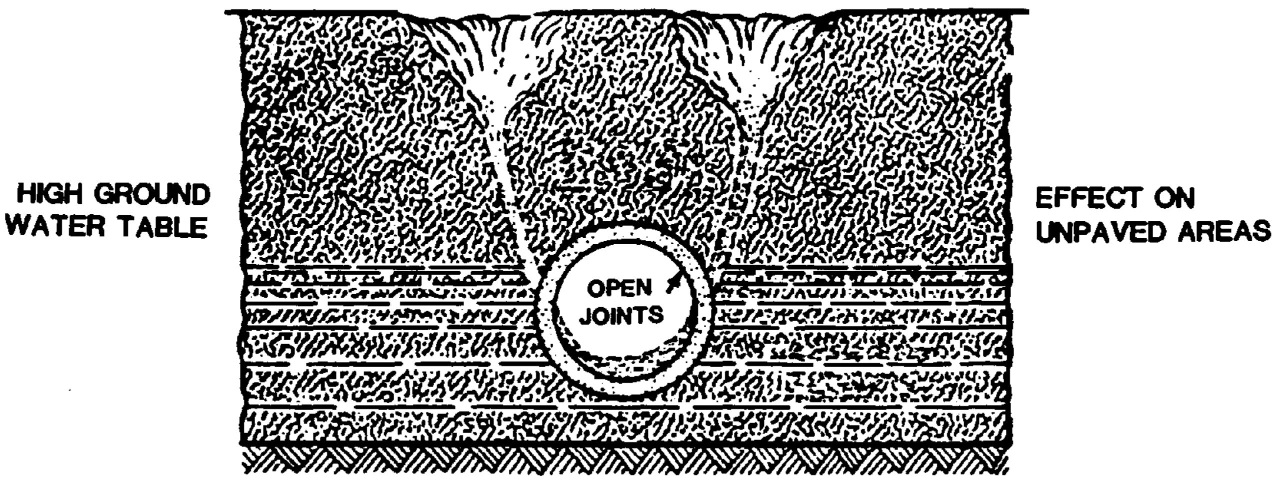
b. Joint Defects--Joint defects are fairly common and can range from minor problems to problems that are serious in nature. Typical joint defects include leakage (exfiltration and infiltration), cracks, and joint separation. Past and current criteria should be reviewed as some agencies design culverts with open joints to perform as subdrains.

(1) Exfiltration--Exfiltration occurs when leaking joints allow water flowing through the pipe to leak into the supporting material. Many culverts are built with joints that are not watertight or with mortar joints that crack with minor deflection, movement, or settlement of the pipe sections. Minor leakage may not always be a significant problem unless soils are quite erosive. However, if leaking joints contribute to or cause piping, then serious misalignment of the culvert or even failure may result. Leaking joints may be detected during low flows by visual observation of the joints and by checking around the ends of the culvert for evidence of piping.

(2) Infiltration--Infiltration is the opposite of exfiltration. Many culverts are essentially empty except during peak flows. When the water table is higher than the culvert invert, water may seep into the culvert between storms. This infiltration of water can cause settlement and misalignment problems if it carries fine grained soil particles from the surrounding backfill. Infiltration may be difficult to detect visually in its early stages although it may be indicated by open joints, staining at the joints on the sides and top of the culvert, deposits of soil in the invert, or by depressions over the culvert, as shown in exhibit 105.

(3) Cracks--Cracks in the joint area may be caused by improper handling during installation, improper gasket placement, and movement or settlement of the pipe sections. Cracked joints are more than likely not watertight even if gaskets were used. However, if no other problems are evident, such as differential movement between pipe sections, and the cracks are not open or spalling, they may be

considered a minor problem to only be noted in the inspection report. Severe joint cracks are similar in significance to separated joints.



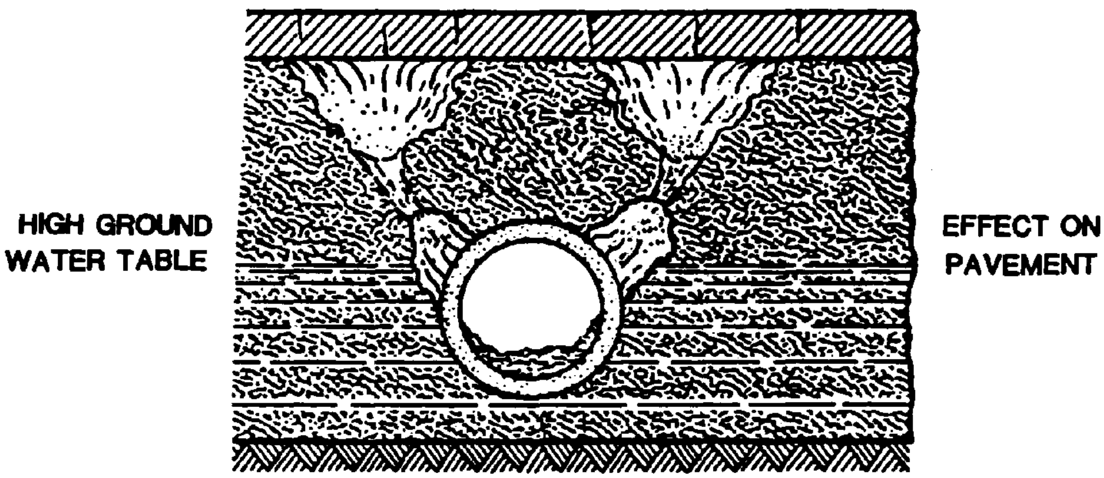


Exhibit 105. Surface indications of infiltration.

(4) Separated Joints--Joint separations may be caused by the same forces described under misalignment (settlement, undermining, or improper installation). Joint separations are significant because they accelerate damage caused by exfiltration and infiltration resulting in the erosion of the backfill material. Examples of severe infiltration through separate joints are shown in exhibits 106 and 107. Separated joints are often found when severe misalignment is found. In fact either problem may cause or aggravate the other. Movement of the soil in the general direction of the culvert's centerline may cause sections to gradually pull apart. Embankment slippage may also cause separations to occur.

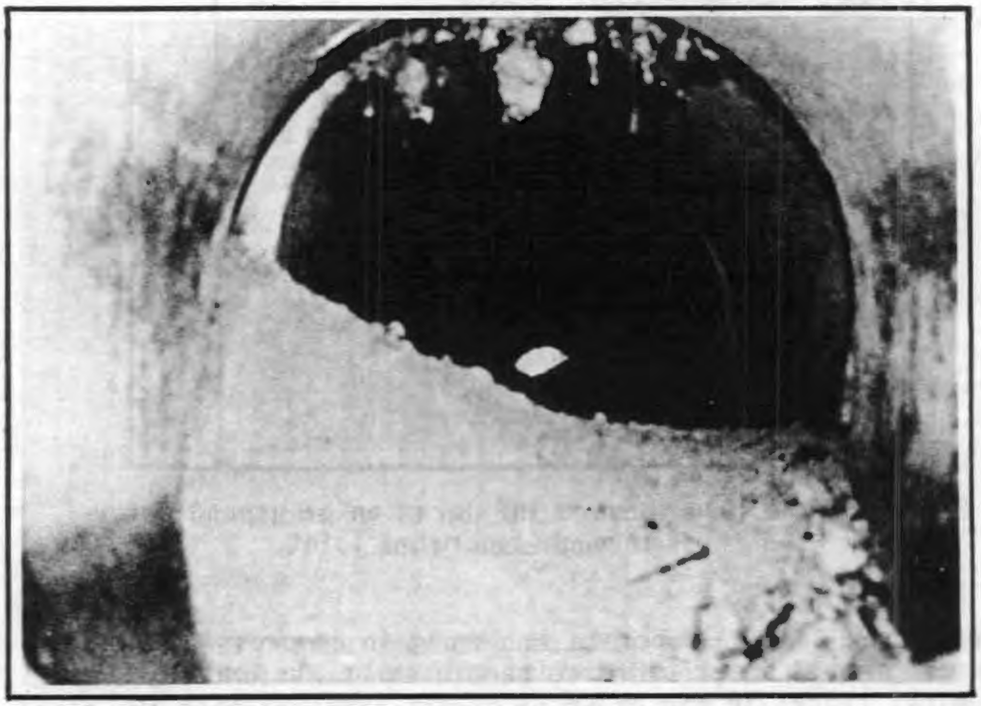


Exhibit 106. Example of severe infiltration of backfill material through separated joints.

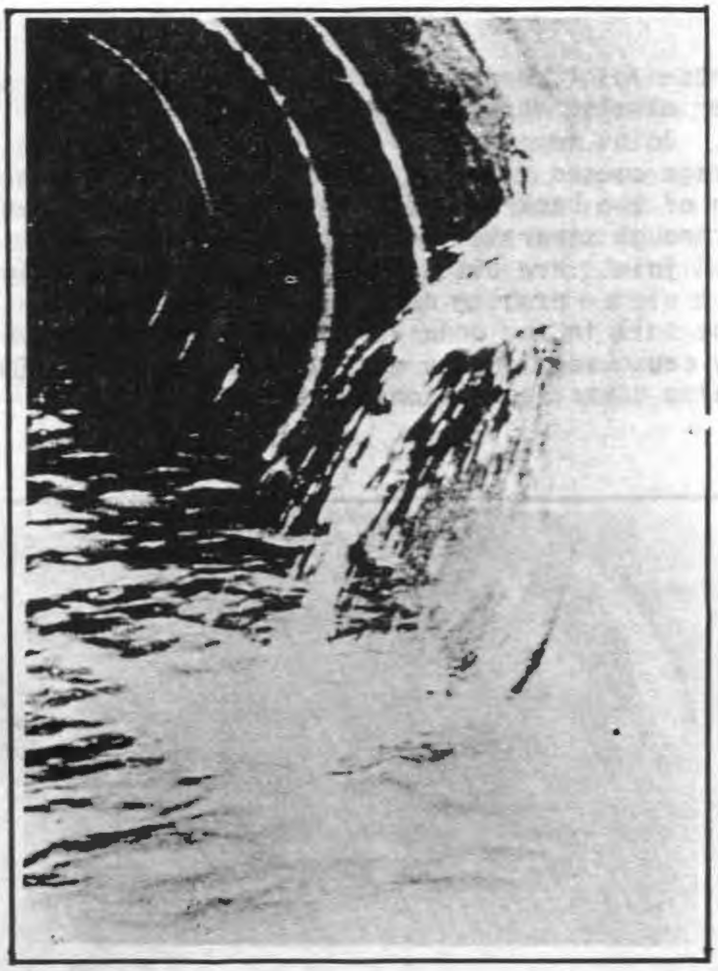


Exhibit 107. Severe infiltration of ground water through separated joint.

c. Longitudinal Cracks--Concrete is strong in compression but weak in tension. Reinforcing steel is provided to handle the tensile stresses. Hairline longitudinal cracks in the crown or invert indicate that the steel has accepted part of the load. Cracks less than 0.01 inches in width are minor and only need to be noted in the inspection report. Cracks greater than hairline cracks, or those more than 0.01 inch in width but less than 0.1 inches, should be described in the inspection report and noted as possible candidates for maintenance. Longitudinal cracking in excess of 0.1 inch in width may indicate overloading or poor bedding. If the pipe is placed on hard material and backfill is not adequately compacted around the pipe or under the haunches of the pipe, loads will be concentrated along the bottom of the pipe and may result in flexure or shear cracking, as illustrated in exhibit 108.

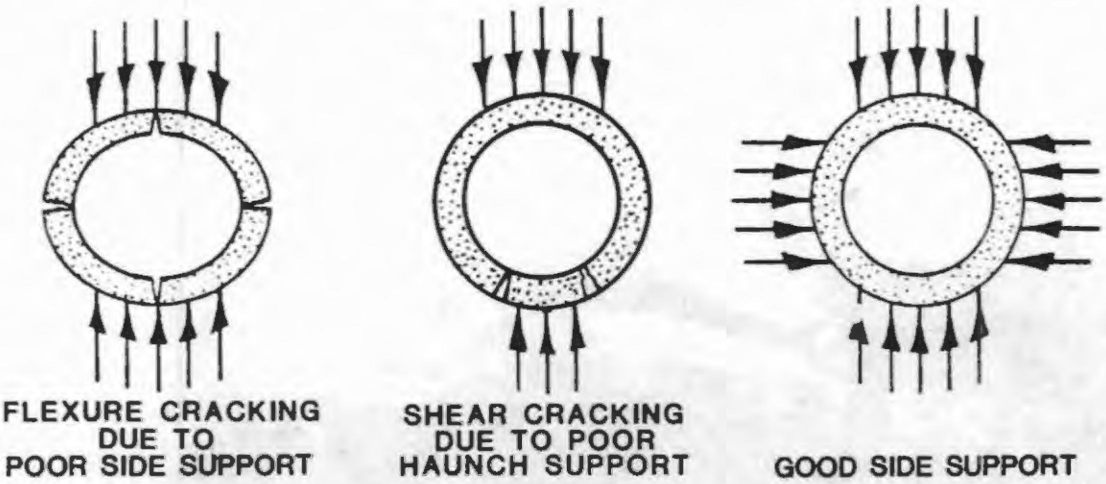


Exhibit 108. Results of poor and good side support, rigid pipe.

Other signs of distress such as differential movement, efflorescence, spalling, or rust stains should also be noted. Examples of longitudinal cracking are shown in exhibits 109 and 110. When cracks are wider than 0.1 inch measurements should be taken of fill height and the diameter of the pipe both horizontally and vertically to permit analysis of the original design. Crack measurements and photographs may be useful for monitoring conditions during subsequent inspections.

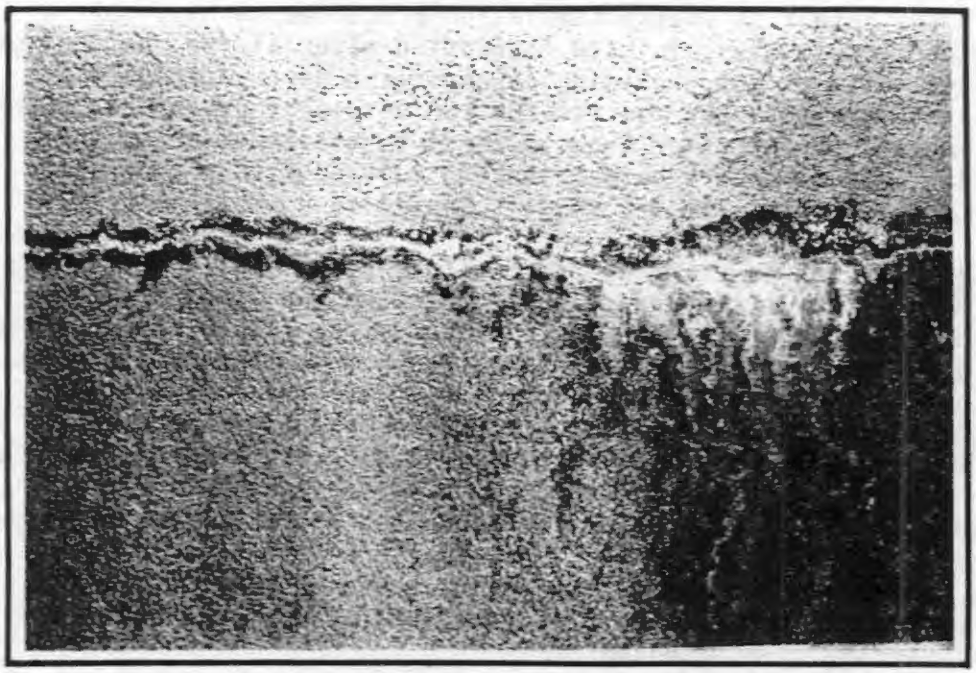


Exhibit 109. Minor longitudinal crack with efflorescence.

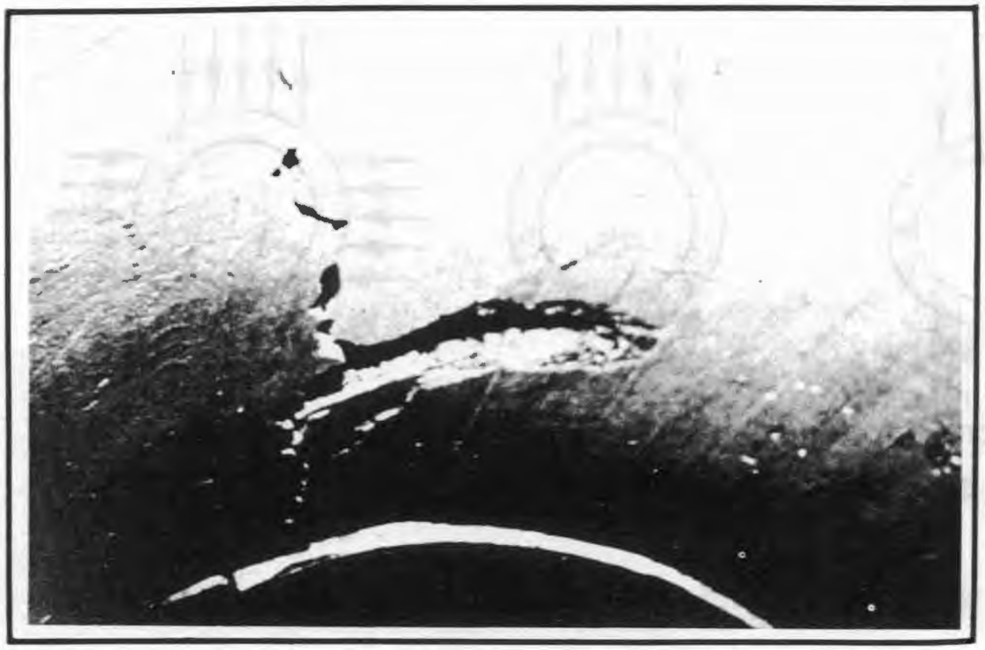
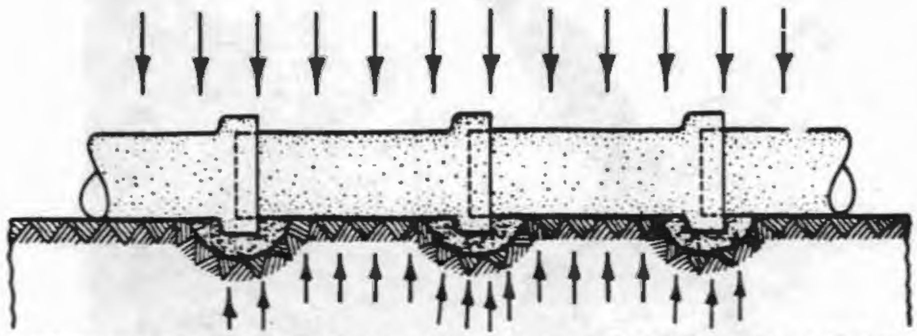


Exhibit 110. Severe longitudinal cracks with differential movement and spalling.

d. Transverse Cracks--Transverse or circumferential cracks may also be caused by poor bedding. Cracks can occur across the bottom of the pipe (broken bell) when the pipe is only supported at the ends of each section. This is generally the result of poor installation practices such as not providing indentions (bell holes) in hard foundation material for the ends of bell and spigot-type pipe or not providing a sufficient depth of suitable bedding material. Cracks may occur across the top of pipe (broken back) when settlement occurs and rocks or other areas of hard foundation material near the midpoint of a pipe section are not adequately covered with suitable bedding material. Transverse cracking is illustrated in exhibit 111.

e. Spalls--Spalling is a fracture of the concrete parallel or inclined to the surface of the concrete. In precast concrete pipe, spalls often occur along the edges of either longitudinal or transverse cracks when the crack is due to overloading or poor support rather than simple tension cracking. Spalling may also be caused by the corrosion of the steel reinforcing when water is able to reach the steel through cracks or shallow louver. As the steel corrodes, the oxidized steel expands, causing the concrete covering the steel to spall. Spalling may be detected by visual examination of the concrete along the edges of cracks. Tapping with a hammer should be performed along cracks to check for areas that have fractured but are not visibly separated. Such areas will produce a hollow sound when tapped. These areas may be referred to as delaminations or incipient spalls. Exhibit 112 shows spalling with reinforcing steel exposed.



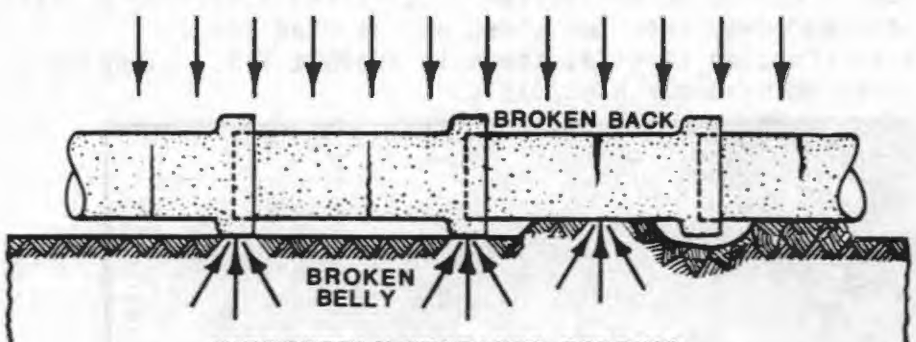


Exhibit 111. Transverse or circumferential cracks.

