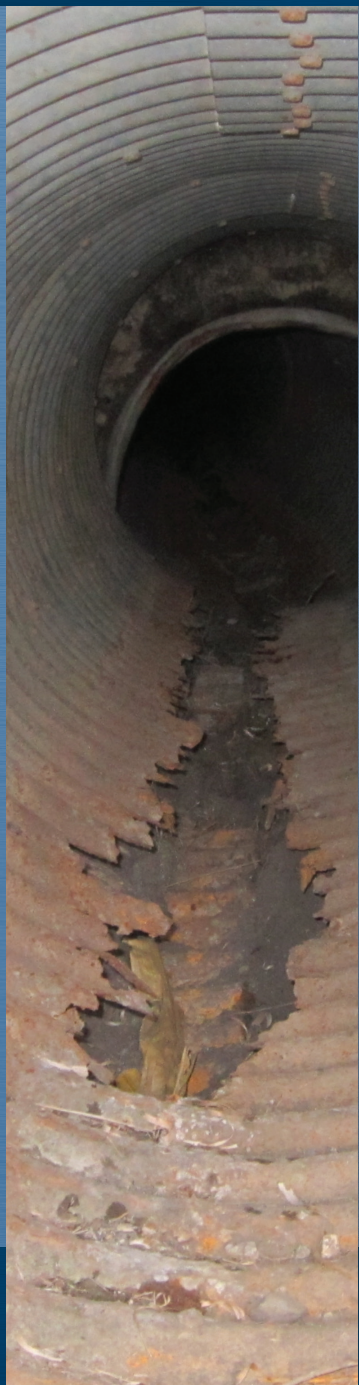


Culvert & Storm Drain System Inspection Guide



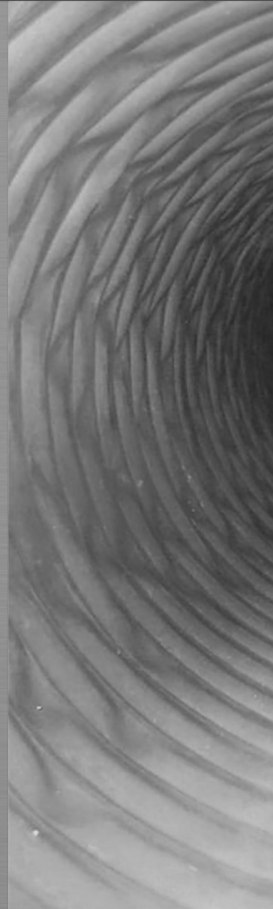
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2020
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SECTION 1

INTRODUCTION TO THE GUIDE

In 1986, the Federal Highway Administration (FHWA) published the *Culvert Inspection Manual* as a supplement to the *Bridge Inspector's Training Manual 70*. This Guide updates the 1986 manual to address the need to inventory, quantify, and rate the condition of in-service culverts and to update the inspection and rating criteria to incorporate over 30 years of change since the original publication.

1.1 General

Culvert and storm drain systems are vital infrastructure assets that require periodic maintenance to achieve their design service life and proper function. Culverts are buried structures designed to allow passage of water under roadways, railways, or embankments. Culverts can be structurally similar to bridges, but are distinguished in terms of span length (diameter for round pipes). The Federal Highway Administration *Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges* defines a culvert as "a structure designed hydraulically to take advantage of submergence to increase hydraulic capacity." Culverts, as distinguished from bridges, are usually covered with embankment and are composed of structural material around the entire perimeter, although some are supported on spread footings with the streambed serving as the bottom of the culvert. Culverts may qualify to be considered "bridge length." Structures defined as such and of "bridge length" are to be inspected following National Bridge Inventory (NBI) specifications and the *AASHTO Manual for Bridge Evaluation* (MBE) and, where necessary, the *AASHTO Manual for Bridge Element Inspection* (MBEI). Storm drain systems are closed-end conduits with inlet and outlet structures and in-line junction boxes that convey storm water runoff from roofs, parking lots, roads, walkways, and other impervious surfaces to collection and discharge points. Together, these drainage and conveyance systems protect our transportation assets from the destructive forces of water and help meet environmental requirements.

Many states have required the inspection of structures less than 20-ft span to follow the NBI specifications and AASHTO MBE and MBEI. The implementation of this AASHTO *Culvert and Storm Drainage System Inspection Guide* is not intended to preclude states from using the NBI specification or the AASHTO MBE and MBEI or other culvert inspection guides for the inspection of their culverts. Further, any reference to inspection frequency of culverts or inspector qualifications within this Guide is intended for guidance for asset management only and is at the discretion of the culvert or storm drain owner, and is not suggested to be implemented in a regulatory sense.

This Guide provides Inspectors with guidelines for routine condition assessment of culverts or storm drains, including all components in their systems. The criteria herein provide a reliable and reproducible method to rate the condition of system components. The component-based rating system enables a qualified Inspector to assess common distress types, evaluate their severity, understand their significance, and assign a numerical condition rating that is associated with recommendations for further action, if necessary. This Guide is a useful resource to agencies developing and conducting culvert and storm drain inspection programs. The Guide also provides guidance for developing a transportation asset management plan for culvert and storm drain system inventories.

1.2 Need for Standardized Inspection

Culverts have traditionally received less attention than bridges, leading to large numbers of structures with deferred maintenance and varying levels of distress that are not contained in any formal inventory database. Individual culvert and storm drain systems are significantly smaller investments than bridges; however, the total inventory of culverts and storm drains greatly outnumber bridges. Taken in total, the large inventory brings the asset value and the need for maintenance more in line with bridges.

Age, physical damage, changing land use, larger loads, and environmental exposure can lead to system deterioration. Lack of maintenance is a primary cause of improper functioning in culvert and storm drain systems. Scheduled routine inspections allow minor problems to be spotted and corrected before they become serious. Failure can lead to roadway collapse or washout, area flooding,

embankment erosion, or blockage to fish passage. These failures can be a heavy cost burden to transportation agencies, local businesses, and the traveling public. Figure 1.2-1 illustrates roadway failure due to progressive piping of soils from around the buried culvert.



Figure 1.2-1—Roadway Collapse Due to Piping along Culvert and Loss of Backfill

(Photo courtesy of FEMA)

The *National Bridge Inspection Standards* (NBIS) define a bridge as “[a] structure including supports erected over a depression or an obstruction, such as water, highway, or railway, and having a track or passageway for carrying traffic or other moving loads, and having an opening measured along the centerline of the roadway of more than 20 feet between undercopings of abutments or spring lines of arches, or extreme ends of openings for multiple boxes; it may also include multiple pipes, where the clear distance between openings is less than half of the smaller contiguous opening.” Federal regulations mandate that all bridges, including culvert-like structures with spans greater than 20 ft, are to be inspected on a two-year cycle. Figure 1.2-2 illustrates the NBIS method for determination of the bridge length for multiple barrel culvert installations.

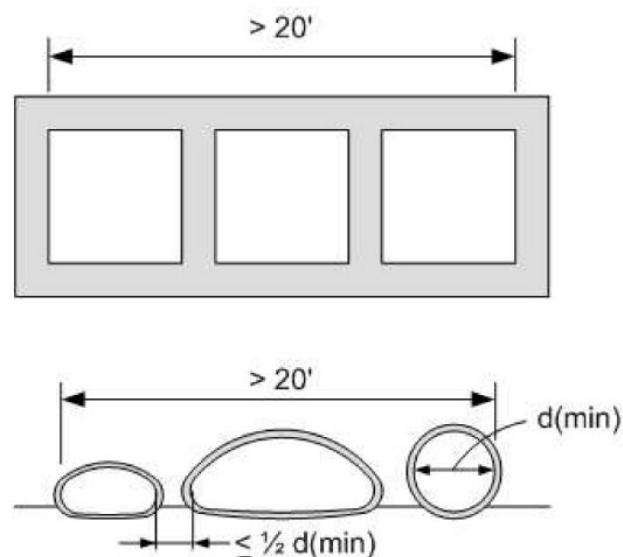


Figure 1.2-2—Culverts Meeting Definition of Bridge Length in the NBIS

(Extract from Figure 3.1.2, *Bridge Inspector's Reference Manual*)



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In contrast, culverts and storm drains under 20-ft spans have no federally mandated (or funded) minimum inspection cycle. An inspection and condition monitoring program for these numerous smaller systems provides the following benefits:

- Identification of minor issues that can be addressed through maintenance before they become safety hazards.
- Mitigation of repair costs.
- Reduction in the risk of failure.
- Allowance for short- and long-term planning and budgeting for repairs and rehabilitation.
- Provision of a method to meet state and federal requirements to quantify the value of highway infrastructure assets.

Agencies in charge of culvert and storm drain inventories have a responsibility to assess the condition of these infrastructure assets in sufficient detail to maintain safe roadways and to meet environmental regulations. Inspection data also provide a strong basis to justify repair funding requests and to prioritize rehabilitation programs. The usefulness of the inspection data for these important functions hinges on the type and accuracy of the recorded data and the consistency of condition ratings between Inspectors. Information must be recorded in a manner that is easy to understand, provides an accurate assessment of condition, provides for cross-disciplinary access and sharing, and is easily verified and updated.