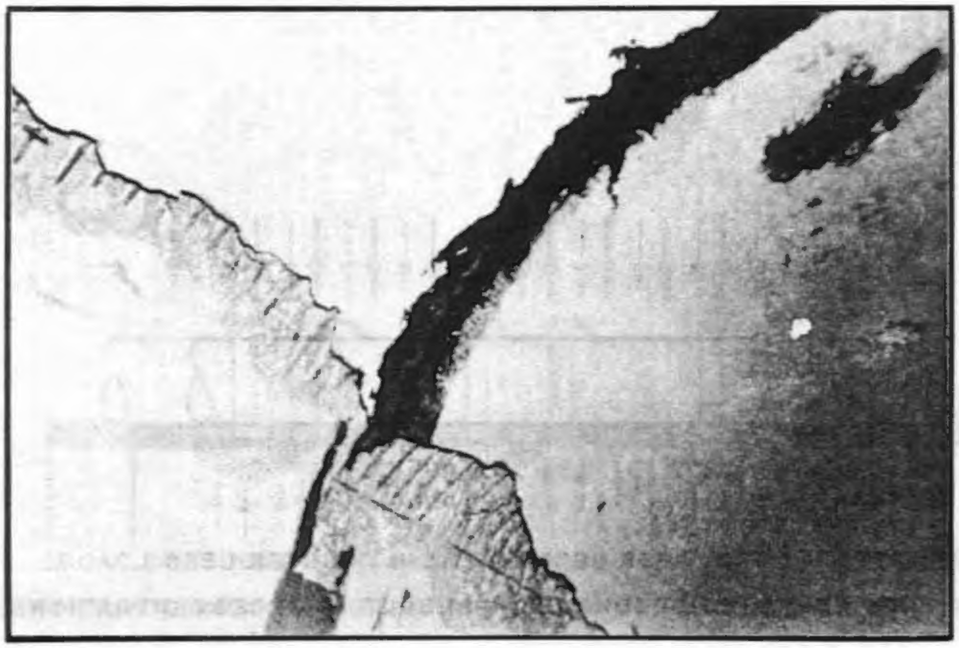


Exhibit 112. Spalling exposing reinforcing steel.

f. Slabbing--The terms slabbing, shear slabbing, or slab shear refer to a radial failure of the concrete which occurs from straightening of the reinforcement cage due to excessive deflection. It is characterized by large slabs of concrete "peeling" away from the sides of the pipe and a straightening of the reinforcing steel as shown in exhibit 113. Slabbing is a serious problem that may occur under high fills.

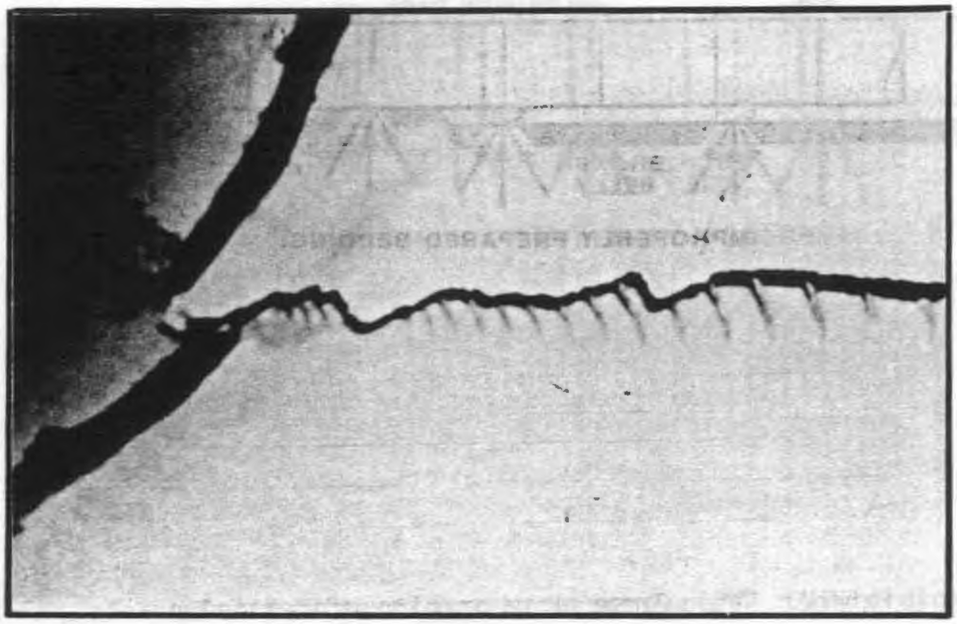


Exhibit 113. Shear slabbing.

g. Durability--Durability is a measure of a culvert's ability to withstand chemical attack and abrasion. Concrete pipes are subject to chemical attack in strongly acidic environments such as drainage from mines and may also be damaged by abrasion. Abrasion damage is a wearing away of the concrete surface by sediment and debris being transported by the stream. Mild deterioration or abrasion less than 1/4 inch deep should be noted in the report. More severe surface deterioration should be reported as a potential candidate for maintenance. In severe cases where the invert is completely deteriorated, maintenance forces should be given immediate notification. When linings are used to protect against chemical attack or abrasion the condition of the lining should be noted in the report.

h. End Section Drop-off--This type of distress is usually due to outlet erosion as discussed earlier in the sections on end treatments and waterways. It is caused by the erosion of the material supporting the pipe sections on the outlet end of the culvert barrel.

5-8.2 Condition Ratings of Concrete Pipe.

Guidelines for rating the condition of concrete pipe are provided in exhibit 114.

Section 9. CAST-IN-PLACE CONCRETE CULVERT BARRELS

5-9.0 General.

Most cast-in-place reinforced concrete culverts are single or multi-cell box culverts. Rigid frame structures are similar to concrete box culverts but are constructed without a bottom slab. Some agencies also consider small concrete arches as culverts. Cast-in-place box culverts are constructed using conventional bridge construction techniques but may function hydraulically and structurally as a culvert rather than as a bridge.

5-9.1 What to Look for During Inspection.

All components of the culvert barrel should be visually examined, including walls, floor, top slab, and joints. The concrete should be sounded by tapping with a hammer particularly around cracks and other defects. Typical types of distress to check for include the following:

a. Misalignment--The vertical and horizontal alignment should be checked by visual observation. Vertical alignment should be checked for sags, faulting, or differential settlement at joints. Sags can best be detected during low flows by looking for areas where the water is deeper, or where sediment has been deposited. When excessive accumulations of sediment are present, it may be necessary to have the sediment removed before checking for sags. An alternate method would be to take profile elevations of the top slab. The horizontal alignment can be checked by sighting along the walls and by examining joints for differential movement.

RATING GUIDELINES FOR PRECAST CONCRETE PIPE CULVERT BARRELS

RATING	CONDITION
9	• New condition
8	• Alignment: good, no settlement or misalignment • Joints: tight with no defects apparent • Concrete: no cracking, spalling, or scaling present; surface in good condition
7	• Alignment: generally good; minor misalignment at joints; no settlement • Joints: minor openings, possible infiltration/exfiltration • Concrete: minor hairline cracking at isolated locations; slight spalling or scaling present on invert
6	• Alignment: fair, minor misalignment and settlement at isolated locations • Joints: minor backfill infiltration due to slight opening at joints; minor cracking or spalling at joints allowing exfiltration • Concrete: extensive hairline cracks, some with minor delaminations or spalling; invert scaling less than 0.25 in. deep or small spalls present
5	• Alignment: generally fair; minor misalignment or settlement throughout pipe; possible piping • Joints: open and allowing backfill to infiltrate; significant cracking or joint spalling • Concrete: cracking open greater than 0.12 in. with moderate delamination and moderate spalling exposing reinforcing steel at isolated locations; large areas of invert with surface scaling or spalls greater than 0.25 in. deep
4	• Alignment: marginal; significant settlement and misalignment of pipe; evidence of piping; end sections dislocated about to drop off • Joints: differential movement and separation of joints, significant infiltration or exfiltration at joints • Concrete: cracks open more than 0.12 in. with efflorescence and spalling at numerous locations; spalls have exposed rebars which are heavily corroded; extensive surface scaling on invert greater than 0.5 in.
3	• Alignment: poor with significant ponding of water due to sagging or misalignment pipes; end section drop off has occurred • Joints: significant openings, dislocated joints in several locations exposing fill material; infiltration or exfiltration causing misalignment of pipe and settlement or depressions in roadway • Concrete: extensive cracking, spalling, and minor slabbing; invert scaling has exposed reinforcing steel
2	• Alignment: critical; culvert not functioning due to alignment problems throughout • Concrete: severe slabbing has occurred in culvert wall, invert concrete completely deteriorated in isolated locations
1	• Culvert: partially collapsed • Road: closed to traffic
0	• Culvert: total failure of culvert and fill • Road: closed to traffic

NOTES: 1. See Coding Guide for description of Rating Scale.
2. As a starting point, select the lowest rating which matches actual conditions.

Exhibit 114. Condition rating guidelines.

b. Joint Defects--Expansion joints should be carefully inspected to verify that the filler material or joint sealant is in place and that the joint is not filled with incompressible material that would prohibit expansion. Spalls or cracks along joint edges are usually an indication that the expansion joint is full of incompressible materials or that one or more expansion joints are not working. Joint inspection also should identify any joints that are opened widely or are not open to uniform width. Joints with infiltration or exfiltration should also be noted. Water flowing or seeping into the culvert through open joints may bring with it supporting soil. Water flowing out of the culvert through open joints may cause erosion of supporting material by piping.

c. Cracks and Spalls--The top slab and walls should be inspected visually for cracks and spalls. When either is observed, the area around the defect should be tapped with a hammer to detect incipient spalls. A ladder may be needed for inspecting the top slab. Longitudinal cracks in the top slab of box culverts may indicate either flexure or shear problems. Transverse cracks may indicate differential settlement. Spalls may occur along the edges of cracks or in the concrete covering corroded reinforcing steel. Cracks in the sides may be caused by settlement or earth pressure. The location, size, and length or area of all cracks and spalls should be noted in the inspection report. Photographs, such as those shown in exhibits 115 and 116.

Exhibit 115. Transverse crack in wall of reinforced concrete box culvert.

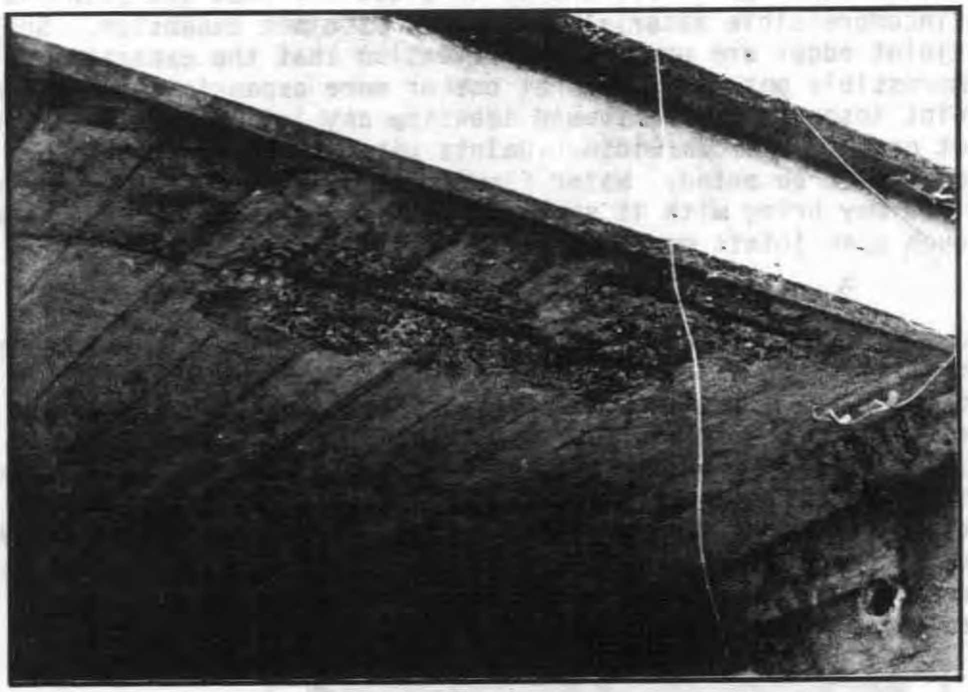


Exhibit 116. Spalls and delaminations in bottom of top slab of box culvert.

d. Durability--The concrete surfaces should be checked by visual inspection and by tapping with a hammer for unsound concrete due to chemical attack or abrasion. The bottom of the top slab, the invert slab, and the water line on the walls are the most likely areas to be damaged.

e. Footings--When an invert slab is not used and the footings are exposed, they should be inspected for undermining and scour. A probing rod or bar should be used to check for voids and scoured areas that may have filled with sediment.

f. Weep Holes--Weep holes are often provided on the sidewalls and wingwalls to drain water from the backfill and reduce the hydraulic pressure on the sidewalls. Weep holes should be inspected to determine if they are functioning properly. Lack of flow during periods when flow has previously been observed may indicate blockage. Fines in the floor also indicate improper functioning.

5-9.2 Condition Rating Guidelines.

Guidelines for rating the condition of cast-in-place concrete culverts are provided in exhibit 117.

RATING GUIDELINES FOR CAST-IN-PLACE CONCRETE CULVERT BARRELS

RATING	CONDITION
9	• New condition
8	• <u>Alignment</u>: good, no settlement or misalignment • <u>Joints</u>: tight with no defects apparent • <u>Concrete</u>: no cracking, spalling, or scaling present; surface in good condition • <u>Footings</u>: good with no invert scour
7	• <u>Alignment</u>: generally good; minor misalignment at joints; no settlement • <u>Joints</u>: joint material deteriorated at isolated locations • <u>Concrete</u>: minor hairline cracking at isolated locations; slight spalling or scaling present on invert or bottom of top slab • <u>Footings</u>: good with only minor invert scour
6	• <u>Alignment</u>: fair, minor misalignment and settlement at isolated locations • <u>Joints</u>: joint material generally deteriorated, minor separation, possible infiltration or exfiltration; minor cracking or spalling at joints allowing exfiltration • <u>Concrete</u>: extensive hairline cracks, some with minor delaminations; scaling less than 0.25 in. deep or small spalls present on invert or bottom of top slab • <u>Footings</u>: minor scour near footings
5	• <u>Alignment</u>: generally fair; minor misalignment or settlement; possible piping • <u>Joints</u>: open and allowing backfill to infiltrate; significant cracking or spalling at joints • <u>Concrete</u>: cracking open greater than 0.12 in.; significant delamination and moderate spalling exposing reinforcing steel; large areas of surface scaling greater than 0.25 in. deep • <u>Footings</u>: moderate scour along footing; protective measures may be required
4	• <u>Alignment</u>: marginal; significant settlement and misalignment; evidence of piping • <u>Joints</u>: differential movement and separation of joints, significant infiltration or exfiltration at joints • <u>Concrete</u>: extensive cracking with cracks open more than 0.12 in. with efflorescence; spalling has caused exposure of rebars which are heavily corroded; extensive surface scaling on invert greater than 0.5 in. • <u>Footings</u>: scour along footing with slight undermining, protection required
3	• <u>Alignment</u>: poor with significant ponding of water due to sagging or misalignment pipes; end section drop off has occurred • <u>Joints</u>: significant openings and differential movement; infiltration or exfiltration causing misalignment of culvert and settlement or depressions in roadway • <u>Concrete</u>: extensive cracking with spalling, delaminations, and slight differential movement; scaling has exposed reinforcing steel in bottom of top slab or invert • <u>Footings</u>: severe undermining with slight differential settlement causing minor cracking or spalling in footing and walls
2	• <u>Alignment</u>: critical; culvert not functioning due to severe misalignment • <u>Concrete</u>: severe cracks with significant differential movement; concrete completely deteriorated in isolated locations in top slab or invert • <u>Footings</u>: severe undermining with significant differential settlement causing severe cracks
1	• <u>Culvert</u>: partially collapsed • <u>Road</u>: closed to traffic • <u>Footings</u>: severe undermining resulting in partial collapse of structure
0	• <u>Culvert</u>: total failure of culvert and fill • <u>Road</u>: closed to traffic

NOTES: 1. See Coding Guide for description of Rating Scale.
2. As a starting point, select the lowest rating which matches actual conditions.

Exhibit 117. Condition rating guidelines.

Section 10. MASONRY CULVERTS

5-10.0. General.

At the present time, masonry construction is limited primarily to headwalls, wingwalls, and inlet structures. While culvert barrels are rarely constructed from masonry, a wide variety of masonry culvert barrels are still in service. Masonry culverts are generally arch-shaped or box-shaped and may be constructed of stone, brick, or concrete blocks. Stone culverts may be dry (no mortar), pointed (stones set in mortar), or cemented (stones set in concrete) masonry.

5-10.1. What to Look for During Inspection.

The walls, floors, and top of masonry culverts should be carefully inspected both visually and by tapping stones, bricks, or blocks and mortar with a geologist's hammer. The inspector should note any apparent signs of distress. Typical items to check include:

a. Masonry Units--The individual stones, bricks or blocks should be checked for displaced, cracked, broken, crushed, or missing units as illustrated in exhibits 118 and 119. For some types of masonry surface deterioration or weathering can also be a problem.

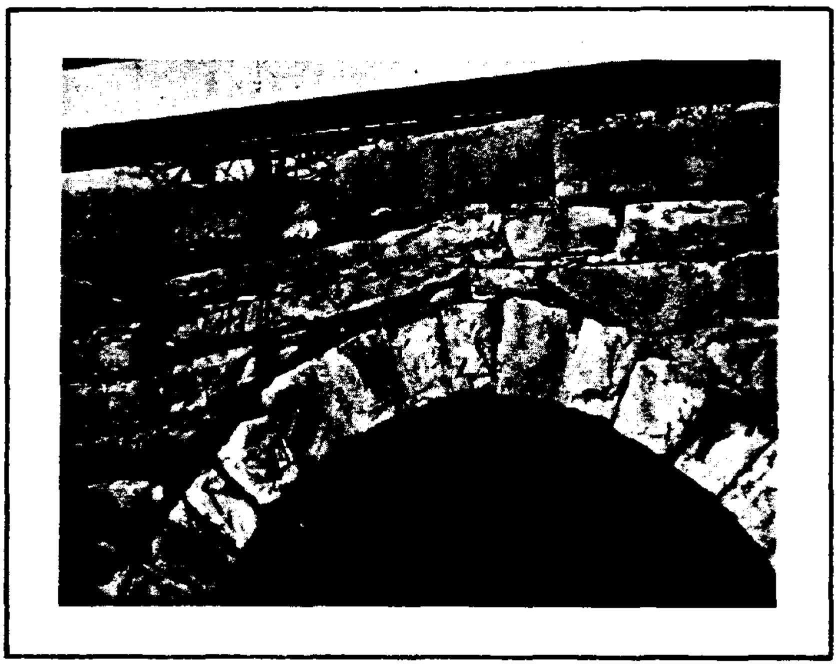


Exhibit 118. Masonry arch mortar deterioration and displaced stones in arch and headwall.

Note: Curvature of left side of arch is flatter than right side.

Exhibit 119. Masonry arch mortar deterioration and displaced stones.

b. Mortar--In most masonry arch culverts mortar is used to cement the masonry units together. The condition of the mortar should be checked to insure that it is still holding strongly. It is particularly important to note cracked, deteriorated, or missing mortar if other deterioration is present such as missing or displaced masonry units.

Although mortar is generally used, masonry culverts have been constructed which rely on the friction between well fitted stones or on the interlocking of rough-worked stones. An example is shown in exhibit 120.

Exhibit 120. Dry masonry box culvert--rough worked stones without masonry.

c. Shape--Masonry arches act primarily in compression. Flattened curvature, bulges in walls, or other shape deformations may indicate unstable soil conditions.

d. Alignment--The vertical and horizontal alignment should be checked visually.

e. Footings--Solid foundations are essential for masonry arch and box culverts. Since many of these culverts do not have floors, the footings should be inspected carefully for undermining and scour. A probing rod should be used to check for voids and scoured areas that may have filled with sediment.

5-10.3. Condition Rating Guidelines.

Guidelines for rating the condition of masonry culvert barrels are provided in exhibit 121.

RATING GUIDELINES FOR MASONRY CULVERT BARRELS

RATING	CONDITION
9	• New condition
8	• Alignment: good, no settlement or misalignment • Mortar: tight with no defects apparent • Masonry: no cracking, no missing dislocated masonry present; surface in good condition • Footings: good with no invert scour
7	• Alignment: generally good; minor misalignment at joints; no settlement • Mortar: shallow mortar deterioration at isolated locations • Masonry: surface deterioration at isolated locations • Footings: good with only minor invert scour
6	• Alignment: fair, minor misalignment or settlement • Mortar: extensive areas of shallow deterioration; missing mortar at isolated locations; possible infiltration or exfiltration; minor cracking • Masonry: minor cracking of masonry units • Footings: minor scour near footings
5	• Alignment: generally fair; minor misalignment or settlement • Mortar: mortar generally deteriorated, loose or missing mortar at isolated locations, infiltration staining apparent • Masonry: minor cracking; slight dislocation of masonry units; large areas of surface scaling • Footings: moderate scour along footing; protective measures may be required
4	• Alignment: marginal; significant settlement and misalignment • Mortar: mortar severely deteriorated, significant loss of mortar, significant infiltration or exfiltration between masonry units • Masonry: significant displacement of individual masonry units • Footings: scour along footing with slight undermining, protection required
3	• Alignment: poor with significant ponding of water due to sagging or misalignment pipes; end section drop off has occurred • Mortar: extensive areas of missing mortar; infiltration or exfiltration causing misalignment of culvert and settlement or depressions in roadway • Masonry: individual masonry units in lower part of structure missing, or crushed • Footings: severe undermining with slight differential settlement causing minor cracking or spalling in footing and minor distress in walls
2	• Alignment: critical; culvert not functioning due to severe misalignment • Masonry: individual masonry units in top of culvert missing, or crushed • Footings: severe undermining with significant differential settlement causing severe cracks in footing and distress in walls
1	• Culvert: partially collapsed • Road: closed to traffic • Footings: severe undermining resulting in partial collapse of structure
0	• Culvert: total failure of culvert and fill • Road: closed to traffic

NOTES: 1. See Coding Guide for description of Rating Scale.

2. As a starting point, select the lowest rating which matches actual conditions.

Exhibit 121. Condition rating guidelines.

Section 11. OVERALL CULVERT RATINGS

5-11.0. General.

The earlier sections of this chapter have addressed the individual components of a culvert. Overall ratings consider all of the components which make up a culvert and are useful in establishing maintenance, rehabilitation, and replacement programs and priorities.

Some of a culvert's individual components are not rated in the SI&A sheet. They are useful supplemental items in defining the condition and in determining the overall ratings. The SI&A sheet has several items that require evaluation of the culvert as a whole. The SI&A items can be divided into three categories including overall condition, load carrying capacity, and remaining life.

5-11.1. Overall Condition.

Two items on the SI&A sheet pertain to the overall condition of culverts. Item 62, Culvert and Retaining Walls, covers the condition of the culvert's structural and hydraulic components (alignment, settlement, culvert barrel, end treatment, and embankment). Item 67, Structural Condition, covers the condition of the structural components and the load carrying capacity. A culvert in good condition with a load carrying capacity lower than current standards may receive a relatively low rating for item 67 while receiving a high rating for item 62.

As described in chapter 4, overall ratings should not be an average of the ratings assigned to individual components. Very often a low rating for one component will control the overall rating; but when assigning an overall rating the inspector should consider each component and its possible effect on the culvert. The inspector should consider whether the component is functioning properly, whether it could pose a threat to safety or cause property damage, whether it could cause more extensive damage if not repaired, and whether the repairs represent rehabilitation or maintenance.

5-11.2. Load Carrying Capacity.

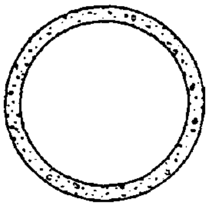
SI&A items 64, 66, and 70 are based on the loads which the structure can carry. Item 64, Operating Rating, is the maximum load the structure can carry. Item 66, Inventory Rating, is the load which can be carried repeatedly for an indefinite period of time. Item 70, Safe Load Capacity, is a rating based on an evaluation of the culvert's load carrying capacity and the state's legal load limits. The procedures used for determination of these capacity ratings should take into account the condition of the culvert at the time of the inspection.

5-11.3. Remaining Life.

Under SI&A item 63, Remaining Life, the inspector estimates the number of years that remain before major rehabilitation or replacement of the culvert is required. The estimate should be based on the design life of the barrel material, the years of service prior to the inspection, and the condition of the culvert at the time of the inspection. The current condition and the performance of the culvert material under similar conditions are the key considerations. Where durability is a problem, electrical resistivity and pH measurements may be helpful in estimating the remaining life.

STANDARD SIZES FOR CONCRETE PIPE

CIRCULAR PIPE

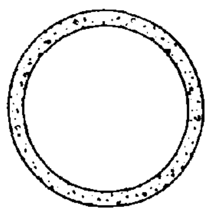


ASTM C 14—Nonreinforced Sewer and Culvert Pipe, Bell and Spigot Joint						
	Class 1		Class 2		Class 3	
Internal Diameter, inches	Minimum Wall Thickness, inches	Approx. Weight, pounds per foot	Minimum Wall Thickness, inches	Approx. Weight, pounds per foot	Minimum Wall Thickness, inches	Approx. Weight, pounds per foot
4	5/8	9.5	3/4	13	3/4	13
6	5/8	17	3/4	20	7/8	21
8	3/4	27	7/8	31	1-1/8	36
10	7/8	37	1	42	1-1/4	50
12	1	50	1-3/8	68	1-3/4	90
15	1-1/4	78	1-5/8	100	1-7/8	120
18	1-1/2	105	2	155	2-1/4	165
21	1-3/4	159	2-1/4	205	2-3/4	260
24	2-1/8	200	3	315	3-3/8	350
27	3-1/4	390	3-3/4	450	3-3/4	450
30	3-1/2	450	4-1/4	540	4-1/4	540
33	3-3/4	520	4-1/2	620	4-1/2	620
36	4	580	4-3/4	700	4-3/4	700

SOURCE: AMERICAN CONCRETE PIPE ASSOCIATION

STANDARD SIZES FOR CONCRETE PIPE

CIRCULAR
PIPE



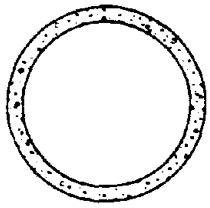
ASTM C76—Reinforced Concrete Culvert, Storm Drain and Sewer Pipe, Bell and Spigot Joint.				
Internal Diameter, inches	Wall A		Wall B	
	Minimum Wall Thickness, inches	Approximate Weight, pounds per foot	Minimum Wall Thickness, inches	Approximate Weight, pounds per foot
12	1-3/4	90	2	106
15	1-7/8	120	2-1/4	148
18	2	155	2-1/2	200
21	2-1/4	205	2-3/4	260
24	2-1/2	265	3	325
27	2-5/8	310	3-1/4	388
30	2-3/4	363	3-1/2	459

These tables are based on concrete weighing 150 pounds per cubic foot and will vary with heavier or lighter weight concrete.

SOURCE: AMERICAN CONCRETE PIPE ASSOCIATION

STANDARD SIZES FOR CONCRETE PIPE

CIRCULAR



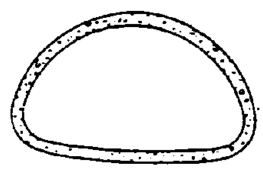
ASTM C 76 – Reinforced Concrete Culvert, Storm Drain and Sewer Pipe, Tongue and Groove Joints						
	Wall A		Wall B		Wall C	
Internal Diameter, inches	Minimum Wall Thickness, inches	Approx Weight, pounds per foot	Minimum Wall Thickness, inches	Approx Weight, pounds per foot	Minimum Wall Thickness, inches	Approx Weight, pounds per foot
12	1-3/4	79	2	93	2-3/4	133
15	1-7/8	103	2-1/4	127	3	177
18	2	131	2-1/2	168	3-1/4	225
21	2-1/4	171	2-3/4	214	3-1/2	279
24	2-1/2	217	3	264	3-3/4	366
27	2-5/8	255	3-1/4	322	4	420
30	2-3/4	295	3-1/2	384	4-1/4	476
33	2-7/8	336	3-3/4	451	4-1/2	552
36	3	383	4	524	4-3/4	654
42	3-1/2	520	4-1/2	686	5-1/4	811
48	4	683	5	867	5-3/4	1011
54	4-1/2	864	5-1/2	1068	6-1/4	1208
60	5	1064	6	1295	6-3/4	1473
66	5-1/2	1287	6-1/2	1542	7-1/4	1735
72	6	1532	7	1811	7-3/4	2015
78	6-1/2	1797	7-1/2	2100	8-1/4	2410
84	7	2085	8	2409	8-3/4	2660
90	7-1/2	2395	8-1/2	2740	9-1/4	3020
96	8	2710	9	3090	9-3/4	3355
102	8-1/2	3078	9-1/2	3480	10-1/4	3760
108	9	3446	10	3865	10-3/4	4160
114	9-1/2	3840	10-1/2	4278	11-1/4	4611
120	10	4263	11	4716	11-3/4	5066
126	10-1/2	4690	11-1/2	5175	12-1/4	5542
132	11	5148	12	5655	12-3/4	6040
138	11-1/2	5627	12-1/2	6156	13-1/4	6558
144	12	6126	13	6679	13-3/4	7098
150	12-1/2	6647	13-1/2	7223	14-1/4	7659
156	13	7190	14	7789	14-3/4	8242
162	13-1/2	7754	14-1/2	8375	15-1/4	8846
168	14	8339	15	8983	15-3/4	9471
174	14-1/2	8945	15-1/2	9612	16-1/4	10,117
180	15	9572	16	10,263	16-3/4	10,785

These tables are based on concrete weighing 150 pounds per cubic foot and will vary with heavier or lighter weight concrete.

SOURCE: AMERICAN CONCRETE PIPE ASSOCIATION

STANDARD SIZES FOR CONCRETE PIPE

ARCH PIPE



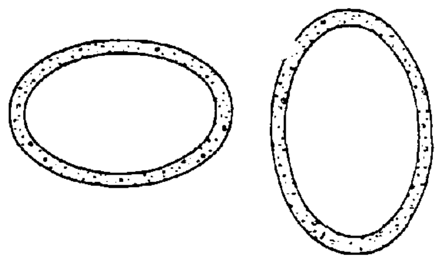
DIMENSIONS AND APPROXIMATE WEIGHTS OF CONCRETE ARCH PIPE

ASTM C 506 – Reinforced Concrete Arch Culvert, Storm Drain and Sewer Pipe					
Equivalent Round Size, inches	Minimum Rise, inches	Minimum Span, inches	Minimum Wall Thickness, inches	Water-Way Area, square feet	Approximate Weight, pounds per foot
15	11	18	2¼	1.1	114
18	13½	22	2½	1.65	170
21	15½	26	2¾	2.2	225
24	18	28½	3	2.8	320
30	22½	36¼	3½	4.4	450
36	26⅝	43¾	4	6.4	595
42	31 11/16	51⅛	4½	8.8	740
48	36	58½	5	11.4	880
54	40	65	5½	14.3	1090
60	45	73	6	17.7	1320
72	54	88	7	25.6	1840
84	62	102	8	34.6	2520
90	72	115	8½	44.5	2750
96	77¼	122	9	51.7	3110
108	87⅛	138	10	66.0	3850
120	96⅛	154	11	81.8	5040
132	106½	168¾	10	99.1	5220

SOURCE: AMERICAN CONCRETE PIPE ASSOCIATION

STANDARD SIZES FOR CONCRETE PIPE

HORIZONTAL AND VERTICAL ELLIPSE PIPE

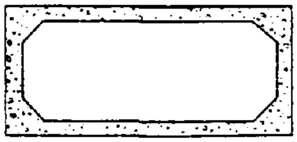


DIMENSIONS AND APPROXIMATE WEIGHTS OF ELLIPTICAL CONCRETE PIPE

ASTM C 507 – Reinforced Concrete Elliptical Culvert, Storm Drain and Sewer Pipe					
Equivalent Round Size, inches	Minor Axis, inches	Major Axis, inches	Minimum Wall Thickness, inches	Water-Way Area, square feet	Approximate Weight, pounds per foot
18	14	23	2¾	1.8	195
24	19	30	3¼	3.3	300
27	22	34	3½	4.1	365
30	24	38	3¾	5.1	430
33	27	42	3¾	6.3	475
36	29	45	4½	7.4	625
39	32	49	4¾	8.8	720
42	34	53	5	10.2	815
48	38	60	5½	12.9	1000
54	43	68	6	16.6	1235
60	48	76	6½	20.5	1475
66	53	83	7	24.8	1745
72	58	91	7½	29.5	2040
78	63	98	8	34.6	2350
84	68	106	8½	40.1	2680
90	72	113	9	46.1	3050
96	77	121	9½	52.4	3420
102	82	128	9¾	59.2	3725
108	87	136	10	66.4	4050
114	92	143	10½	74.0	4470
120	97	151	11	82.0	4930
132	106	166	12	99.2	5900
144	116	180	13	118.6	7000

SOURCE: AMERICAN CONCRETE PIPE ASSOCIATION

STANDARD SIZES FOR CONCRETE PIPE



DIMENSIONS AND APPROXIMATE WEIGHTS OF CONCRETE BOX SECTIONS

ASTM C789—PRECAST REINFORCED CONCRETE BOX SECTIONS

Span (Ft.)	Rise (Ft.)	Thickness (in.) Top Slab	Thickness (in.) Bot. Slab	Thickness (in.) Wall	Waterway Area (Sq. Feet)	Approx. Weight (lbs/ft)
3	2	4	4	4	5.8	600
3	3	4	4	4	8.8	700
4	2	5	5	5	7.7	910
4	3	5	5	5	11.7	1030
4	4	5	5	5	15.7	1160
5	3	6	6	6	14.5	1430
5	4	6	6	6	19.5	1580
5	5	6	6	6	24.5	1730
6	3	7	7	7	17.3	1880
6	4	7	7	7	23.3	2060
6	5	7	7	7	29.3	2230
6	6	7	7	7	35.3	2410
7	4	8	8	8	27.1	2600
7	5	8	8	8	34.1	2800
7	6	8	8	8	41.1	3000
7	7	8	8	8	48.1	3200
8	4	8	8	8	31.1	2800
8	5	8	8	8	39.1	3000
8	6	8	8	8	47.1	3200
8	7	8	8	8	55.1	3400
8	8	8	8	8	63.1	3600
9	5	9	9	9	43.9	3660
9	6	9	9	9	52.9	3880
9	7	9	9	9	61.9	4110
9	8	9	9	9	70.9	4330
9	9	9	9	9	79.9	4560
10	5	10	10	10	48.6	4380
10	6	10	10	10	58.6	4630
10	7	10	10	10	68.6	4880
10	8	10	10	10	78.6	5130
10	9	10	10	10	88.6	5380
10	10	10	10	10	98.6	5630
11	4	11	11	11	42.3	4880
11	6	11	11	11	64.3	5430
11	8	11	11	11	86.3	5980
11	10	11	11	11	108.3	6530
11	11	11	11	11	119.3	6810
12	4	12	12	12	46.0	5700
12	6	12	12	12	70.0	6300
12	8	12	12	12	94.5	6900
12	10	12	12	12	118.0	7500
12	12	12	12	12	142.0	8100

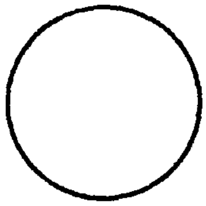
ASTM C850—PRECAST REINFORCED CONCRETE BOX SECTIONS

Span (Ft.)	Rise (Ft.)	Thickness (in.) Top Slab	Thickness (in.) Bot. Slab	Thickness (in.) Wall	Waterway Area (Sq. Feet)	Approx. Weight (lbs/ft)
3	2	7	6	4	5.8	830
3	3	7	6	4	8.8	930
4	2	7½	6	5	7.7	1120
4	3	7½	6	5	11.7	1240
4	4	7½	6	5	15.7	1370
5	3	8	7	6	14.5	1650
5	4	8	7	6	19.5	1800
5	5	8	7	6	24.5	1950
6	3	8	7	7	17.3	1970
6	4	8	7	7	23.3	2150
6	5	8	7	7	29.3	2320
6	6	8	7	7	35.3	2500
7	4	8	8	8	27.1	2600
7	5	8	8	8	34.1	2800
7	6	8	8	8	41.1	3000
7	7	8	8	8	48.1	3200
8	4	8	8	8	31.1	2800
8	5	8	8	8	39.1	3000
8	6	8	8	8	47.1	3200
8	7	8	8	8	55.1	3400
8	8	8	8	8	63.1	3600
9	5	9	9	9	43.9	3660
9	6	9	9	9	52.9	3880
9	7	9	9	9	61.9	4110
9	8	9	9	9	70.9	4330
9	9	9	9	9	79.9	4560
10	5	10	10	10	48.6	4380
10	6	10	10	10	58.6	4630
10	7	10	10	10	68.6	4880
10	8	10	10	10	78.6	5130
10	9	10	10	10	88.6	5380
10	10	10	10	10	98.6	5630
11	4	11	11	11	42.3	4880
11	6	11	11	11	64.3	5430
11	8	11	11	11	86.3	5980
11	10	11	11	11	108.3	6530
11	11	11	11	11	119.3	6810
12	4	12	12	12	46.0	5700
12	6	12	12	12	70.0	6300
12	8	12	12	12	94.5	6900
12	10	12	12	12	118.0	7500
12	12	12	12	12	142.0	8100

SOURCE: AMERICAN CONCRETE PIPE ASSOCIATION

STANDARD SIZES
FOR CORRUGATED STEEL CULVERTS

ROUND



Handling Weight of Corrugated Steel Pipe (2⅔ × ½ in.)
Estimated Average Weights—Not for Specification Use*

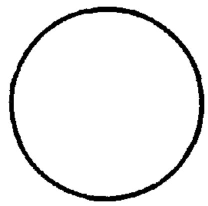
Inside Diameter, in.	Specified Thickness, in.	Approximate Pounds per Lineal Ft***			
		Galvanized	Full-Coated	Full-Coated and Invert Paved**	Full-Coated and Full Paved
12	0.052	8	10	13	
	0.064	10	12	15	
	0.079	12	14	17	
15	0.052	10	12	15	
	0.064	12	15	18	
	0.079	15	18	21	
18	0.052	12	14	17	
	0.064	15	19	22	
	0.079	18	22	25	
21	0.052	14	16	19	
	0.064	17	21	26	
	0.079	21	25	30	
24	0.052	15	17	20	
	0.064	19	24	30	45
	0.079	24	29	35	50
30	0.052	20	22	25	
	0.064	24	30	36	55
	0.079	30	36	42	60
36	0.052	24	26	29	
	0.064	29	36	44	65
	0.079	36	43	51	75
42	0.052	28	30	33	
	0.054	34	42	51	
	0.079	42	50	59	85
48	0.052	31	33	36	
	0.064	38	48	57	
	0.079	48	58	67	95
54	0.064	44	55	66	95
	0.079	54	65	76	105
60	0.079	60	71	85	
	0.109	81	92	106	140
66	0.109	89	101	117	160
	0.138	113	125	141	180
72	0.109	98	112	129	170
	0.138	123	137	154	210
78	0.109	105	121	138	200
	0.138	133	149	166	230
84	0.109	113	133	155	225
	0.138	144	161	179	240
90	0.109	121	145	167	
	0.138	154	172	192	
	0.168	186	204	224	
96	0.138	164	191	217	
	0.168	198	217	239	

*Lock seam construction only; weights will vary with other fabrication practices.
**For other coatings or linings the weights may be interpolated.
***The handling weights for 1½ × ¼ in. and 2 × ½ in. are approximately the same as for 2⅔ × ½ in.
Note: Pipe-Arch weights will be the same as the equivalent round pipe.
For example: for 42 × 29, 2⅔ × ½ in. Pipe-Arch, refer to 36 in. diameter pipe weight.
Smooth steel lined CSP weighs approximately 5% more than single wall galvanized.

SOURCE: AMERICAN IRON AND STEEL INSTITUTE

STANDARD SIZES
FOR CORRUGATED STEEL CULVERTS

ROUND



Handling Weight of Corrugated Steel Pipe (3 × 1 in. or 5 × 1 in.)***
Estimated Average Weights—Not for Specification Use

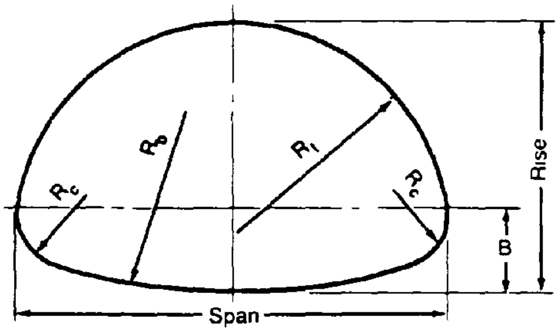
Inside Diameter, in.	Specified Thickness, in.	Approximate Pounds per Lineal Ft**			
		Galvanized	Full-Coated	Full-Coated and Invert Paved	Full-Coated and Full Paved
54	0.064	50	66	84	138
	0.079	61	77	95	149
60	0.064	55	73	93	153
	0.079	67	86	105	165
66	0.064	60	80	102	168
	0.079	74	94	116	181
72	0.064	66	88	111	183
	0.079	81	102	126	197
78	0.064	71	95	121	198
	0.079	87	111	137	214
84	0.064	77	102	130	213
	0.079	94	119	147	230
90	0.064	82	109	140	228
	0.079	100	127	158	246
96	0.064	87	116	149	242
	0.079	107	136	169	262
102	0.064	93	124	158	258
	0.079	114	145	179	279
108	0.064	98	131	166	273
	0.079	120	153	188	295
114	0.064	104	139	176	289
	0.079	127	162	199	312
120	0.064	109	146	183	296
	0.079	134	171	210	329
	0.109	183	220	259	378
126	0.079	141	179	220	346
	0.109	195	233	274	400
132	0.079	148	188	231	363
	0.109	204	244	287	419
138	0.079	154	196	241	379
	0.109	213	255	300	438
144	0.109	223	267	314	458
	0.138	282	326	373	517

*Lock seam construction only; weights will vary with other fabrication practices.
**For other coatings or linings the weights may be interpolated.
***5 × 1 in. weighs approximately 12% less than 3 × 1 in.

Note: Pipe-Arch weights will be the same as the equivalent round pipe.
For example: for 81 × 59, 3 × 1 in. pipe arch, refer to 72-in. diameter pipe weight.
Smooth steel lined CSP weighs approximately 5% more than single wall galvanized.

SOURCE: AMERICAN IRON AND STEEL INSTITUTE

STANDARD SIZES
FOR CORRUGATED STEEL CULVERTS



Sizes and Layout Details—CSP Pipe Arches
2⅔ × ½ in. Corrugation

Equiv. Diameter, in.	Span, in.	Rise, in.	Waterway Area, ft²	Layout Dimensions			
				B in.	R_c in.	R_t in.	R_b in.
15	17	13	1.1	4⅛	3½	8⅝	25⅝
18	21	15	1.6	4⅞	4⅛	10¾	33⅛
21	24	18	2.2	5⅝	4⅞	11⅞	34⅝
24	28	20	2.9	6½	5½	14	42¼
30	35	24	4.5	8⅛	6⅞	17⅞	55⅛
36	42	29	6.5	9¾	8¼	21½	66⅛
42	49	33	8.9	11⅝	9⅝	25⅛	77¼
48	57	38	11.6	13	11	28⅝	88¼
54	64	43	14.7	14⅝	12⅜	32¼	99¼
60	71	47	18.1	16¼	13¾	35¾	110¼
66	77	52	21.9	17⅞	15⅛	39⅜	121¼
72	83	57	26.0	19½	16½	43	132¼

Dimensions shown not for specification purposes, subject to manufacturing tolerances.

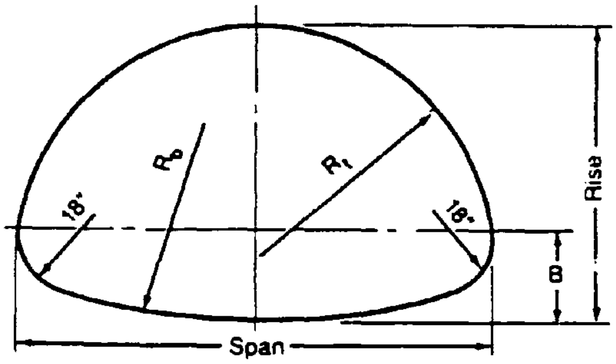
Sizes and Layout Details—CSP Pipe-Arches
3 × 1 in. Corrugation

Equiv. Diameter, in.	Size, in.	Span, in.	Rise, in.	Waterway Area, ft²	Layout Dimensions			
					B in.	R_c in.	R_t in.	R_b in.
54	60 × 46	58½	48½	15.6	20½	18¾	29⅜	51⅛
60	66 × 51	65	54	19.3	22¾	20¾	32⅝	56¼
66	73 × 55	72½	58¼	23.2	25⅛	22⅞	36¾	63¾
72	81 × 59	79	62½	27.4	23¾	20⅞	39½	82⅝
78	87 × 63	86½	67¼	32.1	25¾	22⅜	43⅜	92¼
84	95 × 67	93½	71¾	37.0	27¾	24⅜	47	100¼
90	103 × 71	101½	76	42.4	29¾	26⅛	51¼	111⅝
96	112 × 75	108½	80½	48.0	31⅝	27¾	54⅞	120¼
102	117 × 79	116½	84¾	54.2	33⅜	29½	59⅜	131¾
108	128 × 83	123½	89¼	60.5	35⅝	31¼	63¼	139¾
114	137 × 87	131	93¾	67.4	37⅜	33	67⅜	149½
120	142 × 91	138½	98	74.5	39½	34¾	71⅝	162⅜

Dimensions shown not for specification purposes, subject to manufacturing tolerances.
Similar sizes are available with 5 x 1 in. Corrugation.