A culvert and storm drain system inventory and inspection program should evaluate structural integrity, hydraulic performance, and roadside compatibility. This evaluation requires training and consistent guidance on what to inspect and how to assess inspection findings.

1.2.1—Structural Integrity

Structural failures can be life-threatening to the traveling public, and at a minimum cause roadway closure and traffic delays. Identifying structural and material problems requires a careful evaluation of deterioration and distress of the system components. Figure 1.2.1-1 illustrates roadway failure due to progressive deterioration of a buried culvert system due to deferred maintenance and irregular inspections.



Figure 1.2.1-1—Roadway Collapse Due to Structural Failure of Culvert

(Photo courtesy of Iowa Department of Transportation)

1.2.2—Hydraulic Performance

Inadequate hydraulic performance can result in safety hazards such as flooding of the roadway or adjacent properties, or roadway washout. Aquatic organism passage may also be inhibited when blockage or erosion changes the streambed and flow characteristics.

1.2.3—Roadside Compatibility

Many culverts, like older bridges, present roadside hazards. Headwalls and wing walls higher than the road or embankment surface may constitute a fixed obstacle hazard. Abrupt drop offs over the end of a culvert or steep embankments may represent rollover hazards to vehicles that leave the roadway.

The success of a culvert and storm drain system inspection program hinges on the Inspector's ability to effectively assess the condition of the structure and materials and to make sound evaluations that lead to consistent, accurate ratings. The inspection data collected by the Inspector may be used as an input to an asset management system that allows prioritization of maintenance budgets and to make other decisions that can directly impact public safety. The inspection program thus plays the most critical role in maintaining the large number of systems in a typical agency's culvert and storm drain inventory.

1.3 Objectives, Audience, and Organization of the Guide

1.3.1—Objectives

The objective of this Guide is to provide quantitative and consistent condition rating criteria based on engineering principles and existing best practices. The condition assessment criteria presented in this Guide will enable culvert and storm drain Inspectors to identify structural distress for culvert or storm drain system components, rate the condition of each component, document findings of an inspection, and recommend corrective actions where necessary. To meet this objective, the Guide provides guidelines for conducting culvert or storm drain system inspections and rating system components.

To enable Inspectors to assess the importance of any identified distress, the Guide provides a review of how culvert and storm drain systems function and how buried pipes carry load by soil-structure interaction.

This Guide is not intended to be used as a standard or policy statement. This document is made available to be used as a resource for current information in the area of culvert and storm drain system inspection. Agencies may choose to use this information as one reference on which to build inspection, assessment, and management criteria best suited to their particular agency needs. Knowledgeable inspection, practically and systematically applied, offers the greatest potential for a continually improved transportation system.

1.3.2—Audience

The intended users of the *Culvert and Storm Drain System Inspection Guide* are highway agencies tasked with maintaining culvert and storm drain inventories, including state highway agencies (departments of transportation), city and county highway divisions, and other local agencies. Personnel from these agencies that will benefit from use of the Guide include:

- Culvert and storm drain system Inspectors and bridge inspection personnel.
- Consultants to highway agencies responsible for culvert and storm drain system inspection.
- Maintenance personnel responsible for performing scheduled maintenance on culvert and storm drain systems.

1.3.3—Organization of the Guide

The *Culvert and Storm Drain System Inspection Guide* is organized into five sections with two appendices:

Section 1— Introduction to the Guide

Section 1 introduces the topic of culvert and storm drain system inspections, outlines the need for standardized inspection programs, provides the Guide's objectives, and identifies the intended audience. This section also instructs users on the Guide's organization.

Section 2— Design and Performance Characteristics	Section 2 introduces the general factors that affect structural and functional performance of culvert and storm drain barrels, the structural shapes and materials, the various culvert and storm drain system components, and pipe coatings and linings. This section provides common system characteristics and refers to Appendix A for additional details about system components.
Section 3— Inspection Procedure	Section 3 covers inspection frequency, preparation and planning of inspections, types of inspections, the inspection sequence for routine inspections, type of entry, qualifications of the Inspector, typical equipment and tools for conducting an inspection, and inspection safety.
Section 4— Condition Rating System	Section 4 provides quantitative criteria for rating the condition of culvert and storm drain system components. Tables describe assignment of a condition rating from 1 (Good) to 4 (Severe) using specific criteria obtained by visual inspection or basic measurements.
Section 5— Asset Management	Section 5 introduces culvert and storm drain system inventory asset management with examples of best current practices. This section also provides references for additional information to this large topic.
Appendix A— Structural Shapes, Materials, and System Components	Appendix A augments Sections 2 and 4 to illustrate and describe the various culvert and storm drain barrel shapes, the materials from which they are constructed, and the system components. This appendix provides references for further information.
Appendix B— Catalog of Distressed Conditions	Appendix B provides Inspectors with a photographic guide for assessing the condition of typical culvert and storm drain system component, by distress characteristic, in catalog format. The catalog sequence is organized to match the distress conditions listed in the condition rating tables of Section 4. The catalog includes narrative descriptions of the distress and color-coding for quick reference to distress condition rating tables.
Glossary	The glossary contains definitions for commonly used culvert and storm drain terms.
References	The references section lists documents used in the production of this Guide.

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SECTION 2

DESIGN AND PERFORMANCE CHARACTERISTICS

2.1 General

This Section introduces basic design characteristics of culverts and storm drains, including hydraulics, structural behavior, and design loads. Familiarity with the design and performance characteristics is required to understand how the inspection criteria and collected data relate to the service life of a structure. This section also presents performance issues related to the durability of culverts and storm drains, which present the most significant distress modes for in-service culverts and storm drains. The term “pipe” is used herein to represent the buried barrel section of culvert and storm drain systems.

2.2 Design Characteristics

The design of culverts and storm drains typically starts with selection of the culvert shape and material sized for the required hydraulic capacity of the system. This selection is frequently based on the owner's experience with various culvert materials. Once the size and shape are determined, the structural design of the barrel depends on behavior classification (flexible or rigid), culvert and backfill material properties, and the design loads. Specification of construction and installation requirements is integral to the service performance of a culvert. Assumptions are made in the design phase about trench or embankment and backfill. Good practice includes verification of these assumptions to ensure the culvert behaves as intended. After construction and the first few years of service, the performance of a culvert or storm drain system relates to the durability of the structure or changes in land use. The durability of the structure is primarily dependent on the barrel material, backfill type and competency, water chemistry and velocity, and presence of debris. Durability problems frequently require replacement or rehabilitation as culverts are more likely to wear away than fail prematurely due to structural overload.

2.2.1—Hydraulic Requirements

Culverts are primarily constructed to convey water under gravity flow through a highway, railroad, or other embankment. Storm drain systems convey water under gravity flow along a variety of routes, including under roadways. A culvert or storm drain which fails to perform this function properly may jeopardize the roadway, as shown in Section 1, cause excessive property damage, or even result in loss of life. Therefore, the design of a culvert or storm drain system must carefully consider the characteristics pertaining to the conveyance of water.

The first step in the design of a culvert or storm drain system is to determine the hydraulic requirements. Hydraulic requirements are used to select the size, shape, slope, inlet and outlet end treatments, and elevations such that the system can meet the design flow demand. Engineering analysis is required to quantify the hydraulic requirements of a culvert or storm drain system. A hydraulic analysis has two general elements: estimating runoff and determining hydraulic capacity.

2.2.1.1—Sedimentation

Sedimentation is the accumulation of small soil particles as they settle out of the flow and form of a layer in the bottom of a culvert or storm drain barrel. Sedimentation can be caused by natural transport of particles from the stream bed into the culvert or from other effects such as roadway construction. Buildup of sedimentation can reduce the hydraulic capacity of a culvert and may cause overtopping of the culvert and flooding of the roadway and nearby areas. Inspection for buildup of sedimentation is important for scheduling maintenance of structures to prevent flow problems. Sedimentation is also used in specific design cases to establish natural stream-like conditions for aquatic organisms (see Appendix A).

2.2.1.1.1—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 culverts which are not adequately protected or anchored may be subject to failure due to buoyant forces. The outlet may require energy dissipators or rip-rap to control erosion and scour and to protect downstream properties. High outlet velocities may cause scour, which undermines footings, endwalls, wingwalls, and culvert barrels. Scour can cause damage or end-section drop-off in culverts.

2.2.1.1.2—Protection against Piping

Seepage of groundwater along the outside of the culvert barrel length may remove supporting material. This process is referred to as piping since a hollow, similar to a pipe, is often formed. Piping can be more severe in fine-grained or silty soils. Piping can also occur from leaks along the culvert with water exiting the culvert through open joints or perforations in the culvert wall formed by corrosion. Water flowing out of the culvert along the length of the barrel is called exfiltration. 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, quality backfill material with adequate compaction, proper waterway alignment, and appropriate inlet geometry.

2.2.2—Structural Behavior (*Flexible vs. Rigid*)

Structural behavior of the culvert or storm drain barrel is highly dependent on the structural interaction of the culvert and the backfill. Culverts are structurally classified as either rigid or flexible (though some newer materials behave in a semi-rigid manner): Specific inspection criteria for structural conditions vary by culvert material. Different flexible culvert materials have different defects, deterioration, and failure modes than rigid culvert materials. Different culvert materials also show unique characteristics under stress or corrosive attack.