SOURCE: AMERICAN IRON AND STEEL INSTITUTE

STANDARD SIZES
FOR CORRUGATED STEEL CULVERTS



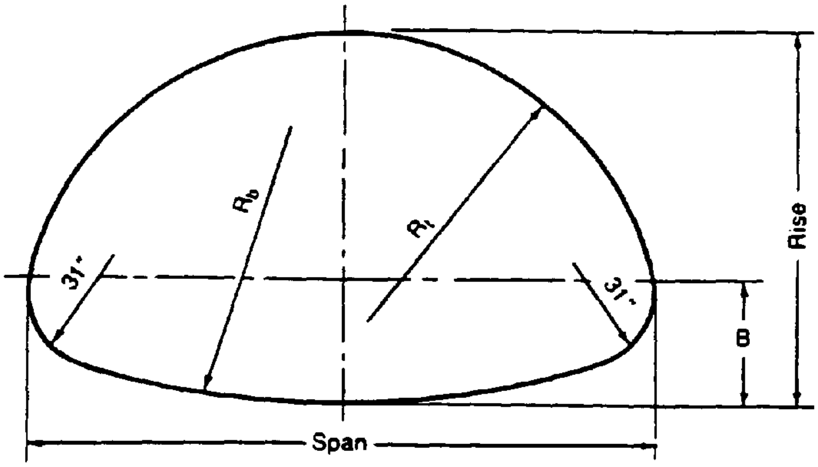
Sizes and Layout Details—Structural Plate Steel Pipe-Arches
6 × 2 in. Corrugations—Bolted Seams
18-inch Corner Radius Rc

Dimensions		Waterway Area, ft²	Layout Dimensions			Periphery		
Span, ft-in.	Rise, ft-in.		B in.	R_t ft	R_b ft	No. of Plates	Total N	Total Pi
6-1	4-7	22	21.0	3.07	6.36	5	22	66
6-4	4-9	24	20.5	3.18	8.22	5	23	69
6-9	4-11	26	22.0	3.42	6.96	5	24	72
7-0	5-1	28	21.4	3.53	8.68	5	25	75
7-3	5-3	31	20.8	3.63	11.35	6	26	78
7-8	5-5	33	22.4	3.88	9.15	6	27	81
7-11	5-7	35	21.7	3.98	11.49	6	28	84
8-2	5-9	38	20.9	4.08	15.24	6	29	87
8-7	5-11	40	22.7	4.33	11.75	7	30	90
8-10	6-1	43	21.8	4.42	14.89	7	31	93
9-4	6-3	46	23.8	4.68	12.05	7	32	96
9-6	6-5	49	22.9	4.78	14.79	7	33	99
9-9	6-7	52	21.9	4.86	18.98	7	34	102
10-3	6-9	55	23.9	5.13	14.86	7	35	105
10-8	6-11	58	26.1	5.41	12.77	7	36	108
10-11	7-1	61	25.1	5.49	15.03	7	37	111
11-5	7-3	64	27.4	5.78	13.16	7	38	114
11-7	7-5	67	26.3	5.85	15.27	8	39	117
11-10	7-7	71	25.2	5.93	18.03	8	40	120
12-4	7-9	74	27.5	6.23	15.54	8	41	123
12-6	7-11	78	26.4	6.29	18.07	8	42	126
12-8	8-1	81	25.2	6.37	21.45	8	43	129
12-10	8-4	85	24.0	6.44	26.23	8	44	132
13-5	8-5	89	26.3	6.73	21.23	9	45	135
13-11	8-7	93	28.9	7.03	18.39	9	46	138
14-1	8-9	97	27.6	7.09	21.18	9	47	141
14-3	8-11	101	26.3	7.16	24.80	9	48	144
14-10	9-1	105	28.9	7.47	21.19	9	49	147
15-4	9-3	109	31.6	7.78	18.90	9	50	150
15-6	9-5	113	30.2	7.83	21.31	10	51	153
15-8	9-7	118	28.8	7.89	24.29	10	52	156
15-10	9-10	122	27.4	7.96	28.18	10	53	159
16-5	9-11	126	30.1	8.27	24.24	10	54	162
16-7	10-1	131	28.7	8.33	27.73	10	55	165

Dimensions are to inside crests and are subject to manufacturing tolerances.
$N = 3\ Pi = 9.6$ in.

SOURCE: AMERICAN IRON AND STEEL INSTITUTE

STANDARD SIZES
FOR CORRUGATED STEEL CULVERTS



Sizes and Layout Details—Structural Plate Steel Pipe-Arches[11]
6 × 2 in. Corrugations—Bolted Seams
31-in Corner Radius, R_c

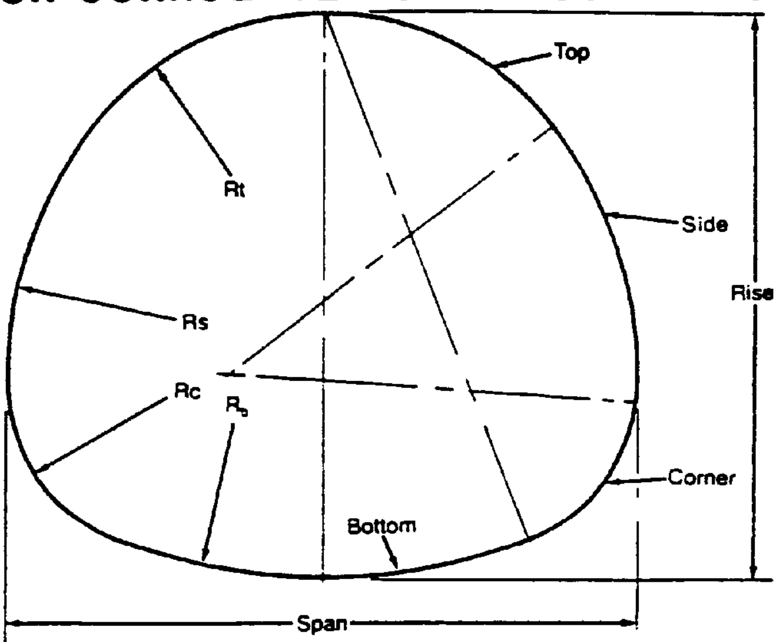
Dimensions		Waterway Area, ft²	Layout Dimensions			Periphery		
Span, ft-in.	Rise, ft-in.		B in.	R_t ft	R_b ft	No. of Plates	Total N	Total Pi
13-3	9-4	97	38.5	6.68	16.05	8	46	138
13-6	9-6	102	37.7	6.78	18.33	8	47	141
14-0	9-8	105	39.6	7.03	16.49	8	48	144
14-2	9-10	109	38.8	7.13	18.55	8	49	147
14-5	10-0	114	37.9	7.22	21.38	8	50	150
14-11	10-2	118	39.8	7.48	18.98	9	51	153
15-4	10-4	123	41.8	7.76	17.38	9	52	156
15-7	10-6	127	40.9	7.84	19.34	10	53	159
15-10	10-8	132	40.0	7.93	21.72	10	54	162
16-3	10-10	137	42.1	8.21	19.67	10	55	165
16-6	11-0	142	41.1	8.29	21.93	10	56	168
17-0	11-2	146	43.3	8.58	20.08	10	57	171
17-2	11-4	151	42.3	8.65	22.23	10	58	174
17-5	11-6	157	41.3	8.73	24.83	10	59	177
17-11	11-8	161	43.5	9.02	22.55	10	60	180
18-1	11-10	167	42.4	9.09	24.98	10	61	183
18-7	12-0	172	44.7	9.38	22.88	10	62	186
18-9	12-2	177	43.6	9.46	25.19	10	63	189
19-3	12-4	182	45.9	9.75	23.22	10	64	192
19-6	12-6	188	44.8	9.83	25.43	11	65	195
19-8	12-8	194	43.7	9.90	28.04	11	66	198
19-11	12-10	200	42.5	9.98	31.19	11	67	201
20-5	13-0	205	44.9	10.27	28.18	11	68	204
20-7	13-2	211	43.7	10.33	31.13	12	69	207

Dimensions are to inside crests and are subject to manufacturing tolerances.
N = 3 Pi = 9.6 in.

SOURCE: AMERICAN IRON AND STEEL INSTITUTE

STANDARD SIZES

FOR CORRUGATED STEEL CULVERTS



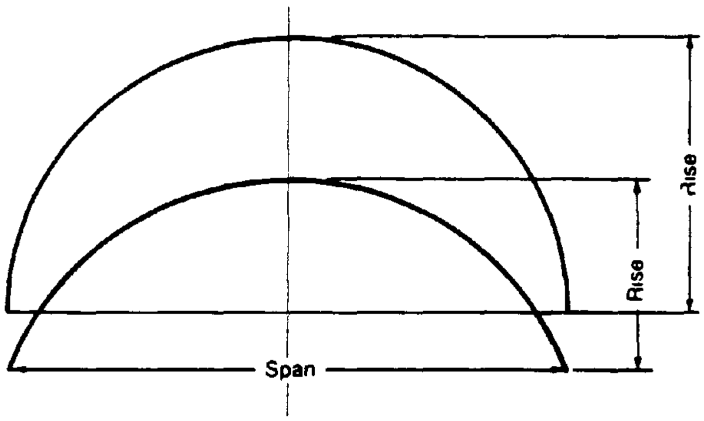
Structural Plate Steel Underpasses
Sizes and Layout Details

Span × Rise, ft and in.		Periphery			Layout Dimensions in In.			
		N	Pi	No. of Plates per Ring	R_t	R_s	R_c	R_b
5-8	5-9	24	72	6	27	53	18	Flat
5-8	6-6	26	78	6	29	75	18	Flat
5-9	7-4	28	84	6	28	95	18	Flat
5-10	7-8	29	87	7	30	112	18	Flat
5-10	8-2	30	90	6	28	116	18	Flat
12-2	11-0	47	141	8	68	93	38	136
12-11	11-2	49	147	9	74	92	38	148
13-2	11-10	51	153	11	73	102	38	161
13-10	12-2	53	159	11	77	106	38	168
14-1	12-10	55	165	11	77	115	38	183
14-6	13-5	57	171	11	78	131	38	174
14-10	14-0	59	177	11	79	136	38	193
15-6	14-4	61	183	12	83	139	38	201
15-8	15-0	63	189	12	82	151	38	212
16-4	15-5	65	195	12	86	156	38	217
16-5	16-0	67	201	12	88	159	38	271
16-9	16-3	68	204	12	89	168	38	246
17-3	17-0	70	210	12	90	174	47	214
18-4	16-11	72	216	12	99	157	47	248
19-1	17-2	74	222	13	105	156	47	262
19-6	17-7	76	228	13	107	158	47	295
20-4	17-9	78	234	13	114	155	47	316

All dimensions, to nearest whole number, are measured from inside crests.
Tolerances should be allowed for specification purposes. 6 × 2 in. Corrugations.

SOURCE: AMERICAN IRON AND STEEL INSTITUTE

STANDARD SIZES
FOR CORRUGATED STEEL CULVERTS



Representative Sizes of Structural Plate Steel Arches

Dimensions(¹)		Waterway Area, ft²	Rise over Span(²)	Radius, in.	Nominal Arc Length	
Span, ft	Rise, ft-in.				N(³)	Pi, in.
6.0	1-9½	7½	0.30	41	9	27
	2-3½	10	0.38	37½	10	30
	3-2	15	0.53	36	12	36
7.0	2-4	12	0.34	45	11	33
	2-10	15	0.40	43	12	36
	3-8	20	0.52	42	14	42
8.0	2-11	17	0.37	51	13	39
	3-4	20	0.42	48½	14	42
	4-2	26	0.52	48	16	48
9.0	2-11	18½	0.32	59	14	42
	3-10½	26½	0.43	55	16	48
	4-8½	33	0.52	54	18	54
10.0	3-5½	25	0.35	64	16	48
	4-5	34	0.44	60½	18	54
	5-3	41	0.52	60	20	60
11.0	3-6	27½	0.32	73	17	51
	4-5½	37	0.41	67½	19	57
	5-9	50	0.52	66	22	66
12.0	4-0½	35	0.34	77½	19	57
	5-0	45	0.42	73	21	63
	6-3	59	0.52	72	24	72
13.0	4-1	38	0.32	86½	20	60
	5-1	49	0.39	80½	22	66
	6-9	70	0.52	78	26	78
14.0	4-7½	47	0.33	91	22	66
	5-7	58	0.40	86	24	72
	7-3	80	0.52	84	28	84

(Table continued on following page)

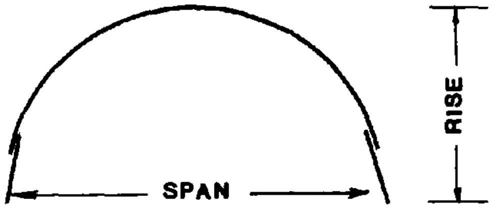
(¹)Dimensions are to inside crests and are subject to manufacturing tolerances.
(²)R/S ratio varies from 0.30 to 0.52. Intermediate spans and rises are available.
(³)N = 3 Pi = 9.6 in. 6 × 2 in. Corrugations—Bolted Seams.

SOURCE: AMERICAN IRON AND STEEL INSTITUTE

STANDARD SIZES

FOR CORRUGATED STEEL CULVERTS

ARCH



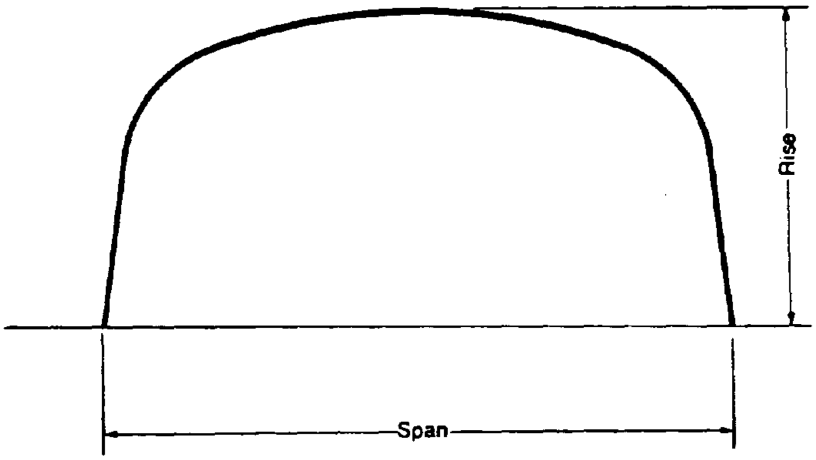
Continued. Representative Sizes of Structural Plate Steel Arches

Dimensions(¹)		Waterway Area, ft²	Rise over Span(²)	Radius, in.	Nominal Arc Length	
Span, ft	Rise, ft-in.				N(³)	Pi, in.
15.0	4-7½	50	0.31	101	23	69
	5-8	62	0.38	93	25	75
	6-7	75	0.44	91	27	81
	7-9	92	0.52	90	30	90
16.0	5-2	60	0.32	105	25	75
	7-1	86	0.45	97	29	87
	8-3	105	0.52	96	32	96
17.0	5-2½	63	0.31	115	26	78
	7-2	92	0.42	103	30	90
	8-10	119	0.52	102	34	102
18.0	5-9	75	0.32	119	28	84
	7-8	104	0.43	109	32	96
	8-11	126	0.50	108	35	105
19.0	6-4	87	0.33	123	30	90
	8-2	118	0.43	115	34	102
	9-5½	140	0.50	114	37	111
20.0	6-4	91	0.32	133	31	93
	8-3½	124	0.42	122	35	105
	10-0	157	0.50	120	39	117
21.0	6-11	104	0.33	137	33	99
	8-10	140	0.42	128	37	111
	10-6	172	0.50	126	41	123
22.0	6-11	109	0.31	146	34	102
	8-11	146	0.40	135	38	114
	11-0	190	0.50	132	43	129
23.0	8-0	134	0.35	147	37	111
	9-10	171	0.43	140	41	123
	11-6	208	0.50	138	45	135
24.0	8-6	150	0.35	152	39	117
	10-4	188	0.43	146	43	129
	12-0	226	0.50	144	47	141
25.0	8-6½	155	0.34	160	40	120
	10-10½	207	0.43	152	45	135
	12-6	247	0.50	150	49	147

(¹)Dimensions are to inside crests and are subject to manufacturing tolerances.
(²)R/S ratio varies from 0.30 to 0.52. Intermediate spans and rises are available.
(³)N = 3 Pi = 9.6 in. 6 × 2 in. Corrugations—Bolted Seams.

SOURCE: AMERICAN IRON AND STEEL INSTITUTE

STANDARD SIZES
FOR CORRUGATED STEEL CULVERTS



Layout Details
Corrugated Steel Box Culverts

Rise, ft-in.	Span, ft-in.	Area ft²	Rise, ft-in.	Span, ft-in.	Area ft²
2-7	9-8	20.8	3-9	12-10	41.0
2-8	10-5	23.2	3-10	13-6	44.5
2-9	11-1	25.7	3-10	17-4	55.0
2-10	11-10	28.3	3-11	14-2	48.2
2-11	12-6	31.1	3-11	18-0	59.1
3-1	13-3	34.0	4-1	14-10	52.0
3-2	13-11	37.1	4-1	18-8	63.4
3-3	14-7	40.4	4-2	10-7	36.4
3-4	10-1	28.4	4-2	15-6	55.9
3-5	10-10	31.4	4-3	11-2	39.9
3-5	15-3	43.8	4-3	19-4	67.9
3-6	11-6	34.5	4-4	11-10	43.5
3-6	16-0	47.3	4-4	16-2	60.1
3-8	12-2	37.7	4-5	12-6	47.3
3-8	16-8	51.1	4-6	13-2	51.2

SOURCE: AMERICAN IRON AND STEEL INSTITUTE

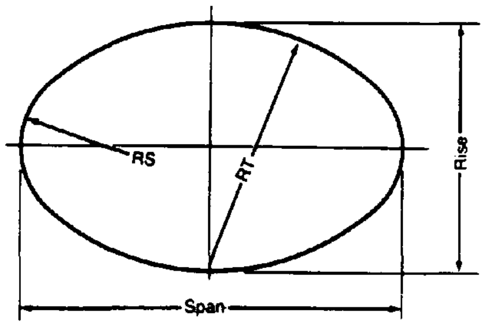
STANDARD SIZES
FOR CORRUGATED STEEL CULVERTS

Continued.
Layout Details Corrugated Steel Box Culverts

Rise, ft-in.	Span, ft-in.	Area ft²	Rise, ft-in.	Span, ft-in.	Area ft²
4-6	16-10	64.4	6-9	13-7	77.9
4-7	17-6	68.9	6-9	16-9	99.3
4-7	20-8	77.6	6-10	14-2	83.3
4-8	13-10	55.3	6-10	17-4	105.1
4-9	14-6	59.5	7-0	14-9	88.9
4-9	18-1	73.5	7-0	17-11	111.1
4-10	15-1	63.8	7-0	20-8	127.2
4-11	11-0	44.7	7-1	15-4	94.6
4-11	18-9	78.4	7-2	18-6	117.3
5-0	11-7	48.7	7-3	12-3	71.5
5-0	15-9	68.3	7-3	15-10	100.5
5-1	12-3	52.9	7-4	12-10	77.1
5-1	16-4	73.0	7-4	16-5	106.5
5-1	19-5	83.4	7-4	19-1	123.6
5-2	12-10	57.2	7-5	13-5	82.8
5-3	17-0	77.8	7-6	13-11	88.6
5-4	13-6	61.7	7-6	17-0	112.7
5-5	14-1	66.2	7-8	14-6	94.5
5-5	17-7	82.8	7-8	17-6	119.0
5-5	20-8	94.1	7-9	15-0	100.6
5-6	14-9	71.0	7-9	18-1	125.5
5-7	18-3	88.0	7-11	15-7	106.8
5-8	11-5	53.3	7-11	18-7	132.1
5-8	15-4	75.8	8-0	12-8	81.1
5-8	18-10	93.4	8-0	16-1	113.1
5-9	12-0	57.9	8-1	19-2	138.9
5-9	16-0	80.9	8-2	16-8	119.6
5-10	12-7	62.6	8-2	13-9	93.3
5-10	19-6	98.9	8-3	19-8	145.9
5-11	16-7	86.1	8-4	17-2	126.2
6-0	13-3	67.4	8-5	14-10	106.0
6-1	13-10	72.4	8-5	17-8	133.0
6-1	17-2	91.4	8-7	18-3	139.9
6-2	14-5	77.5	8-7	20-9	160.3
6-2	17-9	96.9	8-8	15-10	119.2
6-2	20-8	110.6	8-9	18-9	147.0
6-4	15-0	82.7	8-11	16-10	132.9
6-4	18-4	102.6	8-11	19-3	154.2
6-5	11-10	62.2	9-1	19-9	161.6
6-5	15-7	88.1	9-3	17-10	147.1
6-6	18-11	108.5	9-5	20-9	176.9
6-7	12-5	67.3	9-6	18-10	162.0
6-7	16-2	93.6	9-10	19-10	177.4
6-8	13-0	72.5	10-2	20-9	193.5
6-8	19-6	114.5			

SOURCE: AMERICAN IRON AND STEEL INSTITUTE

STANDARD SIZES
FOR CORRUGATED STEEL CULVERTS

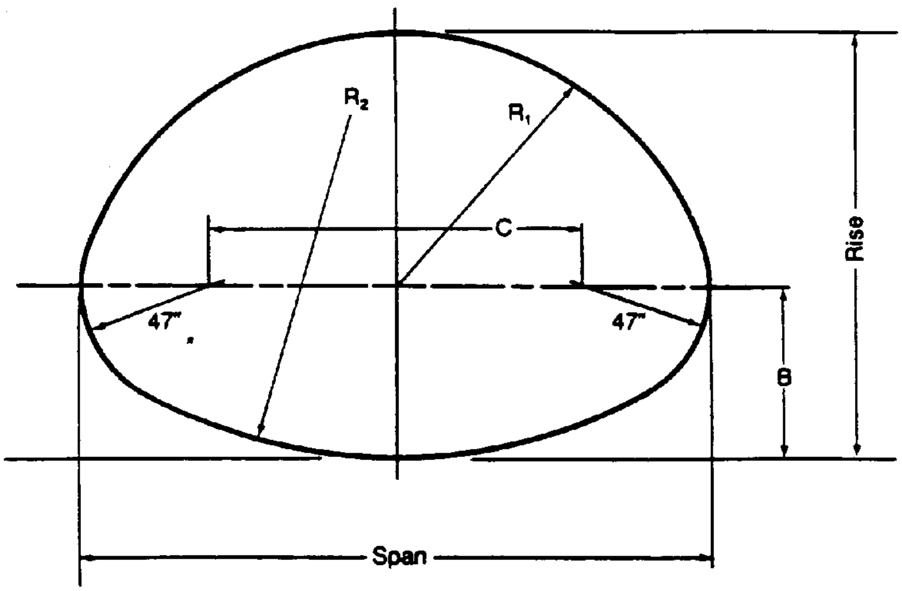


Long Span Horizontal Ellipse Sizes and Layout Details

Span, ft-in.	Rise, ft-in.	Area, ft²	Periphery						Inside Radius	
			Top or Bottom		Side		Total		Top Rad. in.	Side Rad. in.
			N	Pi	N	Pi	N	Pi		
19- 4	12- 9	191	22	66	10	30	64	192	12- 6	4- 6
20- 1	13- 0	202	23	69	10	30	66	198	13- 1	4- 6
20- 2	11-11	183	24	72	8	24	64	192	13- 8	3- 7
20-10	12- 2	194	25	75	8	24	66	198	14- 3	3- 7
21- 0	15- 2	248	23	69	13	39	72	216	13- 1	5-11
21-11	13- 1	221	26	78	9	27	70	210	14-10	4- 1
22- 6	15- 8	274	25	75	13	39	76	228	14- 3	5-11
23- 0	14- 1	249	27	81	10	30	74	222	15- 5	4- 6
23- 3	15-11	288	26	78	13	39	78	234	14-10	5-11
24- 4	16-11	320	27	81	14	42	82	246	15- 5	6- 4
24- 6	14- 8	274	29	87	10	30	78	234	16- 6	4- 6
25- 2	14-11	287	30	90	10	30	80	240	17- 1	4- 6
25- 5	16- 9	330	29	87	13	39	84	252	16- 6	5-11
26- 1	18- 2	369	29	87	15	45	88	264	16- 6	6-10
26- 3	15-10	320	31	93	11	33	84	252	17- 8	4-11
27- 0	16- 2	334	32	96	11	33	86	258	18- 3	4-11
27- 2	19- 1	405	30	90	16	48	92	276	17- 1	7- 3
27-11	19- 5	421	31	92	16	48	94	282	17- 8	7- 3
28- 1	17- 1	369	33	99	12	36	90	270	18-10	5- 5
28-10	17- 5	384	34	102	12	36	92	276	19- 5	5- 5
29- 5	19-11	455	33	99	16	48	98	294	18-10	7- 3
30- 1	20- 2	472	34	102	16	48	100	300	19- 5	7- 3
30- 3	17-11	415	36	108	12	36	96	288	20- 7	5- 5
31- 2	21- 2	512	35	105	17	51	104	312	20- 0	7- 9
31- 4	18-11	454	37	111	13	39	100	300	21- 1	5-11
32- 1	19- 2	471	38	114	13	39	102	306	21- 8	5-11
32- 3	22- 2	555	36	108	18	54	108	324	20- 7	8- 2
33- 0	22- 5	574	37	111	18	54	110	330	21- 1	8- 2
33- 2	20- 1	512	39	117	14	42	106	318	22- 3	6- 4
34- 1	23- 4	619	38	114	19	57	114	342	21- 8	8- 8
34- 7	20- 8	548	41	123	14	42	110	330	23- 5	6- 4
34-11	21- 4	574	41	123	15	45	112	336	23- 5	6-10
35- 1	24- 4	665	39	117	20	60	118	354	22- 3	9- 1
35- 9	25- 9	718	39	117	22	66	122	366	22- 3	10- 0
36- 0	22- 4	619	42	126	16	48	116	348	24- 0	7- 3
36-11	25- 7	735	41	123	21	63	124	372	23- 5	9- 7
37- 2	22- 2	631	44	132	15	45	118	354	25- 2	6-10
38- 0	26- 7	785	44	132	22	66	128	384	24- 0	10- 0
38- 8	27-11	843	42	126	24	72	132	396	24- 0	10-11
40- 0	29- 7	927	43	129	26	78	138	414	27-11	11-10

SOURCE: AMERICAN IRON AND STEEL INSTITUTE

STANDARD SIZES
FOR CORRUGATED STEEL CULVERTS



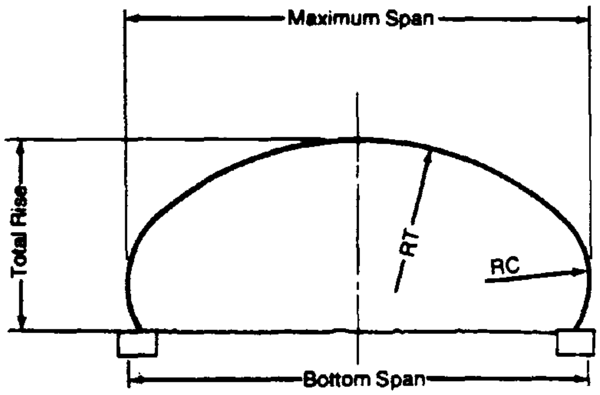
Long Span Pipe Arch Sizes and Layout Details

Span, ft-in.	Rise, ft-in.	Area, ft²	Total No. Plates	Periphery						B, in.	C, in.	Inside Radius	
				Top		Bottom		Total				R_1, in.	R_2, in.
				N	Pi	N	Pi	N	Pi				
20- 0	13-11	218	10	34	102	20	60	68	204	62.8	146.2	122.5	223.6
20- 6	14- 3	231	10	36	108	20	60	70	210	61.4	152.3	124.7	255.7
21- 5	14- 6	243	11	36	108	22	66	72	216	65.3	162.8	131.4	236.7
21-11	14-11	256	11	38	114	22	66	74	222	63.7	168.9	133.5	268.1
22- 5	15- 3	270	11	40	120	22	66	76	228	62.1	174.6	135.5	307.1
23- 4	15- 7	284	11	40	120	24	72	78	234	66.2	185.5	142.4	280.2
24- 2	15-11	297	12	40	120	26	78	80	240	70.7	196.2	149.7	262.1
24- 8	16- 2	312	12	42	126	26	78	82	246	68.8	202.2	151.4	292.2
25- 2	16- 7	326	12	44	132	26	78	84	252	66.9	207.9	153.2	328.6
25- 7	16-11	342	12	46	138	26	78	86	258	64.8	213.3	155.0	373.3
26- 7	17- 3	357	12	46	138	28	84	88	264	69.4	224.7	162.1	339.4
27- 6	17- 6	372	12	46	138	30	90	90	270	74.2	235.8	169.6	315.8
28- 0	17-10	388	12	48	144	30	90	92	276	72.1	241.5	171.1	350.2
28- 5	18- 3	405	13	50	150	30	90	94	282	69.9	246.8	172.7	392.3
29- 4	18- 6	421	13	50	150	32	96	96	288	74.8	258.2	180.2	361.1
30- 4	18-10	438	14	52	156	34	102	100	300	80.0	269.4	188.2	339.1

*Includes 14N for two N7 corner plates.

SOURCE: AMERICAN IRON AND STEEL INSTITUTE

STANDARD SIZES
FOR CORRUGATED STEEL CULVERTS



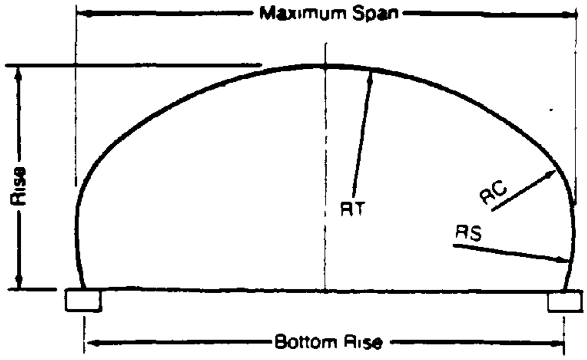
Long Span Low Profile Arch Sizes and Layout Details

Max. Span, ft-in.	Bottom Span, ft-in.	Total Rise, ft-in.	Area, ft²	Periphery						Inside Radius	
				Top		Side		Total		Top rad. in.	Side rad. in.
				N	Pi	N	Pi	N	Pi		
20- 1	19-10	7- 6	121	23	69	6	18	35	105	13- 1	4- 6
19- 5	19- 1	6-10	105	23	69	5	15	33	99	13- 1	3- 7
21- 6	21- 4	7- 9	134	25	75	6	18	37	111	14- 3	4- 6
22- 3	22- 1	7-11	140	26	78	6	18	38	114	14-10	4- 6
23- 0	22- 9	8- 0	147	27	81	6	18	39	117	15- 5	4- 6
23- 9	23- 6	8- 2	154	28	84	6	18	40	120	16- 0	4- 6
24- 6	24- 3	8- 4	161	29	87	6	18	41	123	16- 6	4- 6
25- 2	25- 0	8- 5	169	30	90	6	18	42	126	17- 1	4- 6
25-11	25- 9	8- 7	176	31	93	6	18	43	129	17- 8	4- 6
27- 3	27- 1	10- 0	217	31	93	8	24	47	141	17- 8	6- 4
28- 1	27-11	9- 7	212	33	99	7	21	47	141	18-10	5- 5
28- 9	28- 7	10- 3	234	33	99	8	24	49	147	18-10	6- 4
28-10	28- 8	9- 8	221	34	102	7	21	48	144	19- 5	5- 5
30- 3	30- 1	9-11	238	36	108	7	21	50	150	20- 7	5- 5
30-11	30- 9	10- 8	261	36	108	8	24	52	156	20- 7	6- 4
31- 7	31- 2	12- 1	309	36	108	10	30	56	168	20- 7	7- 3
31- 0	30-10	10- 1	246	37	111	7	21	51	153	21- 1	5- 5
32- 4	31-11	12- 3	320	37	111	10	30	57	171	21- 1	7- 3
31- 9	31- 7	10- 3	255	38	114	7	21	52	156	21- 8	5- 5
33- 1	32- 7	12- 5	330	38	114	10	30	58	174	21- 8	7- 3
33- 2	33- 0	11- 1	289	39	117	8	24	55	165	22- 3	6- 4
34- 5	34- 1	13- 3	377	39	117	11	33	61	183	22- 3	8- 2
34- 7	34- 6	11- 4	308	41	123	8	24	57	183	23- 5	6- 4
37-11	37- 7	15- 8	477	41	123	14	42	69	207	23- 5	10-11
35- 4	35- 2	11- 5	318	42	126	8	24	58	174	24- 0	6- 4
38- 8	38- 4	15- 9	490	42	126	14	42	70	210	24- 0	10-11

NOTE: Larger sizes available for special designs.

SOURCE: AMERICAN IRON AND STEEL INSTITUTE

STANDARD SIZES
FOR CORRUGATED STEEL CULVERTS



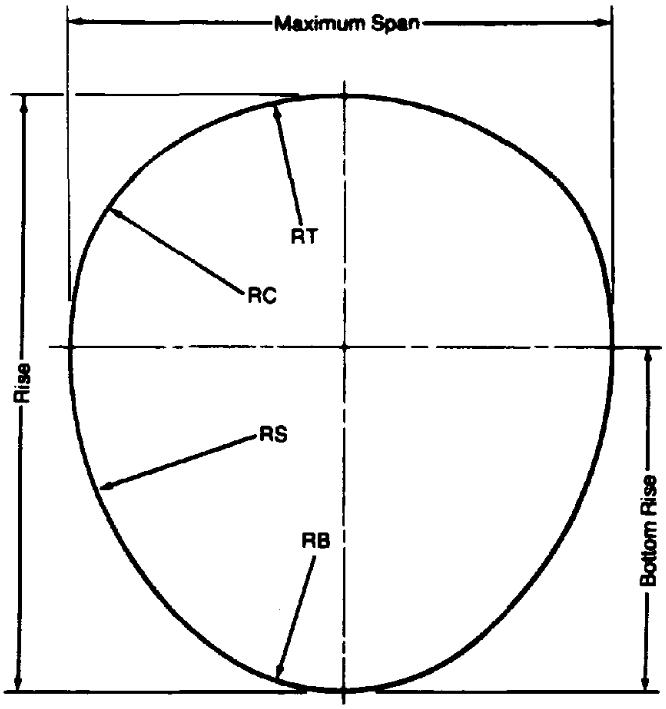
Long Span High Profile Arch Sizes and Layout Details

Max. Span, ft-in.	Bottom Span, ft-in.	Total Rise, ft-in.	Area, ft²	Periphery: Top N	Periphery: Top Pi	Periphery: Upper Side N	Periphery: Upper Side Pi	Periphery: Lower Side N	Periphery: Lower Side Pi	Periphery: Total N	Periphery: Total Pi	Inside Radius: Top Radius, ft-in.	Inside Radius: Upper Side, ft-in.	Inside Radius: Lower Side, ft-in.
20- 1	19- 6	9- 1	152	23	69	5	15	3	9	39	117	13- 1	4- 6	13- 1
20- 8	18-10	12- 1	214	23	69	6	18	6	18	47	141	13- 1	5- 5	13- 1
21- 6	19-10	11- 8	215	25	75	5	15	6	18	47	141	14- 3	4- 6	14- 3
22-10	19-10	14- 7	285	25	75	7	21	8	24	55	165	14- 3	6- 4	14- 3
22- 3	20- 7	11-10	225	26	78	5	15	6	18	48	144	14-10	4- 6	14-10
22-11	20- 0	14- 0	276	26	78	6	18	8	24	54	162	14-10	5- 5	14-10
23- 0	21- 5	12- 0	235	27	81	5	15	6	18	49	147	15- 5	4- 6	15- 5
24- 4	21- 6	14-10	310	27	81	7	21	8	24	57	171	15- 5	6- 4	15- 5
23- 9	22- 2	12- 1	245	28	84	5	15	6	18	50	150	16- 0	4- 6	16- 0
24- 6	21-11	13- 9	289	29	87	5	15	8	24	55	165	16- 6	4- 6	16- 6
25- 9	23- 2	15- 2	335	29	87	7	21	8	24	59	177	16- 6	6- 4	16- 6
25- 2	23- 3	13- 2	283	30	90	5	15	7	21	54	162	17- 1	4- 6	17- 1
26- 6	24- 0	15- 3	348	30	90	7	21	8	24	60	180	17- 1	6- 4	17- 1
25-11	24- 1	13- 3	295	31	93	5	15	7	21	55	165	17- 8	4- 6	17- 8
27- 3	24-10	15- 5	360	31	93	7	21	8	24	61	183	17- 8	6- 4	17- 8
27- 5	25- 8	13- 7	317	33	99	5	15	7	21	57	171	18-10	4- 6	18-10
29- 5	27- 1	16- 5	412	33	99	8	28	8	24	65	195	18-10	7- 3	18-10
28- 2	25-11	14- 5	349	34	102	5	15	8	24	60	180	19- 5	4- 6	19- 5
30- 1	26- 9	18- 1	467	34	102	8	24	10	30	70	210	19- 5	7- 3	19- 5
30- 3	28- 2	15- 5	399	36	108	6	18	8	24	64	192	20- 7	5- 5	20- 7
31- 7	28- 4	18- 4	497	36	108	8	24	10	30	72	216	20- 7	7- 3	20- 7
31- 0	29- 0	15- 7	413	37	111	6	18	8	24	65	195	21- 1	5- 5	21- 1
31- 8	28- 6	17- 9	484	37	111	7	21	10	30	71	213	21- 1	6- 4	21- 1
32- 4	27-11	19-11	554	37	111	8	24	12	36	77	231	21- 1	7- 3	21- 1
31- 9	28- 8	17- 3	470	38	114	6	18	10	30	70	210	21- 8	5- 5	21- 8
33- 1	28- 9	20- 1	571	38	114	8	24	12	36	78	234	21- 8	7- 3	21- 8
32- 6	29- 6	17- 4	484	39	117	6	18	10	30	71	213	22- 3	5- 5	22- 3
33-10	29- 7	20- 3	588	39	117	8	24	12	36	79	237	22- 3	7- 3	22- 3
34- 0	31- 2	17- 8	514	41	123	6	18	10	30	73	219	23- 5	5- 5	23- 5
34- 7	30- 7	19-10	591	41	123	7	21	12	36	79	237	23- 5	6- 4	23- 5
35- 3	30- 7	21- 3	645	41	123	8	24	13	39	83	249	23- 5	7- 3	23- 5
37- 3	32- 6	23- 5	747	41	123	11	33	13	39	89	267	23- 5	10- 0	23- 5
34- 8	31-11	17-10	529	42	126	6	18	10	30	74	222	24- 0	5- 5	24- 0
35- 4	31- 5	20- 0	608	42	126	7	21	12	36	80	240	24- 0	6- 4	24- 0
36- 0	31- 5	21- 5	663	42	126	8	24	13	39	84	252	24- 0	7- 3	24- 0
38- 0	33- 5	23- 6	767	42	126	11	33	13	39	90	270	24- 0	10- 0	24- 0

NOTE: Larger sizes available for special designs.

SOURCE: AMERICAN IRON AND STEEL INSTITUTE

STANDARD SIZES
FOR CORRUGATED STEEL CULVERTS



Long Span Pear Shape Sizes and Layout Details

Max. Span, ft-in.	Rise, ft-in.	Rise Bottom, ft-in.	Area	Periphery										Inside Radius			
				Top		Corner		Side		Bottom		Total		Bottom Radius, ft-in.	Side Radius, ft-in.	Corner Radius, ft-in.	Top Radius, ft-in.
				N	Pi	N	Pi	N	Pi	N	Pi	N	Pi				
23- 8	25- 8	14-11	481	25	75	5	15	24	72	15	30	98	294	8-11	16- 7	6- 3	14- 8
24- 0	25-10	15- 1	496	22	66	7	21	22	66	20	60	100	300	9-11	17- 4	7- 0	16- 2
25- 6	25-11	15-10	521	27	81	7	21	20	60	21	63	102	306	10- 7	18- 1	6-11	15-10
24-10	27- 8	16- 9	544	27	81	5	15	25	75	18	54	105	315	9- 3	19- 8	5- 9	15-11
27- 5	27- 0	18- 1	578	30	90	6	18	26	78	16	48	110	330	9- 7	20- 4	4- 7	19-11
26- 8	28- 3	18- 0	593	28	84	5	15	30	90	12	36	110	330	8- 0	20- 1	4- 9	20-11
28- 1	27-10	16-10	624	27	81	8	24	22	66	25	75	112	336	12- 2	19- 0	7- 3	20- 5
28- 7	30- 7	19- 7	689	32	96	7	21	24	72	24	72	118	354	11- 2	24- 0	7- 0	18- 2
30- 0	29- 8	20- 0	699	32	96	8	24	23	69	25	75	119	357	11-11	24- 0	6- 7	21-10
30- 0	31- 2	19-11	736	34	102	7	21	24	72	26	78	122	366	12- 1	24- 0	7- 0	19- 3

SOURCE: AMERICAN IRON AND STEEL INSTITUTE

STANDARD SIZES
FOR ALUMINUM CULVERTS

Helical Pipe Availability, Weights

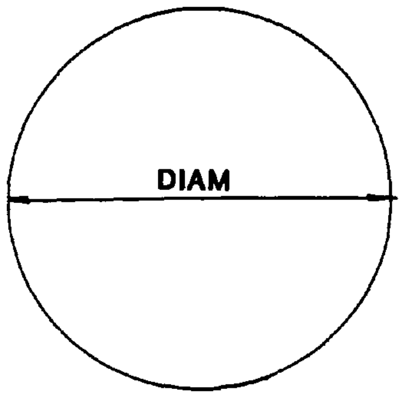
CORR. PATTERN				WEIGHT (Lbs./Lineal Ft.)					
				Equiv. Standard Gauge					
1-1/2 x 1/4	2-2/3 x 1/2	3 x 1	6 x 1	18	16	14	12	10	8
Diameter (In.)									
6				1.4	1.7				
8				1.8	2.2				
10				2.2	2.7				
	12				3.2	4.0	5.5		
	15				3.9	4.9	6.8		
	18				4.7	5.9	8.1		
	21				5.4	6.8	9.4		
	24				6.2	7.8	10.7	13.8	
	27				7.0	8.7	12.1	15.4	
	30				7.8	9.6	13.4	17.1	
		30			8.9	11.2	15.5	19.9	
	36					11.5	16.0	20.5	
		36			10.7	13.4	18.5	23.7	
	42						18.6	23.8	
		42			12.4	15.5	21.5	27.5	
	48						21.2	27.2	32.7
		48			14.1	17.7	24.5	31.4	37.8
			48		12.5	15.6	21.8	28.1	34.1
	54						23.8	30.5	36.7
		54			15.8	19.9	27.5	35.2	42.4
			54		14.0	17.5	24.5	31.5	38.3
	60							33.9	40.8
		60			17.6	22.0	30.5	39.0	47.0
			60		15.5	19.4	27.2	34.9	42.5
	66							37.2	44.8
		66			17.0	21.3	29.8	38.4	46.6
	72								48.8
		72				26.3	36.5	46.7	56.2
			72			23.2	32.5	41.8	50.8
	78								52.9
		78				28.5	39.5	50.5	60.8
			78			25.1	35.2	45.2	55.0
	84								56.9
		84				30.7	42.5	54.3	65.4
			84				37.8	48.7	58.1
		90					46.4	58.2	70.0
			90				40.5	52.1	63.3
		96					48.4	62.0	74.6
			96				43.2	55.5	67.5
		102					51.4	65.8	79.3
			102				45.8	58.9	71.6
		108					54.4	69.7	83.9
			108				48.5	62.4	75.8
		114					57.4	73.5	88.5
			114				51.2	65.8	80.0
		120					60.4	77.3	93.1
			120				53.8	69.2	84.1

NOTES: 1. Sizes 6" thru 10" are available in helical corrugation only.