2.2.2.1—Flexible Culvert Behavior

Flexible culvert barrels have little structural bending strength or stiffness on their own. Flexible culvert materials, such as corrugated metal or plastic, can be flexed or bent with no permanent distress for relatively small deformations. Flexible culverts depend on quality compacted backfill embedment to support applied loads. This is referred to as a soil-structure interaction system.

Flexible culverts derive a substantial amount of their structural integrity from the soil envelope in which they are embedded, making deflection control a key parameter in their design and installation, and for service inspections. Flexible culverts have relatively low bending stiffness and low bending strength without soil support. As loads are applied to the culvert, it attempts to deflect. In a round culvert, for example, the vertical diameter decreases and the horizontal diameter increases, as shown in Figure 2.2.2.1-1. When good backfill material is well compacted around the culvert, the increase in horizontal diameter of the culvert is resisted by the lateral soil pressure of the embedment backfill material.

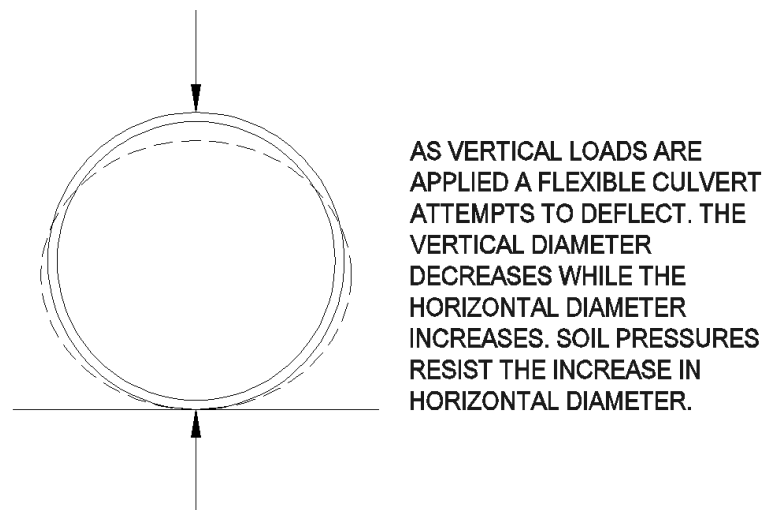


Figure 2.2.2.1-1—Deflection of Flexible Culverts

Good quality backfill includes non-cohesive fines and granular soils and proper installation and compaction are critical in obtaining a stable soil embedment zone around the flexible culvert. Maintenance of the embedment zone is the most important method to ensure structural safety of a flexible culvert installation, and inspection should be completed where possible. An arc of a flexible round culvert, 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 in Figure 2.2.2.1-2 on each end of the arc. The compressive force, C , in a round culvert is equal to the vertical pressure, P , multiplied by one-half the span length, S , where $C = P \times S/2$.

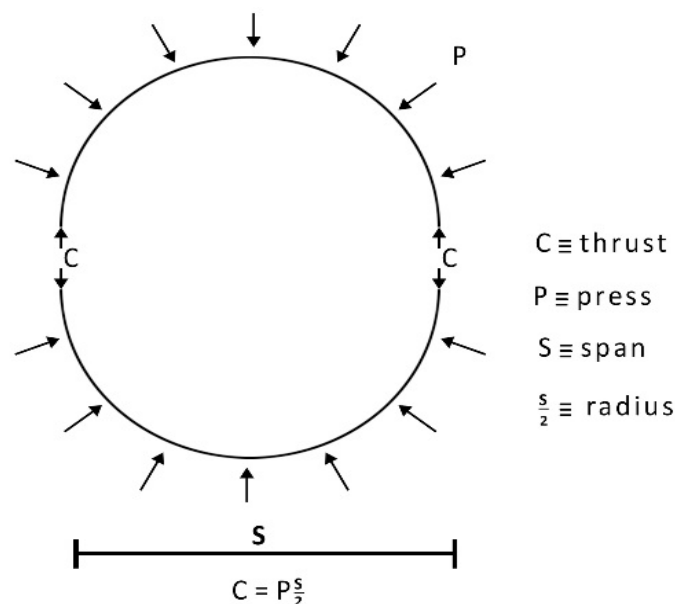


Figure 2.2.2.1-2—Load in Flexible Culverts

Very large flexible culverts include long-span corrugated steel or aluminum structures. Long-span culverts typically have a large radius, R , and may include varying radius around the circumference. To prevent excessive deflection due to external loads, longitudinal or circumferential stiffeners are sometimes added. The circumferential stiffeners are usually metal ribs bolted to the outside of the corrugated metal. Longitudinal stiffeners (thrust beams) are typically reinforced concrete, as shown in Figure 2.2.2.1-3. 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, preventing concentration on the large radius long-span plate.

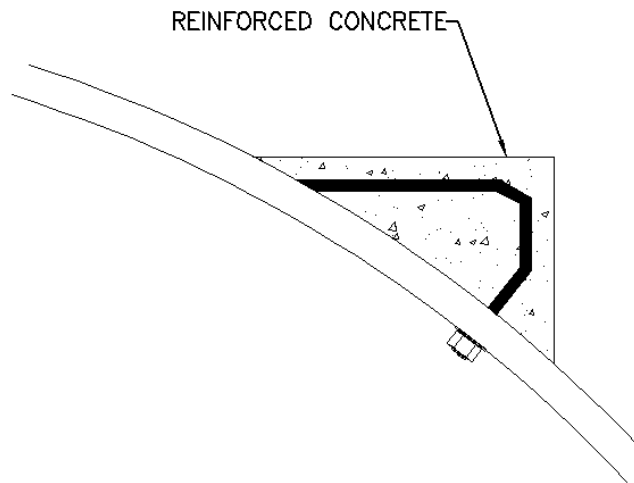


Figure 2.2.2.1-3—Concrete Thrust Beams (Longitudinal Stiffeners)

Flexible culverts will typically accommodate 2 to 7.5 percent deflection (reduction in vertical diameter or rise) without structural distress. Greater than 5 percent deflection typically indicates the need for evaluation by an engineer. Examples of flexible culvert types include corrugated or solid-wall metal (aluminum, steel, or ductile iron), corrugated or solid-wall plastic (polyvinyl chloride (PVC), high-density polyethylene (HDPE) or polypropylene (PP)), fiber-reinforced polymer (FRP), and other composite walls such as steel-reinforced polyethylene (SRPE).

2.2.2.2—Rigid Culvert Behavior

Rigid culverts are stiff and do not deflect appreciably. Rigid culvert materials, such as reinforced concrete, clay, asbestos cement, and cast iron, provide resistance to bending and typically have higher strength to carry loads. These structures rely on support from foundations or bedding materials and rely less heavily on side-soil support. Rigid culverts are not controlled by vertical diameter deflection. The load-carrying capability of rigid culverts is provided by the structural strength of the culvert or box itself and the support by soils around the culvert. When vertical loads are applied to a rigid culvert, zones of tension, compression, and shear are created in the walls. Figure 2.2.2.2-1 shows tension, compression, and shear during the three-edge bearing test (a test used to establish concrete pipe load capacity). With the exception of non-reinforced small diameter circular culvert, reinforcing steel is added to the tension zones to increase the tensile strength of the concrete culvert. Shear stress in the haunch area can be critical for heavily loaded rigid culvert on hard foundations, especially if the haunch support is inadequate. Because rigid culverts are stiffer than the surrounding soil, they carry a substantial portion of the applied soil and live loads.

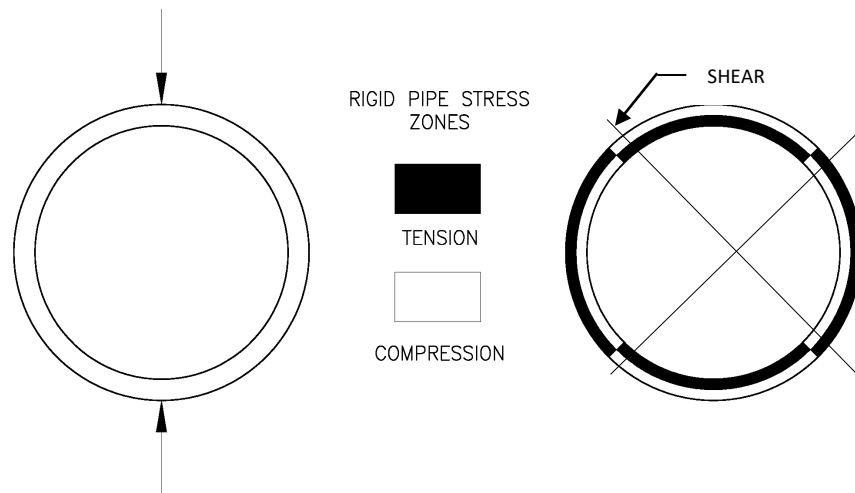


Figure 2.2.2.2-1—Zones of Tension and Compression in Rigid Culverts Develop to Resist Vertical Load in the Three Edge Bearing Test

The weight of soil that must be carried by a rigid culvert varies with soil characteristics and installation conditions. There are two typical types of installations: trench installations and embankment installations.

- *Trench installations:* Culverts are placed in an excavation in natural ground or compacted fill with a controlled trench width. Trenches generally have width < five pipe diameters.
- *Embankment installations:* Culverts are placed above native ground and covered by an embankment, or placed in a very wide trench (generally trench width > five pipe diameters).