2. Sizes 12" through 21" in helical configuration have corrugation depth of 7/16" rather than 1/2".

SOURCE: ALUMINUM ASSOCIATION

STANDARD SIZES
FOR ALUMINUM CULVERTS



Geometric Data — Structural Plate Pipe

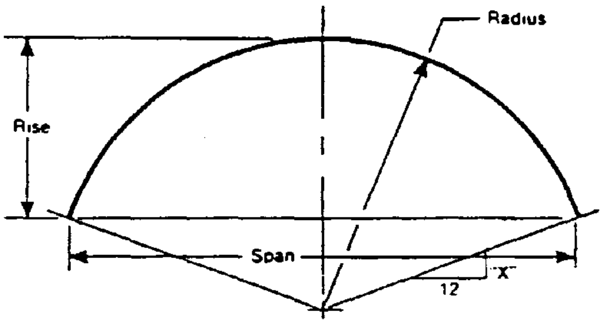
Nom. Diam. In.	Area Sq. Ft.	Total N	Nom. Diam. In.	Area Sq. Ft.	Total N
60	19	20	162	145	54
66	23	22	168	156	56
72	27	24	174	167	58
78	32	26	180	179	60
84	38	28	186	191	62
90	44	30	192	204	64
96	50	32	198	217	66
102	56	34	204	231	68
108	63	36	210	245	70
114	71	38	216	259	72
120	79	40	222	274	74
126	87	42	228	289	76
132	95	44	234	305	78
138	104	46	240	321	80
144	114	48	246	337	82
150	124	50	252	354	84
156	134	52	—	—	—

SOURCE: ALUMINUM ASSOCIATION

STANDARD SIZES
FOR ALUMINUM CULVERTS

GEOMETRIC DATA – ARCH

"X" Values For Rise/Span Ratio			
R/S Ratio	"X"	R/S Ratio	"X"
.30	6.40	.42	2.10
.31	5.96	.43	1.82
.32	5.54	.44	1.54
.33	5.13	.45	1.27
.34	4.74	.46	1.00
.35	4.37	.47	.74
.36	4.01	.48	.48
.37	3.67	.49	.24
.38	3.33	.50	.00
.39	3.01	.51	.24
.40	2.70	.52	.47
.41	2.40		

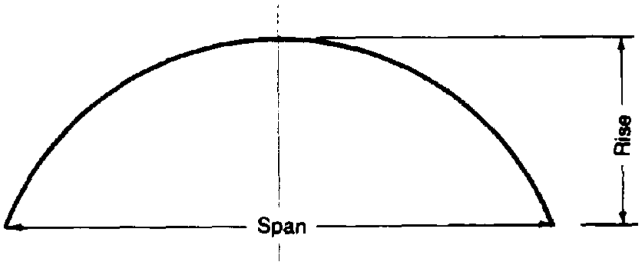


Typical Section

Span Ft.In.	Rise Ft.In.	Area Sq.Ft.	Total N	Rise/ Span Ratio	Radius Inches
5-0	2-7	10.4	10	.52	30
	2-3	8.5	9	.44	30¼
	1-9	6.5	8	.36	31¾
6-0	3-2	14.9	12	.52	36
	2-9	12.6	11	.46	36¼
	2-4	10.2	10	.38	37¼
	1-10	7.8	9	.30	40½
7-0	3-8	20.3	14	.52	42
	3-3	17.5	13	.46	42
	2-10	14.8	12	.40	43
	2-4	12.0	11	.34	45¼
8-0	4-2	26.4	16	.52	48
	3-9	23.3	15	.47	48
	3-4	20.2	14	.42	48¾
	2-11	17.0	13	.36	50½
	2-5	13.6	12	.30	54½
9-0	4-8	33.4	18	.50	54
	4-3	29.9	17	.48	54
	3-10	26.3	16	.43	54½
	3-5	22.8	15	.38	56
	2-11	19.1	14	.33	59
10-0	5-2	41.2	20	.52	60
	4-10	37.3	19	.48	60
	4-5	33.3	18	.44	60½
	3-11	29.4	17	.40	61½
	3-6	25.3	16	.35	64
	3-0	21.1	15	.30	68½
11-0	5-8	49.8	22	.52	66
	5-4	45.5	21	.48	66
	4-11	41.2	20	.45	66½
	4-6	36.8	19	.41	67½
	4-0	32.4	18	.36	69¼
	3-6	27.8	17	.32	72¾

SOURCE: ALUMINUM ASSOCIATION

STANDARD SIZES
FOR ALUMINUM CULVERTS



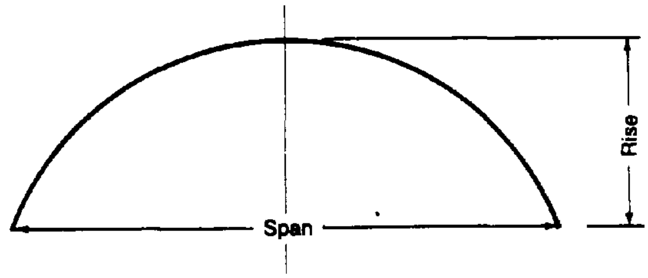
ARCH (CONT'D)

Geometric Data—Arch (Continued)

Span Ft.In.	Rise Ft.In.	Area Sq.Ft.	Total N	Rise/Span Ratio	Radius Inches
12-0	6-3	59.3	24	.52	72
	5-10	54.5	23	.49	72
	5-5	49.8	22	.45	72½
	5-0	45.0	21	.42	73¼
	4-7	40.2	20	.38	75
	4-1	35.3	19	.34	77½
13-0	6-9	69.5	26	.52	78
	6-4	64.4	25	.49	78
	5-11	59.3	24	.46	78¼
	5-6	54.1	23	.42	79
	5-1	48.9	22	.39	80½
	4-7	43.6	21	.35	82¾
	4-1	38.1	20	.31	86½
14-0	7-3	80.8	28	.52	84
	6-10	75.1	27	.49	84
	6-5	69.5	26	.46	84¼
	6-0	64.0	25	.43	85
	5-7	58.4	24	.40	86
	5-2	52.7	23	.37	88
	4-8	46.9	22	.33	91¼
15-0	7-9	92.5	30	.52	90
	7-5	86.5	29	.49	90
	7-0	80.6	28	.46	90¼
	6-7	74.7	27	.44	91
	6-1	68.7	26	.41	92
	5-8	62.6	25	.38	93½
	5-2	56.4	24	.34	96¼
	4-8	50.0	23	.31	100½
16-0	8-3	105.2	32	.52	96
	7-11	98.9	31	.49	96
	7-6	92.5	30	.47	96¼
	7-1	86.2	29	.44	96¾
	6-8	79.8	28	.41	97¾
	6-2	73.3	27	.39	99¼
	5-8	66.8	26	.35	101½
	5-3	60.0	25	.32	105
17-0	8-10	118.7	34	.52	102
	8-5	112.0	33	.48	102
	8-0	105.2	32	.47	102¼
	7-7	98.5	31	.45	102¾
	7-2	91.7	30	.42	103½
	6-9	84.9	29	.39	105
	6-3	77.9	28	.37	107
	5-9	70.9	27	.34	110
	5-3	63.5	26	.31	114¼
18-0	9-4	133.1	36	.52	108
	8-11	125.9	35	.50	108
	8-6	118.8	34	.47	108¼
	8-1	111.8	33	.45	108½
	7-8	104.5	32	.43	109¼
	7-3	97.2	31	.40	110½
	6-9	89.9	30	.38	112½
	6-4	82.5	29	.35	115
	5-9	74.8	28	.32	118¾
19-0	9-10	148.2	38	.52	114
	9-5	140.7	37	.50	114
	9-0	133.2	36	.48	114¼
	8-6	125.8	35	.45	114½
	8-2	118.0	34	.43	115¼
	7-8	110.4	33	.41	116¾
	7-4	102.7	32	.39	118
	6-10	94.9	31	.36	120¼
	6-4	86.8	30	.33	123½
	5-10	78.7	29	.31	128¼
20-0	10-4	164.2	40	.52	120
	10-0	156.3	39	.50	120
	9-7	148.3	38	.48	120
20-0 cont.	9-2	140.4	37	.46	120½
	8-9	132.4	36	.44	121
	8-3	124.4	35	.41	122¼
	7-10	116.3	34	.39	123½
	7-4	108.4	33	.37	125¾
	6-10	99.8	32	.34	128½
	6-4	91.2	31	.32	132½
21-0	10-10	181.0	42	.52	126
	10-6	172.7	41	.50	126
	10-1	164.3	40	.48	126
	9-8	156.0	39	.46	126½
	9-3	147.6	38	.44	127
	8-10	139.2	37	.42	128
	8-4	130.7	36	.40	129¾
	7-11	122.2	35	.38	131¼
	7-5	113.5	34	.35	133¾
	6-11	104.6	33	.33	137¼
	6-4	95.4	32	.30	142
22-0	11-5	198.6	44	.52	132
	11-0	189.9	43	.50	132
	10-7	181.1	42	.48	132
	10-2	172.4	41	.46	132½
	9-9	163.6	40	.44	133
	9-4	154.8	39	.42	133¾
	8-11	146.0	38	.40	135
	8-5	137.0	37	.38	135¾
	7-11	127.9	36	.36	139
	7-5	118.7	35	.34	142¼
	6-11	109.2	34	.31	142¾
23-0	11-11	217.1	46	.52	138
	11-6	207.9	45	.50	138
	11-1	198.8	44	.48	138
	10-8	189.6	43	.47	138¼
	10-3	180.5	42	.45	139
	9-10	171.3	41	.43	139½
	9-5	162.0	40	.41	140¾
	8-11	152.7	39	.39	142¼
	8-6	143.2	38	.37	144½
	8-0	133.6	37	.35	147¼
	7-6	123.8	36	.33	151
	6-11	113.6	35	.30	156
24-0	12-5	236.3	48	.52	144
	12-0	226.6	47	.50	144
	11-7	217.2	46	.48	144
	11-3	207.7	45	.47	144¼
	10-10	198.1	44	.45	144¾
	10-4	188.5	43	.43	145½
	9-11	178.9	42	.41	146½
	9-6	169.2	41	.39	148
	9-0	159.3	40	.38	150
	8-6	149.4	39	.36	152½
	8-0	138.2	38	.33	155¾
	7-8	128.8	37	.31	160¾
25-0	12-11	256.4	50	.52	150
	12-6	246.4	49	.50	150
	12-2	236.5	48	.49	150
	11-9	226.6	47	.47	150¼
	11-4	216.6	46	.45	150¾
	10-11	206.6	45	.44	151½
	10-6	196.8	44	.42	152½
	10-0	186.4	43	.40	153¾
	9-6	176.3	42	.38	155½
	9-1	165.9	41	.36	157¾
	8-7	155.4	40	.34	160¾
	8-1	144.7	39	.32	164¾
	7-6	133.7	38	.30	170
26-0	13-5	277.3	52	.52	156
	13-1	266.8	51	.50	156
	12-9	256.8	50	.49	156

SOURCE: ALUMINUM ASSOCIATION

STANDARD SIZES
FOR ALUMINUM CULVERTS



**ARCH
(CONT'D)**

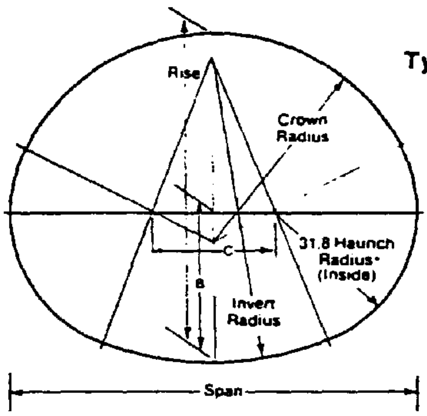
Geometric Data—Arch (Continued)

Span Ft.In.	Rise Ft.In.	Area Sq.Ft.	Total N	Rise/ Span Ratio	Radius Inches
26-0 cont.	12-3	246.2	49	47	156¼
	11-10	235.9	48	46	156¾
	11-5	225.5	47	44	157¼
	11-0	215.1	46	.42	158¼
	10-6	204.6	45	40	159½
	10-1	194.0	44	.39	161
	9-7	183.3	43	.37	163¼
	9-1	172.4	42	.35	166
	8-7	161.4	41	33	169½
	8-1	150.1	40	.31	174
27-0	14-0	299.0	54	.52	162
	13-7	288.2	53	.50	162
	13-2	277.5	52	49	162
	12-9	266.7	51	47	162¼
	12-4	256.0	50	46	162¾
	11-11	245.2	49	44	163¼
	11-6	234.4	48	43	164
	11-1	223.5	47	41	165¼
	10-7	212.6	46	39	166¾
	10-2	201.4	45	38	168¾
	9-8	190.2	44	36	171¼
	9-2	178.8	43	34	174½
	8-7	167.2	42	.32	178½
	8-1	155.3	41	.30	183¾
28-0	14-6	321.5	56	.52	168
	14-1	310.4	55	.50	168
	13-8	299.2	54	49	168
	13-3	288.1	53	47	168¼
	12-10	276.9	52	46	168½
	12-5	265.7	51	44	169¼
	12-0	254.5	50	43	170
	11-7	243.2	49	41	171
	11-1	231.9	48	40	172½
	10-8	220.4	47	38	174¼
28-0 cont.	10-2	208.8	46	.36	176½
	9-8	197.1	45	.35	179½
	9-2	185.1	44	33	183¼
	8-8	172.9	43	.31	188
29-0	15-0	344.8	58	.52	174
	14-7	333.3	57	.50	174
	14-2	321.7	56	49	174
	13-10	310.2	55	.48	174¼
	13-5	298.6	54	46	174½
	13-0	287.1	53	45	175
	12-6	275.4	52	43	175¾
	12-1	263.8	51	42	176¾
	11-8	252.0	50	40	178¼
	11-2	240.2	49	39	180
	10-9	228.2	48	.37	182
	10-3	216.1	47	35	184¾
	9-9	203.8	46	34	188
	9-2	191.3	45	32	192¼
	8-8	178.5	44	30	197¾
30-0	15-6	369.0	60	.52	180
	15-1	357.1	59	50	180
	14-9	345.1	58	49	180
	14-4	333.2	57	48	180¼
	13-11	321.2	56	46	180½
	13-6	309.2	55	45	181
	13-1	297.2	54	44	181¾
	12-7	285.1	53	42	182¾
	12-2	273.0	52	41	184
	11-9	260.8	51	39	185½
	11-3	248.5	50	37	187½
	10-9	236.0	49	.36	190
	10-3	223.3	48	34	193
	9-9	210.5	47	32	197
	9-2	197.3	46	31	201¾

SOURCE: ALUMINUM ASSOCIATION

STANDARD SIZES
FOR ALUMINUM CULVERTS

Geometric Data—Pipe Arch

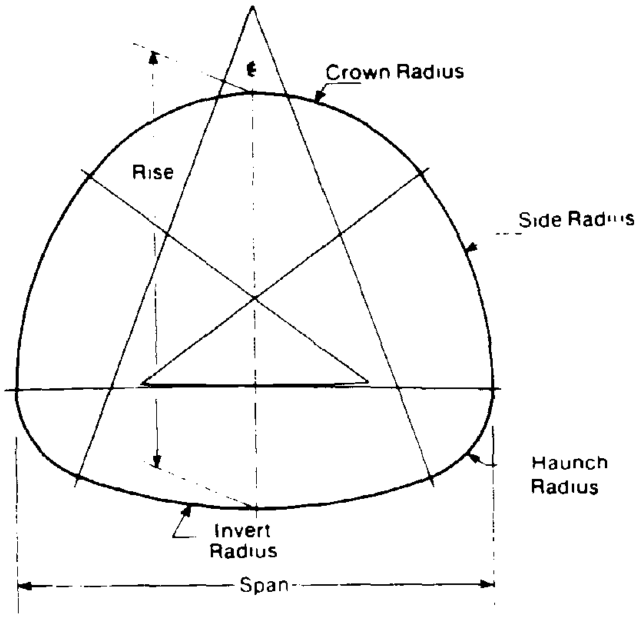


Typical Section

Span Ft.-In.	Rise Ft.-In.	Area Sq. Ft.	Required N				Inside Radius		B	C
			Total	Crown	Invert	Haunch	Crown In.	Invert In.		
6-7	5-8	29.6	25	8	3	7	41.5	69.9	32.5	15.3
6-11	5-9	31.9	26	9	3	7	43.7	102.9	32.4	19.6
7-3	5-11	34.3	27	10	3	7	45.6	188.3	32.2	23.8
7-9	6-0	36.8	28	9	5	7	51.6	83.8	33.8	29.0
8-1	8-1	39.3	29	10	5	7	53.3	108.1	33.5	33.3
8-5	6-3	41.9	30	11	5	7	54.9	150.1	33.2	37.4
8-10	6-4	44.5	31	10	7	7	63.3	93.0	35.6	42.8
9-3	5-5	47.1	32	11	7	7	64.4	112.6	35.2	47.1
9-7	6-6	49.9	33	12	7	7	65.4	141.6	34.7	51.3
9-11	6-8	52.7	34	13	7	7	66.4	188.7	34.2	55.3
10-3	6-9	55.5	35	14	7	7	67.4	278.8	33.5	59.2
10-9	6-10	58.4	36	13	9	7	77.5	139.6	36.8	65.2
11-1	7-0	61.4	37	14	9	7	77.8	172.0	36.1	69.3
11-5	7-1	64.4	38	15	9	7	78.2	222.0	35.3	73.3
11-9	7-2	67.5	39	16	9	7	78.7	309.5	34.4	77.1
12-3	7-3	70.5	40	15	11	7	90.8	165.2	38.4	83.4
12-7	7-5	73.7	41	16	11	7	90.5	200.0	37.5	87.4
12-11	7-6	77.0	42	17	11	7	90.4	251.7	36.5	91.3
13-1	8-2	83.0	43	18	13	6	88.8	143.6	42.0	93.6
13-1	8-4	86.8	44	21	11	6	81.7	300.8	35.8	93.7
13-11	8-5	90.3	45	18	15	6	100.4	132.0	46.0	103.3
14-0	8-7	94.2	46	21	13	6	90.3	215.1	39.4	104.5
13-11	9-5	101.5	47	23	14	5	86.2	159.3	42.8	103.9
14-3	9-7	105.7	48	24	14	5	87.2	176.3	42.0	107.0
14-8	9-8	109.9	49	24	15	5	90.9	166.2	44.0	112.3
14-11	9-10	114.2	50	25	15	5	91.8	183.0	43.2	115.5
15-4	10-0	118.6	51	25	16	5	95.5	173.0	45.3	120.8
15-7	10-2	123.1	52	26	16	5	96.4	189.6	44.4	123.9
16-1	10-4	127.8	53	26	17	5	100.2	179.7	46.6	129.2
16-4	10-6	132.3	54	27	17	5	101.0	196.1	45.7	132.3
16-9	10-8	136.9	55	27	18	5	105.0	186.3	47.9	137.7
17-0	10-10	141.8	56	28	18	5	105.7	202.5	46.9	140.8
17-3	11-0	146.7	57	29	18	5	106.5	221.3	45.9	143.8
17-9	11-2	151.6	58	29	19	5	110.4	208.9	48.2	149.3
18-0	11-4	156.7	59	30	19	5	111.1	227.3	47.2	152.3
18-5	11-6	161.7	60	30	20	5	115.2	215.2	49.6	157.8
18-8	11-8	167.0	61	31	20	5	115.8	233.3	48.5	160.7
19-2	11-9	172.2	62	31	21	5	119.9	221.5	50.9	166.2
19-5	11-11	177.6	63	32	21	5	120.5	239.3	49.8	169.2
19-10	12-1	182.9	64	32	22	5	124.7	227.7	52.3	174.8
20-1	12-3	188.5	65	33	22	5	125.2	245.3	51.1	177.7
20-1	12-6	194.4	66	35	21	5	122.5	310.8	46.2	177.5
20-10	12-7	199.7	67	34	23	5	130.0	251.2	52.5	186.2
21-1	12-9	205.5	68	35	23	5	130.5	270.9	51.2	189.1
21-6	12-11	211.2	69	35	24	5	134.8	257.2	53.9	194.8