In trench installations, the culvert is placed in a relatively narrow trench and covered with backfill material. The backfill tends to settle more than the undisturbed (in situ) soil beside the trench. Friction between the backfill material and the sides of the trench helps support the backfill material, reducing the load on the culvert. To quantify this effect in the soil-structure interaction design (buried culvert design), the width of the soil column over the culvert is decreased. This concept is illustrated in Figure 2.2.2.2-2.

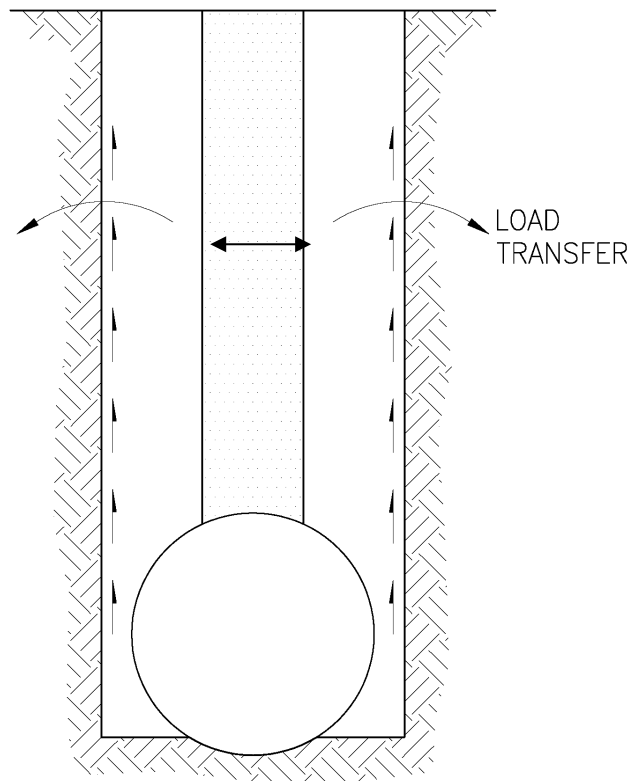


Figure 2.2.2.2-2—Trench Installation (friction on trench sides reduces the width of the column of fill carried by the culvert)

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

Generally, rigid culverts start showing signs of structural distress, such as longitudinal cracking or joint distress, at less than 2 percent deflection. Rigid culvert materials include precast reinforced concrete, reinforced concrete cylinder, prestressed concrete cylinder, vitrified clay, polymer concrete, cast iron, asbestos cement, and cast-in-place concrete in a variety of shapes and sizes.

2.2.3—Loads on Culverts and Storm Drains

Culverts must support the weight of the soil covering the culvert and any imposed load on the ground surface. When the culverts include watertight joints, they must also include the hydrostatic forces from the groundwater head. There are two general types of loads that must be carried by culverts: dead loads and live loads.

2.2.3.1—Dead Loads

Dead loads include the weight of the soil over the culvert and any added surcharge loads such as buildings or other constructed works permanently placed over an existing culvert. If the actual unit weight of soil is not known, 120 lbs/cu ft is typically used in design for the unit weight of compacted soil (*AASHTO LRFD Bridge Design Specifications*, Table 3.5.1-1). Soil unit weight varies by soil type, density (compaction), and water content.

2.2.3.2—Live Loads

Live loads are typically applied at the ground surface above the culvert. The live loads on a culvert include the loads and forces which act at the ground surface due to vehicular or pedestrian traffic. Many design methods also include an impact factor to account for the dynamic effects of a moving live load. Live loads common to buried culvert and storm drain design include highway traffic, train, aircraft, and construction loads.

2.2.3.2.1—Highway Loads

The highway loading generally used for design is the HL-93 live load given in the *AASHTO LRFD Bridge Design Specifications*. The HL-93 live load consists of the greater effects of the Design Truck plus Design Lane Load, or the Design Tandem plus Design Lane Load, shown in Figure 2.2.3.2.1-1.

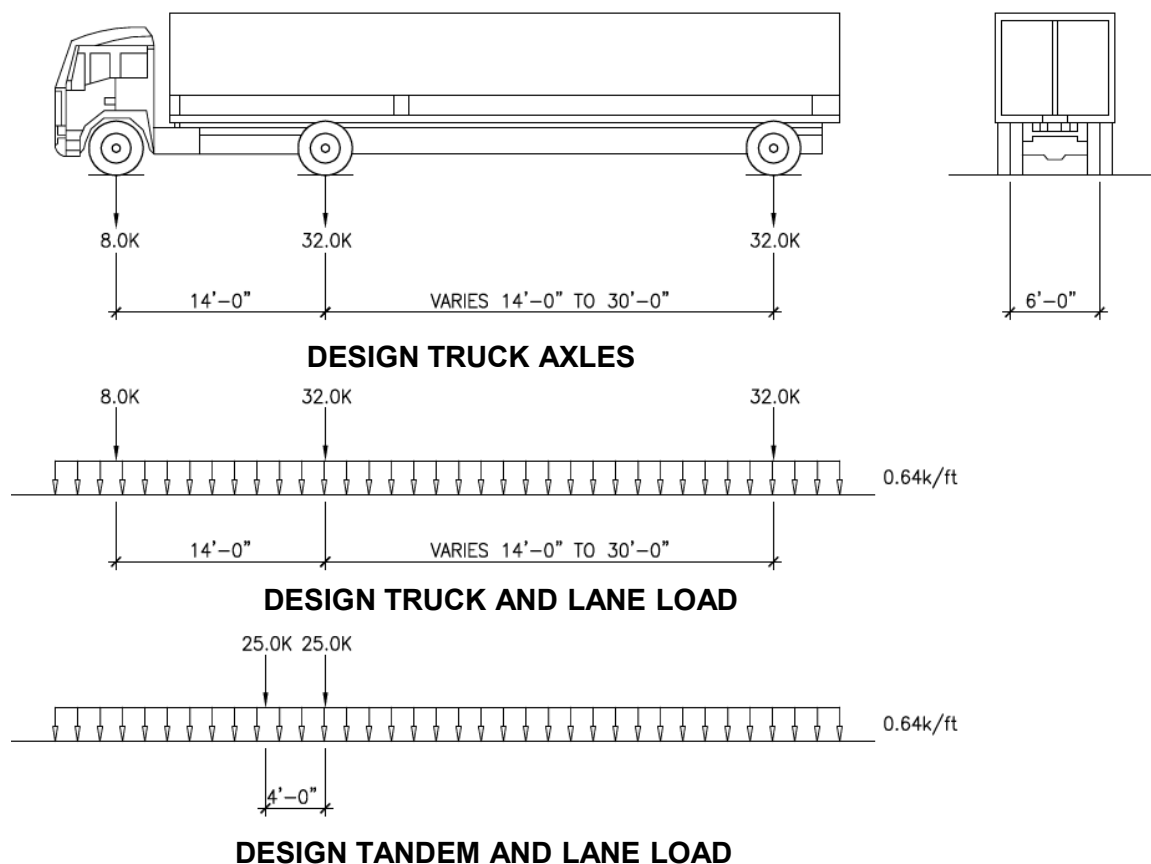


Figure 2.2.3.2.1-1—AASHTO HL-93 Live Load

Live load distribution through fill, under the AASHTO LRFD code, is calculated based on depth of fill. For fill depths less than 2 ft, live load distribution is conservatively not used due to a very large change in live load pressures for a small change in fill depth. For fill depths of 2 ft and greater, the design wheel loads act over the tire footprint and are distributed through the soil to the top of the culvert by a live load distribution factor as shown in Figure 2.2.3.2.1-2.

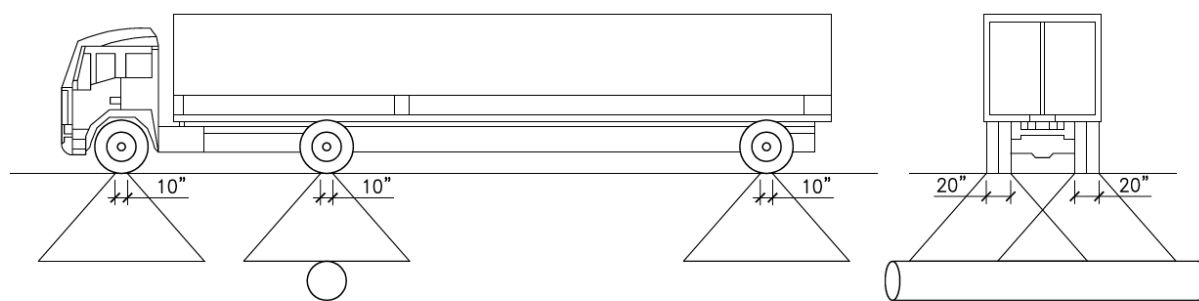


Figure 2.2.3.2.1-2—Live Load Distribution through Fill
(Note: Culvert orientation may vary for storm drains)

Impact forces, called dynamic load allowance in AASHTO LRFD, must be accounted for in buried structures with shallow fill depth. Dynamic load allowance typically adds a 33 percent increase in live load at the roadway surface, decreasing linearly to 0 percent at 8 ft of fill.

Railway Loads

For culverts and storm drains passing beneath active railways, design live loads include railway loads. The design of structures for railway loading is typically governed by The American Railway Engineering and Maintenance-of-Way Association (AREMA). Figure 2.2.3.2.1-3 shows the AREMA recommended railway loading, the Cooper E80 railway loading.

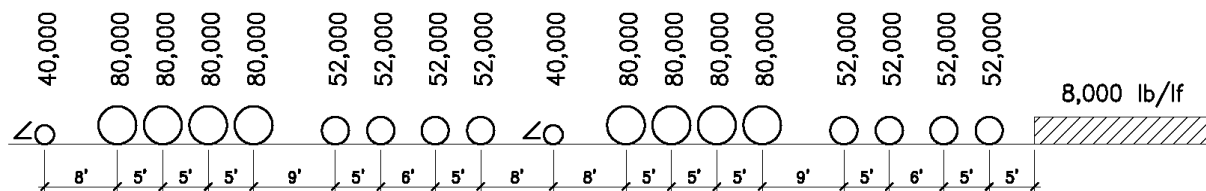


Figure 2.2.3.2.1-3—AREMA Cooper E80 Railway Loading

Aircraft Loads

Culverts and storm drains below runways and taxiways are designed for aircraft loading specified by the airport authority. The design aircraft vary depending on airport use and many airports require design of live loads based on notional new large aircraft which do not yet exist. The Federal Aviation Administration provides design circulars to aide engineers in the design of airport structures.

Construction Loads

Culverts and storm drains are generally designed for the loads they must carry after construction is completed with generic restrictions for construction loads. Heavy construction vehicles 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 or high localized loadings. Additional protective fill, steel plates, timber mats, or other protective measures may be required for equipment crossing points when fill depths are lower than design. Post-construction inspections are highly recommended to ensure proper installation with no construction damage and to establish the inventory inspection record.

2.2.4—Construction and Installation Requirements

Construction and installation practices play a critical role in the structural behavior of flexible and rigid culverts and storm drains. Critical items are discussed briefly in the following text.

2.2.4.1—Installation Conditions

Culverts and storm drains are installed in excavated (narrow) trench, or in embankments. Figures 2.2.4.1-1 and 2.2.4.1-2 depict typical trench and embankment cross sections with associated terminology. Governing design standards define the allowable geometry, soil types, and level of compaction for each of the installation types shown. Project drawings and specifications provide the site-specific installation details. In the structural design of culverts, the soil or embankment material surrounding the culvert plays an important role in supporting the culvert and maintaining joint integrity. If bedding or compaction is inadequate, rigid culvert sections may separate resulting in joint separation and offset. Flexible culverts may deflect, resulting in sags and heaves along the culvert length.

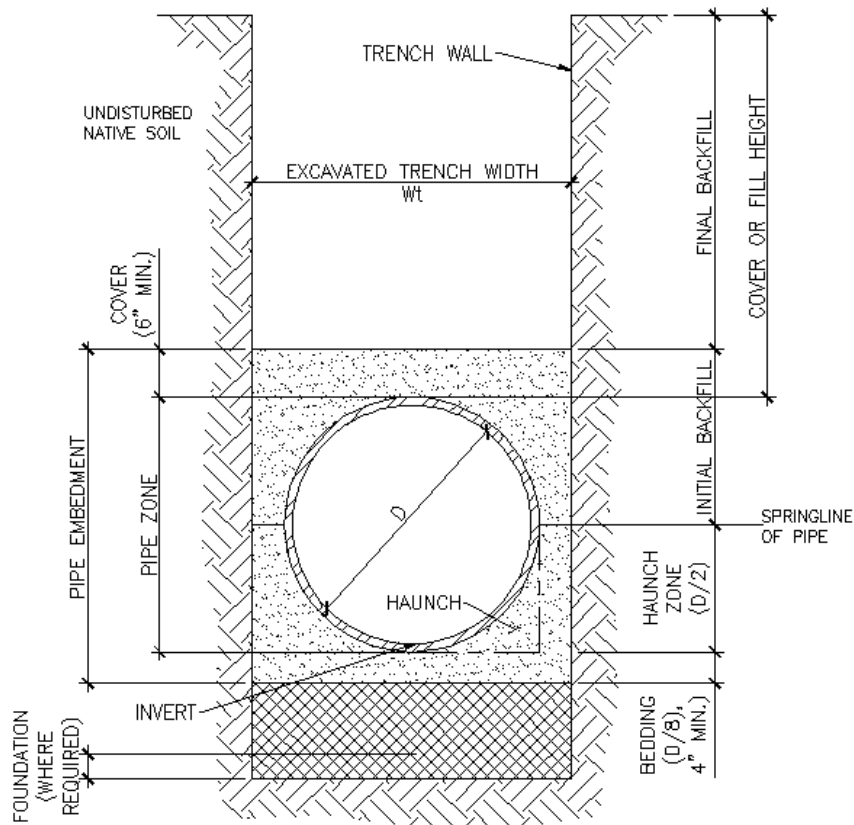


Figure 2.2.4.1-1 –Trench Installation for Buried Culvert or Storm Drain

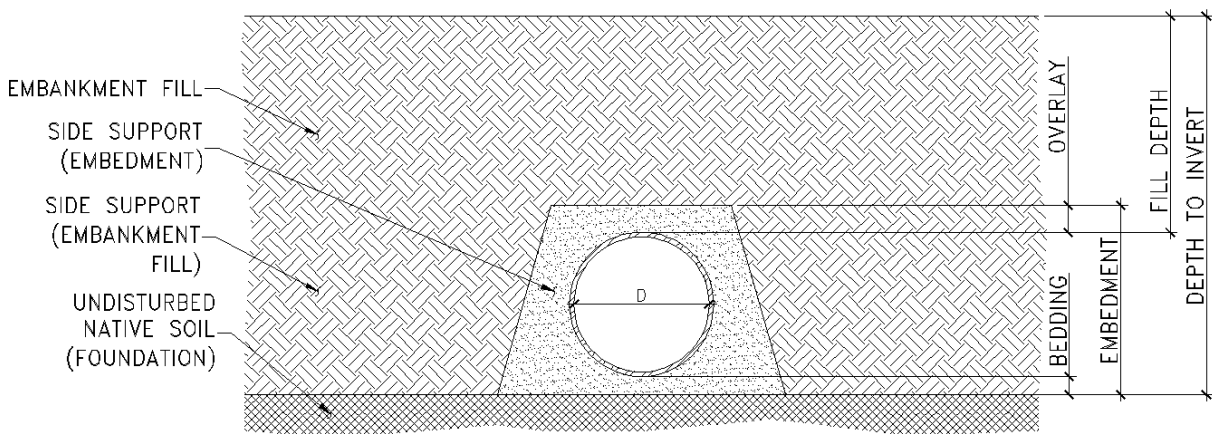


Figure 2.2.4.1-2—Embankment Installation for Buried Culvert or Storm Drain

2.2.4.2—Compaction and Side Support

Quality backfill material (granular, free-draining) and adequate compaction are of critical importance to flexible culverts. Poorly compacted soils or poor quality backfill do not provide the required lateral support. A well-compacted soil envelope is required to develop the lateral pressures required to maintain the shape of flexible culverts. Well-compacted haunch zone backfill (under the springline) is also important to the performance of rigid culverts. Where possible, inspections should note any indicator of embedment soil infiltration in the culvert.

2.2.4.3—Trench Width

Trench width is important to all culvert types but is included in rigid culvert design. Therefore, trench widths must be specified on the plans and the specified width should not be exceeded without authorization from the design engineer. Trench width for culverts should be sufficient to allow compaction of the foundation and bedding. Loose material may be placed on top of the bedding to fill the corrugations, provided it is fully worked (knifed or shovel-sliced) to fill the haunch zone. Where native soil is fine and trench fill is granular, a geotextile is typically wrapped around the trench to prevent loss of fines.

2.2.4.4—Foundations and Bedding

A foundation and bedding system capable of providing uniform and stable support for all moisture conditions is important for both flexible and rigid culverts. The foundation soils must be able to support the structure at the proposed grade and elevation without concentration of foundation pressures. For closed-bottom culvert shapes, bedding under the culvert should be relatively yielding (lower stiffness) when compared to side fill. This is often accomplished by using soft bedding under the center third of the culvert diameter. Establishing suitable foundation soils may require removal and replacement of any hard spots, soft spots, or unsuitable soils such as organic soil (peat) or highly moisture-sensitive soil (such as highly plastic clay). Bedding material functions to level out irregularities in the foundation soil, and provide uniform support. When installing rigid (solid-wall) 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 joints. Uniform support is critical along the length of rigid culvert installations to prevent longitudinal bending or joint offset distress.

Open-bottom structures are supported on foundations that create concentrated loads over narrow foundation widths, such as for an arch structure supported on reinforced concrete spread footings or pile-supported footings.

2.2.4.5—Minimum Fill Depth

The intensity of surface live loads dissipates through the soil depth, reducing its effect on the structure. At high fill depths, the live load effects can be very small or even negligible. Conversely, as the fill depth over a buried structure decreases, the live load intensity increases. Significant damage can occur to a buried structure if certain levels of fill are not maintained during live load events. Therefore, most buried structures have minimum fill depth requirements.