SOURCE: ALUMINUM ASSOCIATION

STANDARD SIZES
FOR ALUMINUM CULVERTS



Typical Section

Geometric Data—Vehicular Underpass

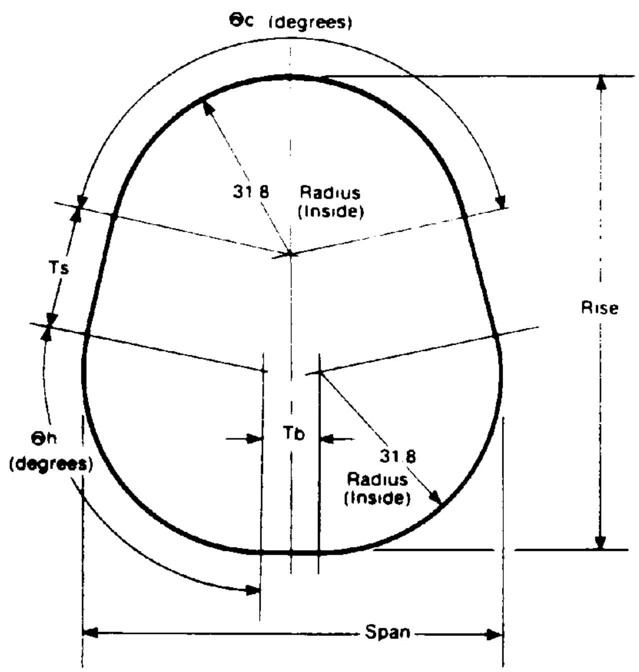
Span Ft	Span In.	Rise Ft	Rise In.	Tot N	Required N Invert	Required N Haunch	Required N Side	Required N Crown	Inside Radius (Inches) Invert	Inside Radius (Inches) Haunch	Inside Radius (Inches) Side	Inside Radius (Inches) Crown
12	1	11	0	47	10.00	4.32	7.69	12.99	135.95	37.95	88.00	67.95
12	10	11	2	49	11.04	4.44	7.50	14.10	148.53	38.53	86.78	74.53
13	0	12	0	51	10.97	4.27	8.79	13.91	160.54	37.54	98.19	72.54
13	8	12	4	53	11.98	4.36	8.67	14.96	167.77	37.77	102.62	76.77
14	0	12	11	55	11.99	4.39	9.62	14.98	182.90	37.90	110.65	76.90
14	6	13	5	57	13.07	4.61	9.26	16.18	174.88	38.88	124.73	78.88
14	8	14	1	59	13.00	4.42	10.58	15.99	192.96	37.96	130.01	78.96
15	5	14	5	61	14.04	4.59	10.33	17.11	201.54	38.54	135.39	83.54
15	6	15	2	63	13.97	4.45	11.61	16.92	211.59	37.59	149.14	81.59
16	2	15	6	65	14.99	4.50	11.52	17.97	216.85	37.85	154.40	85.85
16	6	16	0	67	14.07	4.73	12.10	19.29	272.34	39.34	153.89	89.34
16	8	16	4	68	15.01	4.49	12.49	19.03	246.17	38.17	160.82	89.17
17	3	17	1	70	15.04	5.71	12.20	19.13	214.64	47.64	171.19	90.64
18	5	16	11	72	16.09	5.87	11.95	20.27	249.37	48.37	155.02	100.37
19	0	17	3	74	17.02	5.60	12.36	21.06	262.29	47.29	153.14	105.29
19	7	17	7	76	17.07	5.79	13.06	21.24	296.21	48.21	154.46	108.21
20	5	17	9	78	18.08	5.78	13.05	22.27	317.39	48.39	149.94	115.39

SOURCE: ALUMINUM ASSOCIATION

STANDARD SIZES
FOR ALUMINUM CULVERTS

Geometric Data—Pedestrian/Animal Underpass

Span Ft.-In.	Rise Ft.-In.	Total N	Tb In.	Ts In.	Θc Degrees	Θh Degrees
6-1	5-9	24	9.2	7.2	100.2	129.9
6-3	6-1	25	11.1	11.0	119.3	120.4
6-3	6-6	26	11.6	15.6	136.5	111.7
6-2	7-0	27	10.2	21.1	152.2	103.9
6-3	7-4	28	11.6	25.2	153.3	103.4
6-1	7-10	29	9.8	30.9	161.7	99.2
6-3	8-2	30	11.3	35.0	161.3	99.3

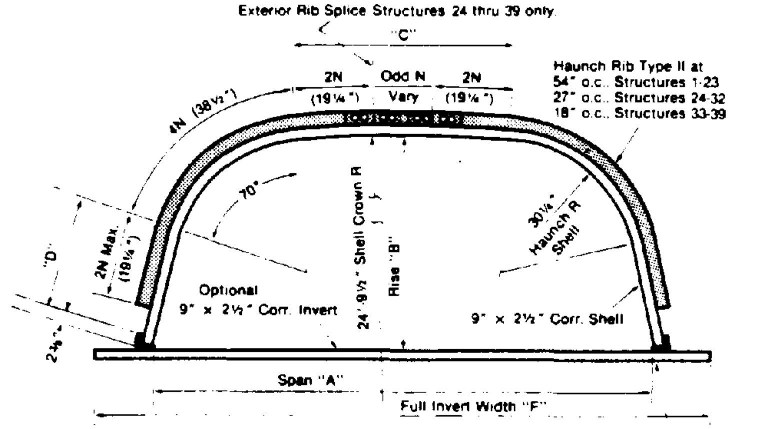


Typical Section

SOURCE: ALUMINUM ASSOCIATION

STANDARD SIZES
FOR ALUMINUM CULVERTS

Box Culvert Geometric Data



BOX CULVERT CROSS SECTION

Structure Number	Span "A" (Ft.-In.)	Rise "B" (Ft.-In.)	Area (Sq. Ft.)	SHELL: Crown Width "C" (N)	SHELL: Leg Length "D" (N)	SHELL: Side Angle "E" Deg. Min.	SHELL: Total N	SHELL: Haunch Plate Length (N)	SHELL: Crown Plate Length (N)	SHELL: Bolts/Ft.	FULL INVERT: Width "F" (N)	FULL INVERT: Supplemental/Stub Pl. Thick.	FULL INVERT: Supplemental/Stub Pl. Width (N)	FULL INVERT: Weight/Ft.	FULL INVERT: Bolts/Ft.
1	8- 9	2- 6	18.4	5	.5	15-24	14	1 @ 14	–	6.67	13	–	–	23.06	5.78
2	9- 2	3- 3	25.4	5	1.5	15-24	16	2 @ 8	–	11.56	13	–	–	23.06	5.78
3	9- 7	4- 1	32.6	5	2.5	15-24	18	2 @ 9	–	12.00	14	–	–	24.44	6.00
4	10- 0	4-10	40.2	5	3.5	15-24	20	2 @ 10	–	12.44	14	–	–	24.44	6.30
5	10- 6	5- 7	48.1	5	4.5	15-24	22	2 @ 11	–	12.89	15	–	–	25.82	6.22
6	10-11	6- 4	56.4	5	5.5	15-24	24	2 @ 12	–	13.33	17	–	–	28.58	6.57
7	11- 4	7- 2	65.0	5	6.5	15-24	26	2 @ 13	–	13.78	17	–	–	28.58	6.67
8	10- 2	2- 8	23.0	7	.5	13-33	16	2 @ 8	–	12.89	15	–	–	25.82	6.22
9	10- 7	3- 5	31.1	7	1.5	13-33	18	2 @ 9	–	13.33	15	–	–	25.82	6.22
10	10-11	4- 3	39.5	7	2.5	13-33	20	2 @ 10	–	13.78	17	–	–	28.58	6.57
11	11- 4	5- 0	48.2	7	3.5	13-33	22	2 @ 11	–	14.22	17	–	–	28.58	6.37
12	11- 8	5- 9	57.2	7	4.5	13-33	24	2 @ 12	–	14.67	17	–	–	28.58	6.37
13	12- 1	6- 7	66.4	7	5.5	13-33	26	2 @ 13	–	15.11	17	–	–	28.58	6.37
14	12- 5	7- 4	76.0	7	6.5	13-33	28	2 @ 14	–	15.56	17	–	–	28.58	6.37
15	11- 7	2-10	28.1	9	0.5	11-42	18	2 @ 9	–	14.67	17	–	–	28.58	6.37
16	11-11	3- 7	37.4	9	1.5	11-42	20	2 @ 10	–	15.11	17	–	–	28.58	6.37
17	12- 3	4- 5	46.9	9	2.5	11-42	22	2 @ 11	–	15.56	17	–	–	28.58	6.67
18	12- 7	5- 2	56.6	9	3.5	11-42	24	2 @ 12	–	16.00	19	–	–	32.02	7.11
19	12-11	6- 0	66.6	9	4.5	11-42	26	2 @ 13	–	16.44	19	–	–	32.02	7.11
20	13- 3	6- 9	76.9	9	5.5	11-42	28	2 @ 14	–	16.89	19	–	–	32.02	7.11
21	13- 0	3- 0	33.8	11	0.5	9-52	20	2 @ 10	–	16.44	19	–	–	32.02	7.11
22	13- 4	3-10	44.2	11	1.5	9-52	22	2 @ 11	–	16.89	19	–	–	32.02	7.11
23	13- 7	4- 7	54.8	11	2.5	9-52	24	2 @ 12	–	17.33	19	–	–	32.02	7.11
24	13-10	5- 5	65.6	11	3.5	9-52	26	2 @ 13	–	23.11	19	–	–	32.02	7.11
25	14- 1	6- 2	76.6	11	4.5	9-52	28	2 @ 14	–	23.56	20	–	–	33.34	12.14
26	14- 5	3- 3	40.0	13	0.5	8-1	22	2 @ 11	–	22.67	20	–	–	33.34	12.14
27	14- 8	4- 1	51.5	13	1.5	8-1	24	2 @ 8	8	25.56	21	.100	2	40.23	12.37
28	14-10	4-10	63.2	13	2.5	8-1	26	2 @ 9	8	26.44	21	.100	2	40.23	12.37
29	15- 1	5- 6	75.1	13	3.5	8-1	28	2 @ 10	8	26.89	21	.100	2	40.23	12.37
30	15- 4	6- 5	87.2	13	4.5	8-1	30	2 @ 11	8	27.33	21	.100	2	40.23	12.37
31	15- 6	7- 3	99.4	13	5.5	8-1	32	2 @ 12	8	27.78	22	.100	2	41.61	12.49
32	15- 9	8- 0	111.8	13	6.5	8-1	34	2 @ 13	8	28.22	22	.100	2	41.61	12.39
33	15-10	3- 6	46.8	15	0.5	6-10	24	2 @ 8	8	32.22	22	.100	2	41.61	12.39
34	16- 0	4- 3	59.5	15	1.5	6-10	26	2 @ 9	8	33.56	22	.100	2	41.61	12.39
35	16- 2	5- 1	72.3	15	2.5	6-10	28	2 @ 10	8	34.89	23	.100	2	42.99	13.11
36	16- 4	5-11	85.2	15	3.5	8-10	30	2 @ 11	8	35.33	23	.100	3	45.75	13.11
37	16- 6	6- 8	98.3	15	4.5	8-10	32	2 @ 12	8	35.78	23	.100	3	45.75	13.11
38	16- 8	7- 6	111.5	15	5.5	6-10	34	2 @ 13	8	36.22	23	.100	3	45.75	13.11
39	16-10	8- 3	124.8	15	6.5	6-10	36	2 @ 14	8	36.67	24	.100	3	47.13	13.33

NOTES:

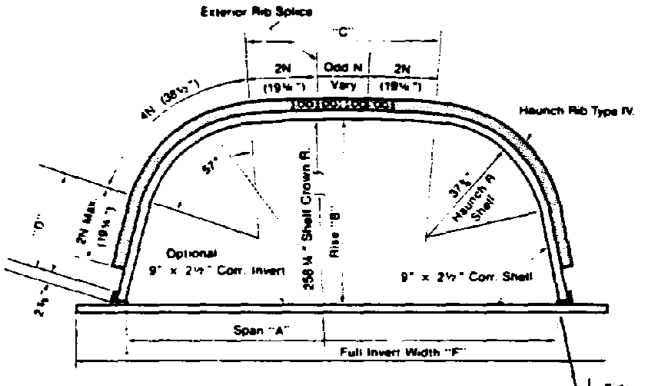
1) "N" equals 9.62".
2) All crowns of shells have Type IV ribs outside at 18" on centers.
3) Weights per foot listed do not include bolt weight.
4) Weight per foot of full invert includes 3½ x 3 x ¼ connecting angle and scalloped closure plate for each side. Inverts for 20N and greater are two-piece.
5) Weight per foot of footing pad includes a 3½ x 3 x ¼-in. connecting angle for each side. Optional wale beam not included.
6) Full invert plates are .100 thick. When reactions to invert require additional thickness supplemental plates of thickness and width listed are furnished to bolt between full invert and side connecting angle.
7) Width of footing pad is for each side.
8) For structures using short footing pads with leg length "D" equal to 3.5 N or more, either wale beam stiffeners should be used to avoid

SOURCE: ALUMINUM ASSOCIATION

STANDARD SIZES

FOR ALUMINUM CULVERTS

Box Culvert Geometric Data



BOX CULVERT CROSS SECTION

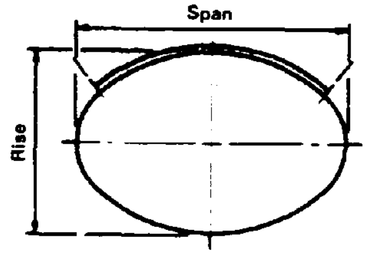
Structure Number	Span "A" (Ft.-In.)	Rise "B" (Ft.-In.)	Area (Sq. Ft.)	SHELL: Crown Width "C" (N)	Leg Length "D" (N)	Side Angle "E" Deg. Min.	Total N	Haunch Plate Length (N)	Crown Plate Length (N)	Bolts Per Foot	FULL INVERT: Width "F" (N)	Supplemental Stub Plates: Thickness	Supplemental Stub Plates: Width (N)	Weight Per Foot	Bolts Per Foot
40	17- 9	3-10	54.4	17	.5	14-54	26	8	10	33.56	25	.100	3	48.51	13.56
41	18- 2	4- 7	68.3	17	1.5	14-54	28	9	10	34.89	25	.100	3	48.51	13.56
42	18- 7	5- 4	82.5	17	2.5	14-54	30	10	10	36.22	26	.100	3	49.88	13.78
43	19- 0	6- 1	97.1	17	3.5	14-54	32	11	10	36.67	27	.100	3	51.26	14.00
44	19- 5	6-11	111.9	17	4.5	14-54	34	12	10	37.11	27	.100	3	51.28	14.00
45	19-10	7- 8	127.1	17	5.5	14-54	36	13	10	37.56	28	.100	3	52.64	14.22
46	20- 3	8- 5	142.6	17	6.5	14-54	38	14	10	38.00	28	.100	3	52.64	14.22
47	19- 1	4- 2	63.3	19	.5	12-47	28	8	12	34.89	27	.100	3	51.28	14.00
48	19- 5	4-11	78.3	19	1.5	12-47	30	9	12	36.22	27	.100	3	51.28	14.00
49	19- 9	5- 8	93.6	19	2.5	12-47	32	10	12	37.56	27	.100	3	51.28	14.00
50	20- 1	6- 6	109.2	19	3.5	12-47	34	11	12	38.00	28	.100	3	52.64	14.22
51	20- 6	7- 3	125.0	19	4.5	12-47	36	12	12	54.44	29	.125	3	56.09	14.44
52	20-10	8- 1	141.2	19	5.5	12-47	38	13	12	54.89	29	100	3	54.02	14.44
53	21- 2	8-10	157.6	19	6.5	12-47	40	14	12	55.33	30	.150	3	59.54	14.67
54	20- 4	4- 6	73.1	21	.5	10-40	30	8	14	49.56	29	.150	3	58.16	14.44
55	20- 7	5- 3	89.2	21	1.5	10-40	32	9	14	52.22	29	.125	3	56.09	14.44
56	20-11	6- 1	105.5	21	2.5	10-40	34	10	14	54.89	29	.100	3	54.02	14.44
57	21- 3	6-10	122.1	21	3.5	10-40	36	11	14	55.33	30	.150	3	59.54	14.67
58	21- 6	7- 8	139.0	21	4.5	10-40	38	12	14	55.78	30	.125	3	57.47	14.67
59	21-10	8- 5	156.0	21	5.5	10-40	40	13	14	56.22	31	.175	3	62.99	14.89
60	22- 1	9- 3	173.3	21	6.5	10-40	42	14	14	56.67	31	.150	3	60.92	14.89
61	21- 7	4-11	83.8	23	.5	8-32	32	9	14	50.89	30	.125	3	57.47	14.67
62	21-10	5- 8	101.0	23	1.5	8-32	34	10	14	53.56	31	.175	3	62.99	14.89
63	22- 1	6- 6	118.4	23	2.5	8-32	36	11	14	56.22	31	.150	3	60.92	14.89
64	22- 3	7- 3	135.9	23	3.5	8-32	38	12	14	56.67	31	.150	4	65.05	14.89
65	22- 6	8- 1	153.7	23	4.5	8-32	40	13	14	57.11	32	.200	4	71.95	15.11
66	22- 9	8-10	171.6	23	5.5	8-32	42	14	14	57.56	32	.175	4	69.19	15.11
67	23- 0	9- 8	189.8	23	6.5	8-32	44	15	14	58.00	32	.150	4	66.43	15.11
68	22- 9	5- 4	95.5	25	.5	8-25	34	10	14	52.22	32	.175	4	69.19	15.11
69	23- 0	6- 1	113.7	25	1.5	6-25	36	11	14	54.89	32	.150	4	66.43	15.11
70	23- 2	6-11	132.1	25	2.5	6-25	38	12	14	57.56	33	.225	4	76.09	15.33
71	23- 4	7- 8	150.6	25	3.5	6-25	40	13	14	58.00	33	.200	4	73.33	15.33
72	23- 6	8- 6	169.3	25	4.5	6-25	42	14	14	58.44	33	.200	4	73.33	15.33
73	23- 8	9- 3	188.1	25	5.5	6-25	44	15	14	58.89	33	.175	4	70.57	15.33
74	23-10	10- 1	207.0	25	6.5	6-25	46	16	14	59.33	34	.250	4	80.22	15.56
75	24- 0	5- 9	108.2	27	.5	4-18	36	10	16	53.56	34	.225	4	77.46	15.56
76	24- 1	6- 6	127.5	27	1.5	4-18	38	11	16	56.22	34	.225	4	77.46	15.56
77	24- 3	7- 4	146.8	27	2.5	4-18	40	12	16	58.89	34	.200	4	74.71	15.56
78	24- 4	8- 2	166.2	27	3.5	4-18	42	13	16	59.33	34	.200	4	74.71	15.56
79	24- 5	8-11	185.7	27	4.5	4-18	44	14	16	59.78	34	.200	4	74.71	15.56
80	24- 7	9- 9	205.3	27	5.5	4-18	46	15	16	60.22	35	.300	4	87.12	15.78
81	24- 8	10- 6	225.0	27	6.5	4-18	48	16	16	60.67	35	.250	4	81.80	15.78
82	25- 2	6- 2	122.0	29	.5	2-11	38	11	16	54.89	35	.200	4	76.09	15.78
83	25- 2	7- 0	142.2	29	1.5	2-11	40	12	16	57.56	35	.200	4	76.09	15.78
84	25- 3	7- 9	162.4	29	2.5	2-11	42	13	16	60.22	36	.300	4	88.50	16.00
85	25- 4	8- 7	182.6	29	3.5	2-11	44	14	16	60.67	36	.300	4	88.50	16.00
86	25- 4	9- 5	202.9	29	4.5	2-11	46	15	16	61.11	36	.300	4	88.50	16.00
87	25- 5	10- 2	223.3	29	5.5	2-11	46	16	16	61.56	36	.300	4	88.50	16.00

NOTES:

1) "N" = 9.82"
2) All shells have Type IV ribs outside only. Both haunch and crown ribs are 18" on centers for structures 40 through 50 and 9" on centers for structures 51 through 87.
3) Weights per foot listed do not include bolt weight.
4) Weight per foot of full invert includes 3½ x 3 x ¼ connecting angle and scalloped closure plate for each side. Inverts for 20 N width and greater are two piece.
5) Full invert plates are .100" thick. When reactions to invert require additional thickness, supplemental plates of thickness and width listed are furnished to bolt between full invert and side connecting angles. When thickness listed is greater than a .250" supplemental plates will be two pieces equalling the composite thickness required.
6) Weight per foot of footing pads includes 3½ x 3 x ¼ connecting angle for each side. Optional wale beam weight is not included.
7) Width of footing pads is for each side. When thickness listed is greater than .250" the footing pads will be two pieces equalling the composite thickness required.