2.2.4.6—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. 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 as indicated on the project plans. The installed grades should not cause water to pond or pocket along the culvert length.

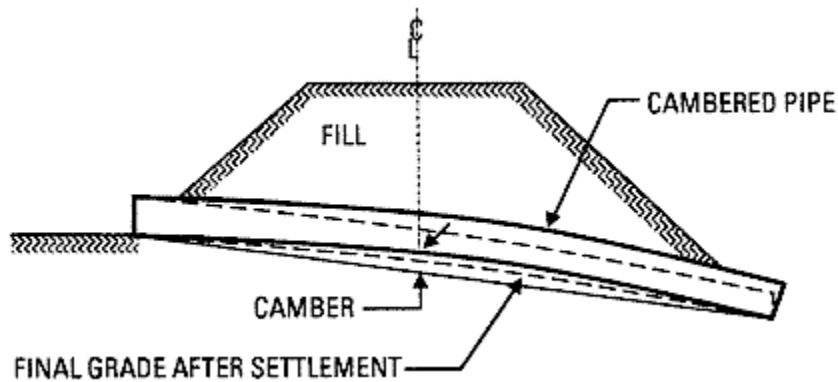


Figure 2.2.4.6-1—Camber in Culvert to Allow for Settlement under High Fill

2.2.4.7—High Groundwater

All types and sizes of culvert, including concrete culvert, will float under the right conditions. The soil type, soil density, fill depth, location of the water table, and culvert weight per unit length all affect the flotation potential of culverts. Culverts installed in areas where the groundwater table regularly encroaches into the culvert zone must be installed to resist external pressure from the groundwater and uplift from buoyancy. For high groundwater tables or other submerged applications, the culvert design should account for flotation of the culvert during installation or in service. Design for buoyancy may require minimum cover greater than that specified in standard tables, or anchorage to resist buoyant forces.

2.3 Performance Characteristics of Culverts and Storm Drains

The preceding section discussed the design characteristics that are important to providing a functional culvert or storm drain. In order for that structure to function as designed over its intended service life, it must also be durable in the installed environment.

2.3.1—Durability

Durability refers to the ability of a material to resist corrosion and abrasion. Although the structural condition is a very important element in the performance of culverts, durability problems are the most frequent cause for replacement. Culvert barrels are more likely to wear away than fail prematurely due to structural concerns. Durability is mainly affected by two mechanisms: corrosion/degradation and abrasion. These mechanisms are discussed in the following sections.

2.3.1.1—Corrosion of Metals

Corrosion is the deterioration of metal materials by chemical or electrochemical reaction to the environment. Metal culvert corrosion may occur in many different soils and waters. These soils and waters may contain acids, alkalis, dissolved salts, organics, industrial wastes or chemicals, mine drainage, sanitary effluents, and dissolved or free gases. However, corrosion is generally related to water and the chemicals that have reacted to, become dissolved in, or been transported by the water. Corrosion can also be initiated by loss of galvanization caused by abrasion.

Corrosion can attack the interior or exterior (soil-side) surface of the culvert barrel; however, soil-side corrosion is rarely the determining factor in culvert performance. Chemicals in drainage water will 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 groundwater which can originate in the soil, be introduced through contaminants 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 Figures 2.3.1.1-1 and 2.3.1.1-2. Chemicals present in the water can greatly influence its effectiveness as an electrolyte.



Figure 2.3.1.1-1—Severe Corrosion of Corrugated Steel Culvert

(Photo courtesy of Ohio Department of Transportation)



Figure 2.3.1.1-2—Steel Culvert with Invert Perforations

(Photo courtesy of Ohio Department of Transportation)

Durability of Metals in Soil

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 *Corrugated Steel Pipe Design Manual*, published by the National Corrugated Steel Pipe Association (NCSPA), provides a valuable discussion on how soil properties affect the durability of steel culvert. An extract of that information is presented in Table 2.3.1.1-1, with permission from NCSPA.

The material in the soil envelope around the culvert is generally controlled by the project specifications. The better suited the material is for structural support of the culvert, the less corrosive it is likely to be toward the culvert. Table 2.3.1.1-1 compares the corrosiveness of several soil types. In corrosive soils, an envelope of properly specified backfill material around the culvert can help to protect the culvert from most of the corrosive elements inherent in the native soil. However, soil-side corrosion is rarely the determining factor in predicting culvert service life.

Table 2.3.1.1-1—Corrosiveness of Soils

Soil Type	Description	Aeration	Drainage	Color	Water Table
I. Non Corrosive	1. Clean sands 2. Well graded gravel	Excellent	Excellent	Uniform	Very low
II. Lightly Corrosive	1. Sandy loams 2. Light textured silt loams 3. Porous loams or clay loams thoroughly oxidized to great depths	Good	Good	Uniform color	Very low
III. Moderately Corrosive	1. Sandy loams 2. Silt loams 3. Clay loams	Fair	Fair	Slight mottling	Low
IV. Badly Corrosive	1. Clay loams 2. Clay	Poor	Poor	Heavy texture Moderate mottling	2 to 3 ft below surface
V. Unusually Corrosive	1. Muck 2. Peat 3. Tidal marsh 4. Clays and organic soils	Very poor	Very poor	Blue, gray, green	At surface; or extreme impermeability
NOTE Soil Type III, IV, and V are poor quality and are not recommended for use as backfill.					

The durability of steel culvert in soil is a function of several interacting parameters including soil resistivity, acidity (pH), moisture content, soluble salts, and oxygen content (aeration). All underground corrosion processes involve the flow of current (conductivity) through the ground from one location to another (a corrosion cell). Resistance to current flow through a material is measured by the resistivity of that material. Higher soil resistivity means smaller current flow and a lower corrosion rate. The resistivity value, expressed as ohm-cm, is inversely proportional to the conductivity.

The pH value of a substance is a measure of the hydrogen ion concentration in the substance. Most soils fall within a pH range of 6.0 to 8.0, which is considered to be the neutral range and is favorable to the durability of steel culvert. Soils with lower pH values (acidic soils), usually found in areas of high rainfall, tend to be more corrosive and require a more careful selection of the culvert coating. The pH values of soil and water at a site are significant factors in selection of the right culvert product.

The moisture content in the soil can also be a significant factor affecting the durability of corrugated steel pipe (CSP). Granular soils that allow rapid drainage of the culvert backfill enhance durability. Soils with moisture content less than 20 percent tend to be noncorrosive to CSP on the soil side. Soils with high clay content tend to hold water longer and therefore are more corrosive than well-drained soils.

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.

2.3.1.2—Degradation of Concrete

Material degradation can take place in concrete culvert and appurtenant structures. 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 groundwater are involved and can result in deterioration of the concrete. Concrete culverts are subject to chemical attack in certain environments and may also be damaged by abrasion. Common forms of concrete degradation are discussed below.

2.3.1.2.1—*Acid Attack*

Acidity in the water can attack concrete by dissolving the cement paste and susceptible aggregate. Exposed aggregate due to loss of cement paste is a typical indicator of acid attack. Exposed aggregate weakens the concrete section.

2.3.1.2.2—*Alkali–Aggregate Reactivity (AAR)*

Concrete consists of cement paste and aggregate (stone, gravel, sand, etc.). Most aggregates are chemically stable in concrete; however, an increasingly large number of aggregate sources contain constituents that react with the cement paste, which is highly alkaline. This is called alkali–aggregate reactivity, AAR, and has two forms.

- Alkali–silica reaction (ASR) is the most common form of AAR and is a reaction that occurs between the alkaline cement paste and reactive silica commonly found in many aggregates. The ASR reaction forms a reactive gel in the concrete which expands in the presence of moisture. This internal expansion creates pressure around the aggregate that eventually results in degradation of the concrete. Evidence of ASR includes surface map-cracking or white exuding gel. ASR is found in areas that experience repeated wetting and drying cycles or in wet areas. Petrographic examination can confirm ASR.
- Alkali–carbonate reaction (ACR) is a rarer form of AAR that occurs when dolomitic aggregate reacts with the cement paste to form an expansive reaction product. Dolomitic aggregate is rarely used in concrete because of its low strength and poor durability.

2.3.1.2.3—*Sulfate Attack*

Sulfate attack in concrete is typically caused by dissolved sulfates in groundwater penetrating the concrete and reacting with the cement paste. Sulfate attack can cause the concrete to crack and scale.

2.3.1.2.4—*Hydrogen Sulfide Attack*

Hydrogen sulfide attack, also called biogenic sulfide corrosion or microbial induced corrosion, is corrosion produced by bacterial action inside a culvert in which sulfate-reducing bacteria produce hydrogen sulfide, which can produce sulfuric acid. Sulfuric acid is corrosive to both concrete and steel. This type of degradation is typically only a problem in sanitary sewers where the wastewater provides ideal conditions and ample sulfates to support this reaction.

2.3.1.2.5—*Freeze–Thaw Damage*

Freeze–thaw damage is caused when pore water in concrete freezes and exerts pressure in the pores of the concrete that exceeds the concrete tensile strength. This results in scaling of the concrete, or loss of surface mortar surrounding the coarse aggregate.

2.3.1.2.6—*Impact Damage*

Impact damage to barrel projecting ends or end treatments may result from traffic or mower impact or debris impact when in boulder bed load locations.

When linings are used to protect against chemical attack or abrasion, the condition of the lining should be noted in the report. Fiber additives in concrete mixes are an increasingly common method to limit physical damage.

2.3.1.2.7—*Corrosion of Reinforcing Steel*

Although less common than with metal culverts, 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 Figure 2.3.1.2.7-1. If the steel corrodes, the corrosion products expand and may cause spalling of the concrete.



Figure 2.3.1.2.7-1—Corrosion of Reinforcing Steel in Soffit of Concrete Box Culvert

(Photo courtesy of Ohio Department of Transportation)

2.3.1.3—Degradation of Plastics

Although generally resistant to corrosion types discussed above, plastic culverts are subject to other types of degradation mechanisms. The principal forms of plastic degradation follow.

2.3.1.3.1—Oxidation Degradation

Polymers can react with atmospheric oxygen in a process that results in polymer chain scission. Susceptibility to oxidation becomes greater at elevated temperatures and exposure to UV light. Antioxidant stabilizers are added to the polymer formulation to improve the resistance to oxidative degradation. The stabilizers react with oxygen to be depleted sacrificially; however, once the antioxidants are depleted, oxidation will attack the polymer.

2.3.1.3.2—Environmental Stress Cracking (ESC)

Environmental stress cracking (ESC) is a leading factor in polymer cracking and brittle failure. It is caused by resin degradation due to chemical exposure while the polymer is under stress. When ESC is not addressed in the polymer compound, plastics are subject to slow crack growth resulting in brittle-type fracture at stress levels below short-term or long-term breaking strengths.

2.3.1.3.3—Photo-Induced Degradation (UV Degradation)

Polymers like polyethylene, polyvinyl chloride, and polypropylene can be degraded by UV radiation and suffer photo-induced embrittlement and/or cracking in sunlight. Buried culverts and plastic end treatments may be at risk for photo-induced degradation at culvert ends where they may be exposed to daylight at the inlet and outlet structures. UV exposure can also occur when a culvert is being stored uncovered prior to installation. Additives and coatings can provide resistance to UV degradation. Photo-induced degradation can be prevented by using a UV stabilizer in the polymer formulation. These UV stabilizers absorb the UV radiation and dissipate the absorbed energy as low-level heat.

2.3.1.3.4—Thermal Degradation

Thermal degradation (thermolysis) is a decomposition of the polymer chains due to exposure to high temperatures. Thermal degradation can reduce strength, stiffness, and toughness of the polymer. Thermal degradation is not typically a concern with culvert and storm-drain pipe as they are operated at relatively low temperatures. Stabilizers can be added to the polymer formulation to provide better resistance to heat exposure.

2.3.1.3.5—Chlorine-Induced Degradation

Under common environmental conditions, polyethylene can be susceptible to degradation due to exposure to chlorine, a common disinfectant. Trace chlorine in the water can cause oxidative embrittlement and crack initiation. Documented studies have found that chlorine has contributed to the premature failure of many pressurized pipelines in the United States and Europe.

2.3.1.4—Abrasion

Abrasion is the process of wearing or grinding away of surface material of the culvert barrel by water carrying particulates such as sand, gravel, or stones in the flow. The severity of abrasion is directly related to the particle size, shape, and hardness. Harder, sharper particles create more abrasion. Bed load is defined as the sand, gravel, boulders, or other debris transported by rolling or sliding along the bottom of a stream. Bed load are the particles primarily responsible for abrasive action. The abrasiveness of a waterway on a culvert can be estimated using the guidelines provided in the Office of the Federal Lands Highway (FLH) Project Development and Design Manual (PDDM), Section 7 Hydrology and Hydraulics:

- Level 1 (Non-Abrasive):* No bed load and very low velocities; this is the condition assumed for the soil side of all culverts.
- Level 2 (Low Abrasion):* Minor bed loads of sand and gravel and velocities of 5 ft/sec. or less.
- Level 3 (Moderate Abrasion):* Bed loads of sand and small stone or gravel with velocities between 5 and 15 ft/sec.
- Level 4 (Severe Abrasion):* Heavy bed loads of gravel and rock with velocities exceeding 15 ft/sec.

Abrasive forces increase as the flow volume, velocity, and/or duration of flow increases. For example, doubling the velocity of a stream flow can cause the abrasive power to increase approximately four-fold. All culvert materials can experience abrasion and subsequent failure, typically at the invert, if not properly protected. However, abrasion resistance is different between materials. 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. In addition, abrasion of some materials, such as PVC, may be accelerated in acidic environments.

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SECTION 3

INSPECTION PROCEDURE

3.1 General

The success of a culvert and storm drain inspection program hinges on the Inspector's ability to assess the condition of the entire culvert or storm drain system, including structural and materials issues. The Inspector must also assess service performance and make accurate ratings that are repeatable by other Inspectors. The inspection data collected by the Inspector will be used as part of an agency's asset management system to make decisions that can directly impact maintenance, repair, and rehabilitation budgets. The data will also be used to directly assess roadway safety for the traveling public. Thus, the Inspector and their inspection team play the most critical role in maintaining culvert and storm drain infrastructure inventories.

This section outlines the elements of an inspection program and provides general procedures for conducting and reporting inspections of culvert and storm drain system structures. It also introduces the roles of the inspection team; outlines the duties, responsibilities, and qualifications of the Inspectors; presents a basic standard of safety required for performing culvert inspections; and provides guidance for an inspection quality management system. A list of standard and specialized equipment available to the Inspector with a description of use and function is provided. In recognition of the similarities between culvert and bridge inspection, and to leverage accepted highway agency inspection processes, this section incorporates content from the Federal Highway Administration's *Bridge Inspector's Reference Manual*, where appropriate.

NOTE: This Guide does not purport to address all of the safety concerns associated with the inspections described herein. It is the responsibility of the user and the user's employer to establish appropriate safety practices which comply with all federal, state, local municipality, and agency regulations. All Inspectors should have appropriate training and experience as a highway culvert and storm drain system inspector.

3.2 Purpose and Scope of Inspections

The purpose of a culvert and storm drain inspection program is to provide a measure of structural health to maintain the safe passage of vehicles. The inspection program provides a database from which statistics on the structural safety and service function of these structures are derived and is the basis for developing an effective culvert asset management approach.

The scope of inspections should include all culverts and storm drains in an agency's inventory. All systems should be inventoried upon installation or when creating an asset tracking system. All systems should then be evaluated for importance and the need for periodic inspection. Some limitations are necessary because a considerable effort (and budget) is required to inspect all culverts, many of which may not require normal inspection. As example, many small culverts do not warrant routine inspection. If small-diameter, buried culverts are not repaired but are replaced after failures occur, then the periodic collection of detailed condition data is not prioritized above collection of that same data for the larger diameter buried culverts and associated systems. The types and amount of condition information to be collected is based on the purpose for which the information will be used. Agencies may want to limit the data collected to just the documentation of failures and their causes.

Each agency should define its inspection program in terms of inspection frequency, characteristics of culverts to be inventoried and inspected, and the information to be collected.

3.3 Inspection Frequency

Highway culverts larger than 20 ft are defined as bridges and are required to be inspected at a regular frequency under the NBIS program. Inspection frequency for culverts and storm drain systems is at the discretion of the agency and is specifically not dictated by the guidance provided herein. The following discussion is provided for consideration when establishing a culvert and storm drain system inspection program.

Inspection of culvert and storm drain systems on a regular schedule will assist agencies with maintenance and planning for rehabilitation. Each state or agency should define a frequency for inspection in terms of the system consequence of failure. The most common criteria is the system barrel size. Table 3.3-1 provides an illustrated example of frequency for routine inspection of culverts and storm drain systems, based on the largest barrel size, S , typically taken as the diameter for round pipes or the span (widest unsupported width) for other shapes (see Appendix A); however, agency-developed inspection frequencies may be less frequent than those recommended in Table 3.3-1. Note that this is an illustrated example of frequency for routine inspection, condition assessment, and condition rating of the culvert or storm drain system and is not the frequency for routine maintenance. Some culvert and storm drain systems may require more frequent visits than is listed in the table below for maintenance actions such as clearance of debris or sediment accumulation.

Table 3.3-1—Example Frequency for Routine Inspections

Barrel Size (S)	Inspection Frequency
$S < 4$ ft	Inspect during roadway maintenance activities.
$4 \text{ ft} \leq S < 10$ ft	Every 10 years or prior to routine roadway maintenance activities, whichever is less.
$S \geq 10$ ft	Every 5 years or prior to routine roadway maintenance activities, whichever is less.

Table 3.3-1 is only an illustrative example. Each state should weigh their risks in developing a state specific inspection frequency. Developing a schedule for inspection frequency should carefully weigh the consequence of failure within the frequency between routine inspections versus the cost of inspection, condition assessment, and inventory data management. Factors to consider in the risk and consequence of failure include system condition at the last inspection, barrel size, system age, roadway traffic volume, and special environmental or service performance requirements.

3.3.1—Size

The diameter or span and rise of a culvert or storm drain barrel should be considered when determining inspection frequency. Culverts whose size and geometry are essentially short-span bridges should be inspected on a frequency similar to bridges as the consequence of failure is also similar. Large structures under shallow fill also carry higher consequence of failure to the traveling public when compared with small structures under high fill cover. Some small-diameter culverts whose consequence of failure is relatively low may not need frequent routine inspection as agency protocol dictates that these structures are replaced rather than repaired, and the consequence of failure is reduced approximately proportional to the reduced span.