SOURCE: ALUMINUM ASSOCIATION

STANDARD SIZES
FOR ALUMINUM CULVERTS

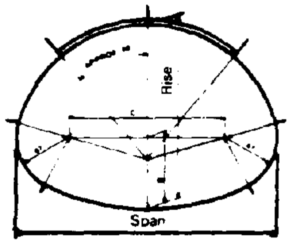


Span Ft.-in		Rise Ft-in.		Area ft²	Required N			Inside Radius	
					Crown or Invert	Haunch	Total	Crown & Invert in.	Haunch in.
19	4	12	9	191	22	10	64	150.3	53.9
20	1	13	0	202	23	10	66	157.2	53.9
20	2	11	10	183	24	8	64	164.1	42.8
20	10	12	2	193	25	8	66	171.0	42.8
21	0	15	1	248	23	13	72	157.2	70.4
21	11	13	1	220	26	9	70	177.9	48.4
22	6	15	8	274	25	13	76	171.0	70.4
23	0	14	1	249	27	10	74	184.8	53.9
23	3	15	11	288	26	13	78	177.9	70.4
24	4	16	11	320	27	14	82	184.8	75.9
24	6	14	7	274	29	10	78	198.6	53.9
25	3	14	11	287	30	10	80	205.4	53.9
25	6	16	9	330	29	13	84	198.6	70.4
26	1	18	2	369	29	15	88	198.6	81.4
26	3	15	10	320	31	11	84	212.3	59.4
27	0	16	2	334	32	11	86	219.2	59.4
27	2	19	1	405	30	16	92	205.4	86.9
27	11	19	5	421	31	16	94	212.3	86.9
28	1	17	1	369	33	12	90	226.1	64.9
28	10	17	4	384	34	12	92	233.0	64.9
29	5	19	11	455	33	16	98	226.1	86.9
30	2	20	2	472	34	16	100	233.0	86.9
30	4	17	11	415	36	12	96	246.8	64.9
31	2	21	2	513	35	17	104	239.9	92.5
31	4	18	11	454	37	13	100	253.7	70.4
32	1	19	2	471	38	13	102	260.6	70.4
32	3	22	2	555	36	18	108	246.8	98.0
33	0	22	5	574	37	18	110	253.7	98.0
33	2	20	1	513	39	14	106	267.5	75.9
34	1	23	4	619	38	19	114	260.6	103.5
34	8	20	8	548	41	14	110	281.2	75.9
35	0	21	4	574	41	15	112	281.2	81.4
35	2	24	4	666	39	20	118	267.5	109.0
35	10	25	9	719	39	22	122	267.5	120.0
36	1	22	4	620	42	16	116	288.1	86.9
36	11	25	7	736	41	21	124	281.2	114.5
37	2	22	2	632	44	15	118	301.9	81.4
38	0	26	7	786	42	22	128	288.1	120.0
38	8	28	0	844	42	24	132	288.1	131.0
40	1	29	8	928	43	26	138	295.0	142.1

SOURCE: ALUMINUM ASSOCIATION

STANDARD SIZES
FOR ALUMINUM CULVERTS

Geometric Data—Pipe Arch

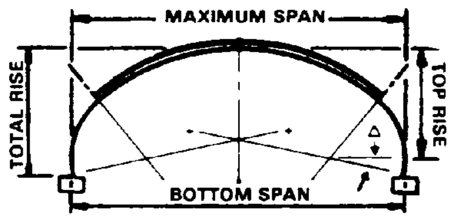


Span Ft-in		Rise Ft-in.		Area ft²	Required N				Inside Radius		B	C
					Total	Crown	Invert	Haunch	Crown in.	Invert in.		
20	1	13	11	216	68	34	20	7	122.7	224.2	62.9	146.7
20	7	14	3	229	70	36	20	7	124.9	256.4	61.4	152.8
21	5	14	7	241	72	36	22	7	131.7	237.3	65.4	163.4
21	11	14	11	254	74	38	22	7	133.7	268.8	63.8	169.4
22	8	15	3	267	76	39	23	7	138.2	274.9	65.0	177.8
23	4	15	7	281	78	40	24	7	142.7	281.0	66.3	186.1
24	3	15	10	295	80	40	26	7	150.0	262.8	70.8	196.8
24	9	16	3	309	82	42	26	7	151.7	293.0	68.9	202.9
25	5	16	7	324	84	43	27	7	156.2	299.0	70.2	211.3
26	4	16	10	339	86	43	29	7	163.9	281.3	75.0	222.1
27	0	17	2	354	88	44	30	7	168.6	287.4	76.4	230.5
27	9	17	6	369	90	45	31	7	173.3	293.5	77.9	238.9
28	5	17	10	385	92	46	32	7	178.0	299.6	79.3	247.3
29	4	18	2	401	94	46	34	7	186.6	286.7	84.6	257.9
29	10	18	6	418	96	48	34	7	187.5	311.6	82.3	264.2
30	4	18	10	435	98	50	34	7	188.6	340.1	80.0	270.2

SOURCE: ALUMINUM ASSOCIATION

STANDARD SIZES
FOR ALUMINUM CULVERTS

Geometric Data—Low Profile Arch



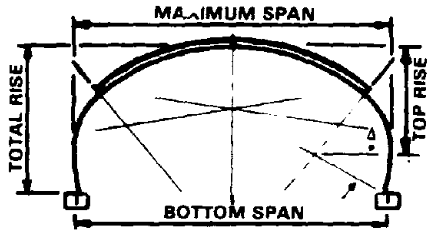
Max. Span Ft-in.		Total Rise Ft-in		Area ft²	Bottom Span Ft-in.		Top Rise Ft-in.		Required N			Inside Radius		Δ	
									Crown	Side	Total	Crown In.	Side In.	Deg.	Min.
20	1	7	6	120	19	10	6	6	23	6	35	157.2	54.0	12	19
19	5	6	9	105	19	2	5	10	23	5	33	157.2	43.0	15	22
21	6	7	9	133	21	4	6	9	25	6	37	171.0	54.0	12	19
22	3	7	11	140	22	1	6	11	26	6	38	177.9	54.0	12	19
23	0	8	0	147	22	10	7	1	27	6	39	184.8	54.0	12	19
23	9	8	2	154	23	6	7	2	28	6	40	191.7	54.0	12	19
24	6	8	3	161	24	3	7	4	29	6	41	198.6	54.0	12	19
25	3	8	5	168	25	0	7	5	30	6	42	205.4	54.0	12	19
26	0	8	7	175	25	9	7	7	31	6	43	212.3	54.0	12	19
27	3	10	0	217	27	1	9	0	31	8	47	212.3	76.0	8	51
28	1	9	6	212	27	11	8	7	33	7	47	226.1	65.0	10	17
28	9	10	3	234	28	7	9	3	33	8	49	226.1	76.0	8	52
28	10	9	8	220	28	8	8	8	34	7	48	233.0	65.0	10	17
30	4	9	11	237	30	2	9	0	36	7	50	246.8	65.0	10	17
31	0	10	8	261	30	10	9	8	36	8	52	246.8	76.0	8	52
31	7	12	1	309	31	2	10	4	36	10	56	246.8	87.0	14	0
31	1	10	1	246	30	10	9	1	37	7	51	253.7	65.0	10	17
32	4	12	3	319	31	11	10	6	37	10	57	253.7	87.0	14	0
31	9	10	2	255	31	7	9	3	38	7	52	260.6	65.0	10	17
33	1	12	5	330	32	8	10	8	38	10	58	260.6	87.0	14	0
33	2	11	0	289	33	0	10	1	39	8	55	267.5	76.0	8	52
34	6	13	3	367	34	1	11	6	39	11	61	267.5	98.0	12	26
34	8	11	4	308	34	6	10	4	41	8	57	281.2	76.0	8	52
37	11	15	7	478	37	8	13	10	41	14	69	281.2	131.0	9	23
35	5	11	5	318	35	3	10	6	42	8	58	288.1	76.0	8	52
38	8	15	9	491	38	4	14	0	42	14	70	288.1	131.0	9	23

See "Notes" Table 5-20A or 5-20B for rib spacing when required.

SOURCE: ALUMINUM ASSOCIATION

STANDARD SIZES
FOR ALUMINUM CULVERTS

Geometric Data—High Profile Arch



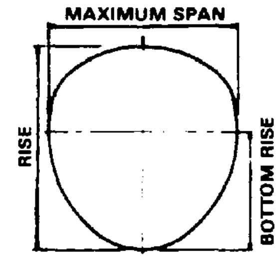
Max Span Ft.-in.		Total Rise Ft.-in.		Area ft²	Bottom Span Ft-in.		Top Rise Ft-in.		Required N				Inside Radius			Δ	
									Crown	Haunch	Side	Total	Crown in.	Haunch in.	Side in.	Deg.	Min.
20	1	9	1	152	19	6	6	6	23	5	3	39	157.2	54.0	157.2	11	40
20	9	12	1	214	18	10	7	3	23	6	6	47	157.2	65.0	157.2	22	8
21	6	11	8	215	19	10	6	9	25	5	6	47	171.0	54.0	171.0	20	20
22	10	14	6	284	19	10	8	6	25	7	8	55	171.0	76.0	171.0	26	48
22	3	11	9	224	20	7	6	11	26	5	6	48	177.9	54.0	177.9	19	33
22	11	14	0	275	20	1	7	7	26	6	8	54	177.9	65.0	177.9	25	44
23	0	11	11	234	21	5	7	1	27	5	6	49	184.8	54.0	184.8	18	49
24	4	14	10	309	21	7	8	5	27	7	8	57	184.8	76.0	184.8	24	50
23	9	12	1	244	22	2	7	2	28	5	6	50	191.7	54.0	191.7	18	8
24	6	13	8	288	21	11	7	4	29	5	8	55	198.6	54.0	198.6	23	2
25	10	15	1	334	23	3	8	9	29	7	8	59	198.6	76.0	198.6	23	6
25	3	13	1	283	23	3	7	5	30	5	7	54	205.4	54.0	205.4	19	35
26	6	15	3	347	24	0	8	10	30	7	8	60	205.4	76.0	205.4	22	19
26	0	13	3	294	24	1	7	7	31	5	7	55	212.3	54.0	212.3	18	57
27	3	15	5	360	24	10	9	0	31	7	8	61	212.3	76.0	212.3	21	36
27	5	13	6	317	25	8	7	10	33	5	7	57	226.1	54.0	226.1	17	48
29	5	16	5	412	27	1	10	0	33	8	8	65	226.1	87.0	226.1	20	18
28	2	14	5	348	25	11	8	0	34	5	8	60	233.0	54.0	233.0	19	37
30	2	18	0	466	26	8	10	2	34	8	10	70	233.0	88.0	233.0	23	51
30	4	15	5	399	28	2	9	0	36	6	8	64	246.8	65.0	246.8	18	34
31	7	18	4	497	28	5	10	4	36	8	10	72	246.8	87.0	246.8	23	3
31	1	15	7	412	29	0	9	1	37	6	8	65	253.7	65.0	253.7	18	3
31	8	17	9	483	28	7	9	10	37	7	10	71	253.7	76.0	253.7	22	25
32	4	19	11	554	27	11	10	6	37	8	12	77	253.7	87.0	253.7	26	45
31	9	17	2	468	28	9	9	3	38	6	10	70	260.6	65.0	260.6	21	47
33	1	20	1	571	28	9	10	8	38	8	12	78	260.6	87.0	260.6	26	3
32	6	17	4	484	29	6	9	4	39	6	10	71	267.5	65.0	267.5	21	14
33	10	20	3	568	29	7	10	9	39	8	12	79	267.5	87.0	267.5	25	23
34	0	17	8	514	31	2	9	8	41	6	10	73	281.2	65.0	281.2	20	11
34	8	19	10	591	30	7	10	4	41	7	12	79	281.2	76.0	281.2	24	7
35	4	21	3	845	30	7	11	0	41	8	13	83	281.2	87.0	281.2	26	6
37	3	23	4	747	32	7	13	2	41	11	13	89	281.2	120.0	281.2	26	8
34	9	17	9	529	31	11	9	9	42	6	10	74	288.1	65.0	288.1	19	42
35	5	20	0	608	31	5	10	6	42	7	12	80	288.1	76.0	288.1	23	33
36	1	21	5	663	31	5	11	2	42	8	13	84	288.1	87.0	288.1	25	28
38	0	23	6	767	33	5	13	3	42	11	13	90	288.1	120.0	288.1	25	31

See "Notes" Table 5-20A or 5-20B for rib spacing when required.

SOURCE: ALUMINUM ASSOCIATION

STANDARD SIZES
FOR ALUMINUM CULVERTS

Geometric Data—Pear Shape



Max. Span Ft.-in.	Rise Ft.-in.	Rise Bottom Ft-in.	Area ft²	Required N					Inside Radius			
				Top	Corner	Side	Bottom	Total	Bottom in.	Side in.	Corner in.	Top in.
23 7	25 6	14 10	477	25	5	24	15	98	108.31	198 07	74 07	175.07
24 0	25 10	15 1	497	22	7	22	20	100	119.07	208.07	84 07	194 07
25 4	25 11	15 10	518	27	7	20	20	102	124.23	218.24	84 24	191.24
24 10	27 7	16 9	545	27	5	25	18	105	110.90	236.21	69 21	191.21
28 10	27 3	19 8	590	32	7	27	8	110	79.61	257.96	68.96	252.96
26 8	28 3	18 0	594	28	5	30	12	110	95.45	241 24	57.24	251 24
28 0	27 10	16 9	624	27	8	22	25	112	146.38	227 72	86.72	244 72
28 7	30 7	19 7	690	32	7	24	24	118	133.13	288 45	84.45	218 45
30 0	29 7	20 0	699	32	8	23	25	119	142.41	288.26	79 26	262.26
30 0	31 2	19 11	739	34	7	24	26	122	144 43	·288.58	84 58	231.58

SOURCE: ALUMINUM ASSOCIATION

GLOSSARY OF TERMS

Abrasion
Wearing or grinding away of material by water laden with sand, gravel, or stones.

Aggradation
General and progressive raising of the streambed by deposition of sediment.

Aggressive Environment
A soil-stream environment where corrosion-abrasion deterioration is highly destructive to culvert life.

Allowable Headwater
Difference in elevation between the flowline of the culvert and the lowest point at which the water surface upstream would either flood the roadway or jeopardize property.

Anode
A metallic surface on which oxidation occurs, giving up electrons with metal ions going into solution or forming an insoluble compound of the metal.

Autogeneous Healing
A process where small cracks are healed by exposure to moisture, forming calcium carbonate crystals that accumulate along the crack edges, inter-twining and building until the crack is filled.

Backfill
The material used to refill the trench, or the embankment placed over the top of the bedding and culvert.

Backwater
The water upstream from an obstruction in which the free surface is elevated above the normal water surface profile.

Bedding
The soil used to support the load on the pipe. For rigid pipe, the bedding distributes the load over the foundation. It does the same thing for flexible pipe except that it is not as important a design factor.

Bed Load
Sediment that moves by rolling, sliding, or skipping along the bed and is essentially in contact with the streambed.

Bituminous (Coating)
Of or containing bitumen; as asphalt or tar.

Box Section
A concrete or corrugated pipe with a rectangular or nearly rectangular cross section.

Buckling
Failure by an inelastic change in alignment (usually as a result of compression).

Buried Pipe
A structure that incorporates both the properties of the pipe and the properties of the soil surrounding the pipe.

Buoyancy
The power of supporting a floating body, including the tendency to float an empty pipe (by exterior hydraulic pressure).

Capacity
Maximum flow rate that a channel, conduit, or structure is hydraulically capable of carrying. The units are usually CFS or GPM.

Cathode
A surface that accepts electrons and does not corrode.

Cathodic Protection
A means of preventing metal from erroding. This is done by making the metal a cathode through the use of impressed direct current or by attaching a sacrificial anode.

Cavitation
A phenomenon associated with the vaporization of a flowing liquid at high velocities in a zone of low pressure, wherein cavities filled with liquid (vapor bubbles) alternately develop and collapse; surface pitting of a culvert may result.

CFS
Rate of flow in cubic feet per second.

Critical Flow
The condition of flow in a channel where the specific energy for a given discharge is minimum.

Class
The grade or quality of pipe.

Coating
Any material used to protect the integrity of the structural elements of a pipe from the environment, and add service life to the culvert.

Compaction
The process by which a sufficient amount of energy is applied to soil to achieve a specific density.

Conductor
A metallic connection (in drainage facilities, usually the pipe itself) that permits electrical current flow by completing the circuit.

Conduit
Usually a pipe, designed to flow according to open channel equations.

Corrosion
Deterioration or dissolution of a material by chemical or electrochemical reaction with its environment.

Cover
The depth of backfill over the top of the pipe.

Crack
A fissure in installed precast concrete culvert.

Critical Flow
That flow in open channels or conduits at which the energy content of the fluid is at a minimum.

Crown
The top or highest point of the internal surface of the transverse cross section of a pipe.

Culvert
A drainage opening beneath an embankment, usually a pipe, designed to flow according to open channel equation.

D-Load
The supporting strength of a pipe loaded under three-edge-bearing test conditions expressed in pounds per lineal foot per foot of inside diameter or horizontal span, or expressed in new tons per linear meter per millimeter of inside diameter or horizontal span.

D-Load, 0.01-in. (0.25 mm) Crack
The maximum three-edge-bearing test load supported by a concrete pipe before a crack occurs having a width if 0.01 in measured at close intervals, throughout a length of at least 1 ft expressed as D-load.

Debris
Any material including floating woody materials and other trash, suspended sediment, or bed load, moved by a flowing stream.

Degradation
General progressive lowering of the stream channel by erosion.

Discharge (Q)
Flow from a culvert, sewer, or channel in cubic feet per second (CFS).

Drainage
Interception and removal of ground water or surface water by artificial or natural means.

Drop Inlet
A type of inlet structure which conveys the water from a higher elevation to a lower outlet elevation smoothly without a free fall at the discharge.

Electrolyte
Moisture or a liquid carrying ionic current between two metal surfaces, the anode and the cathode.

Embankment
A bank of earth, rock or material constructed above the natural ground surface over a culvert.

End Section
A concrete or steel appurtenance attached to the end of a culvert for the purpose of hydraulic efficiency and anchorage.

Energy Gradient
The increase or decrease in total energy of flow with respect to distance along the channel.

Energy Grade Line
The line which represents the total energy gradient along the channel. It is established by adding together the potential energy expressed as the water surface elevation referenced to a datum and the kinetic energy (usually expressed as velocity head) at points along the streambed or channel floor.

Erosion (Culvert)
Wearing or grinding away of culvert material by water laden with sand, gravel, or stones; generally referred to as abrasion.

Erosion (Stream)
Wearing away of the streambed by flowing water.

Female End of Pipe (bell, socket, groove, modified groove)
That portion of the end of the pipe, regardless of its shape, size, or dimensions, which overlaps a portion of the end of the adjoining pipe.

Flexible Pipe
A pipe with relatively little resistance to bending. As the load increases, the vertical diameter decreases and the horizontal diameter increases, which is resisted by the soil around the pipe.

Flood Frequency
The average time interval in years in which a flow of a given magnitude, taken from an infinite series, will recur.

Flow Line
A line formed by the inverts of pipe.

Foundation
The inplace material beneath the pipe.

Free Outlet
Exists when the backwater does not diminish the discharge of a conduit.

Gauge
A standard or scale of measurement.

GPM
Gallons per minute.

Grade
The longitudinal slope of the channel as a ratio of the drop in elevation to the distance.

Gradient
See grade

Groundwater
Water contained in the subsoil which is free to move either vertically or horizontally.

Hair Line Cracks
Very small cracks that form in the surface of the concrete pipe due to tension caused by loading.

Haunches
The outside areas of a pipe between the spring line and the bottom of the pipe.

Head (Static)
The heights of water above any plane or point of reference.

Headloss
The loss of energy reported in feet of head.

Headwall
A concrete structure placed at the inlet and outlet of a culvert to protect the embankment slopes, anchor the culvert, and prevent undercutting.

Headwater
The distance between the flowline elevation at the inlet of a culvert and the water surface at the inlet.

Hydraulics
The mechanics of fluids, primarily water.

Hydraulic Gradeline
An imaginary line, representing the total energy and paralleling the free water surface if the flow were at atmospheric pressure.

Hydraulic Jump
An abrupt rise in the water surface in the direction of flow when the type of flow changes from supercritical to subcritical.

Hydraulic Radius
The cross-sectional area of flow divided by the length of that part of its periphery in contact with its containing conduit; the ratio of area to wetted perimeter.

Hydrology
The science of water related to its properties and distribution in the atmosphere, on the land surface, and beneath the surface of the land.

Inlet Control
A culvert operates with inlet control when the flow capacity is controlled at the entrance by the depth of headwater and the entrance geometry, including the barrel shape, cross-sectional area and the inlet edge.

Invert
The bottom or lowest point of the internal surface of the transverse cross section of a pipe.

Joint
A connection between two pipe sections, made either with or without the use of additional parts

Male End of Pipe (Spigot, Tongue, Modified Tongue)
That portion of the end of the pipe, regardless of its shape or dimensions, which is overlapped by a portion of the end of the adjoining pipe.

Manning's Formula
An equation for the value of coefficient C in the Chezy Formula, the factors of which are the hydraulic radius and a coefficient of roughness.

Metal Corrosion
An electrical process involving an electrolyte (moisture), an anode (the metallic surface where oxidation occurs), a cathode (the metallic surface that accepts electrons and does not corrode), and a conductor (the metal pipe itself).

Minor Head Losses
Head lost through transitions such as entrances, outlets, obstructions, and bends.

O-Ring Gasket
A solid gasket of circular cross section.

Outfall
In hydraulics, the discharge end of drains or sewers. Also referred to as outlet.

Outlet
See Outfall.

pH Value
The log of the reciprocal of the hydrogen ion concentration of a solution. A pH value of 7.0 is neutral; values of less than 7.0 are acid; values of more than 7.0 are alkaline.

Pipe
A tube or conduit.

Pipe Diameter
The inside diameter of a pipe.

Piping
A process of subsurface erosion in which surface runoff flows along the outside of a culvert and with sufficient hydraulic gradient erodes and carries away soil around or beneath the culvert.

Ponding
Water backed up in a channel or ditch as the result of a culvert of inadequate capacity or design to permit the water to flow unrestricted.

Prestressed Concrete
In pretensioned concrete, the steel bars, wires, or cables are held in a stretched condition during placing of the plastic concrete and until the concrete has hardened; then the pull on the reinforcing steel is released.

Reinforced Concrete Pipe
A concrete pipe designed with reinforcement as a composite structure.

Rigid Pipe
A pipe with a high resistance to bending.

Rip Rap
Rough stone of various sizes placed compactly or irregularly to prevent scour by water or debris.

Roughness Coefficient (n)
A factor in the Kutter, Manning, and other flow formulas representing the effect of channel (or conduit) roughness upon energy losses in flowing water.

Resistivity (Soil)
An electrical measurement in ohm-cm, which is one of the factors for estimating the corrosivity of a given soil to metals.

Runoff
That part of precipitation carried off from the area upon which it falls.

Sacrificial Coating
A coating over the base material to provide protection to the base material. Examples include galvanizing on steel and alucIading on aluminum.

Sacrificial Thickness
Additional pipe thickness provided for extra service life of the culvert in aggressive environment.

Scour (Outlet)
Degradation of the channel at the culvert outlet as a result of erosive velocities.

Seepage
The escape of water through the soil, or water flowing from a fairly large area of soil instead of from one spot, as in the case of a spring.

Skew (Skew Angle)
The acute angle formed by the intersection of the line normal to the centerline of the road with the centerline of a culvert or other structure.

Slabbing
Radical tension failure of the concrete, resulting from the tendency of the curved reinforcing to straighten out under load.

Slide
Movement of a part of the earth (embankment) under the force of gravity.

Spalling (Culvert)
The separation of surface concrete due to fractures in the concrete parallel or slightly inclined to the surface of the concrete.

Springline
The points on the internal surface of the transverse cross section of a pipe intersected by the line of maximum horizontal dimension; or in box sections, the mid-height of the internal vertical wall.

Suspended Load
Sediment that is supported by the upward components of the turbulent currents in a streamand that stays for an appreciable length of time.

Tailwater Depth
The depth of water just downstream from a structure.

Three-Edge-Bearing Method
A method for applying the load to a pipe in an external load-crushing strength test.

Velocity Head
For water moving at a given velocity, the equivalent head through which it would have to fall by gravity to acquire the same velocity.

Wall (Concrete Pipe)
The structural element composed of concrete or concrete and reinforcing steel between the inside and outside of a concrete pipe.

Watercourse
A channel in which a flow of water occurs, either continuously or intermittently, with some degree of regularity.

Watershed
Region or area contributing to the supply of a stream or lake; drainage area, drainage basin, catchment area.

Wetted Perimeter
The length of the wetted contact between the water and the containing conduit measured at right angles to the conduit.

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