3.3.2—Condition Rating

The inspection frequency should increase as the culvert shows signs of deterioration. At the onset of deterioration, the rate at which the structure degrades may increase. The frequency of routine inspections may be too low to capture the point at which degradation progresses to a level that maintenance or repairs could prevent failure. When a component receives a “poor” or “severe” condition rating, an agency-level decision should be made to determine if the routine frequency of

inspections will be adequate to ensure a consistent minimum level of safety unless action, such as rehabilitation, is taken to rectify the distress.

3.3.3—Structure Age

The age of the buried pipe should influence inspection frequency. New culverts should be inspected within 30 days after construction and, for more important systems (based on span > 1 ft or other criteria), should be inspected annually for the first two years after they are placed in service. Structural problems with culverts are typically related to poor installation and distress indicators will often appear within the first two years after installation, as the system is subject to loading and weather cycles.

Culverts and storm drains often deteriorate at an accelerated rate as the structure ages. Older structures therefore may require more frequent inspection than newer structures to prevent increased risk of failure. Older structures may also be designed to older codes with lower design vehicular loads (live loads). Lastly, older structures may have cyclic load-induced distress (i.e., fatigue) from years of passing traffic loads, freeze–thaw cycles, etc.

3.3.4—Average Daily Traffic (ADT)

Average daily traffic should also be considered in assigning inspection frequency. Culverts and storm drains under roads with higher average daily traffic or unusually large trucking loads have greater consequence of failure (increased importance) and may warrant more frequent inspection intervals.

3.3.5—Environmental Conditions

Structures in environments which are corrosive towards the material may require more frequent inspection. For example, buried metal pipes with poorly-performing coatings or linings in acidic soil or water may deteriorate at a more rapid rate requiring more frequent inspection. Corrosion and abrasion often work together to produce a greater rate of deterioration than either would individually. Hence, abrasive conditions may also warrant more frequent inspections. As discussed in this Guide, the abrasiveness of a waterway affects all barrel material types and can be determined using the FLH PDDM.

3.3.6—Special Function

Special functions, such as aquatic organism passage (AOP), may have additional guidelines that require its own frequency of inspection. Consideration should be given to the special function importance to coordinate inspection schedules that ensure required functional performance is met.

3.4 Preparation and Planning

Preparation and planning are the first steps in a culvert or storm drain inspection. While the breadth of preparation and planning presented in this section may seem daunting initially, its implementation in practice can be accomplished quickly and with ease once an asset management plan is established. The value of proper planning cannot be understated as it will save time and costs in the long term.

3.4.1—Organizing and Scheduling Inspections

Prior to any field inspections, the inspection team should organize and schedule inspections to ensure that the inspection program is accomplished effectively and efficiently within the time and resources available. Organizing and scheduling should consider the inspection type and the target frequency for each culvert or storm drain system, review of prior inventory and condition assessment reports, selection of proper equipment for the entry type and inspection forms, and evaluation of site access requirements and site safety concerns. This preparation will allow the inspection team to develop an inspection schedule.

Guidance for organizing an inspection:

- Schedule timing of inspections to satisfy the requirements of the inspection frequency interval identified by the owner agency.
- Organize inspections to group locations in the same geographic vicinity to minimize travel time between inspection locations.
- Whenever possible, schedule inspections for culverts and storm drains during lowest flow periods of the year for maximum access to the interior and to survey the embankment and foundations which may be submerged under water at other times. This will also minimize the need for return inspections. If hydraulic capacity issues are a concern, it may be advantageous to inspect culverts during or immediately after a heavy rainstorm.
- If a culvert or storm drain structure is cleaned on a known schedule, inspection soon after cleaning is recommended in order to optimize information that can be obtained through visual inspection. If a problem is identified, note that the next inspection should occur before cleaning to observe possible signs of any ongoing deterioration or other distress.
- Identify any special equipment or access needs. Special equipment, skills, or qualifications may be required for some structures (e.g., remote entry equipment or OSHA confined space entry qualification). Efficiency may be gained by grouping such inspections or by use of teams trained to use special equipment.
- Rotate Inspectors such that no structure is inspected by the same Inspector during consecutive inspections. This will help provide independent verification of prior condition ratings.
- Understand the specific personnel requirements for each inspection. Some structures or agency policies may require a multiple person inspection team, while others may be able to be accomplished by a single Inspector. For example, small diameter culverts of short length that can be effectively inspected without entry may only require a single Inspector. Entry into storm drains and some culverts will require a multi-person inspection team and compliance with OSHA Permit Required Confined Space regulations. Specialists in hydraulics, soils, materials, or structural analysis may be required for inspections other than routine inspections.
- Identify and address any requirements for coordination with other entities such as environmental permits, notification of local landowners or businesses, or coordination of emergency responders (e.g., permit required confined spaces).
- Ensure inspections are completed during planning for any roadway maintenance or construction activities.

3.4.2—Review of Inventory and Data from Previous Inspections

The inspection team should review previous inspection reports and plans, prior to and during the field inspection. Review of the previous inspection reports will familiarize the Inspector with the structure and facilitate detection of changed conditions. This review can be done very quickly and will ensure detailed inspection of critical areas that need special attention and help to identify the possible need for special equipment.

Additionally, planning for inspections should include a thorough review for any aquatic organism/fish passage (AOP) requirements and site hazards. To identify possible AOP requirements, consult with agency environmental specialists. Conduct a Job Hazard Analysis (JHA) to identify any safety hazards that may be encountered during the inspection. This includes identification, evaluation, and mitigation of any hazards. Depending on the hazards identified, this could affect the number of inspections and qualification of inspection teams, Personal Protective Equipment (PPE) required, inspection methodology, and/or coordination with other entities. Also check available topographic maps in order to plan for environmental conditions such as remote locations, steep terrain, or thick vegetation.

All limitations or special considerations identified for a structure should be noted in the inspection report for future reference. This information should be recorded as part of an asset management plan.

3.4.3—Gaining Access through Locked Access Points

Some locations may require entry through locked gates or access points. The inspection plan should identify these locations and the appropriate points of contact for gaining access to these locations prior to arriving at the inspection site.

3.4.4—Inspection Sequence

A logical sequence for inspecting culverts leads to more complete and thorough inspections. The Inspector should evaluate more than just the components of a culvert or storm drain; look also for high water marks, changes in the drainage area, settlement of the roadway, and other indications of potential problems based on an understanding of culvert and storm drain system functionality gained by training and experience. A general plan and sequence is useful to avoid oversights.

For culvert installations it is usually convenient to begin the field inspection with general observations of the overall condition of the approach roadway and the structure. The Inspector should select one end of the culvert and inspect the embankment, waterway, end treatments, and culvert barrel. The Inspector should then move to the other end of the culvert. Detailed component inspection guidelines are provided in Section 4. The inspection guidelines and the following general elements of inspection are discussed in this section.

- Observation of overall condition
- Approach roadway and embankment, and access structures (manholes) for storm drains
- Channel alignment and protection, and barrel alignment
- End treatments and appurtenant structures, and footings
- Culvert barrel, seams/joints, and footings (three-sided culverts)

The use of a checklist for recording the inspection is recommended. Checklists are procedural tools that help reduce error and support consistency, improving the quality of inspections. An inspection checklist defines the minimum steps necessary to complete the inspection and instills discipline and an attitude of quality in the work. The checklist, which should become part of the inspection record, provides a tool for systematic recording of observations, a level of protection against failure to comply with the minimum requirements, and a basis for verification of compliance and completeness. By extension, the checklist also provides a record of items which could not be inspected or verified. The culvert and storm drain inventory and inspection forms in this Guide provide a basis for inspection checklists.

3.5 Types of Inspections

The following articles define four types of culvert and storm drain inspections, based on the NBIS program for bridge structures. These include initial (inventory), routine, special, and damage inspections. The scope and purpose of each type of inspection is discussed below.

3.5.1—Initial (Inventory) Inspection

The initial system inspection, or inventory inspection, is the first inspection conducted after a culvert or storm drain is commissioned, just after the completion of construction. Initial inspections are also conducted after any major rehabilitation or expansion work is completed. If an inventory record does not exist for a structure, one should be developed as part of the first routine inspection. This inspection data will provide a baseline for comparison with data from future inspections.

The purpose of an initial inspection is to verify the as-built structure meets the design as provided in stamped construction drawings and is safe for service. The initial inspection also records the necessary data for the culvert or storm drain system to become a part of the agency inventory database along with any condition data relevant to provide a baseline for the soil-structure interaction system, using the component level rating system in this Guide. The inventory record provides all data required for agency asset management decisions.

3.5.2—Routine Inspection

Routine inspections are the focus of this Guide and are conducted at a defined frequency. These inspections consist of the visual and nondestructive measurements necessary to assess the condition and assign condition ratings using the system described in Section 4. Changes to the inventory record are also identified and recorded in the inspection report. The purposes of the routine inspection are to document the condition of system components at the time of inspection, to evaluate overall system functional performance, and to track how the system components are aging.

3.5.3—Special Inspection

Special inspections are conducted outside of the routine inspection. These inspections are used to monitor a particular condition or deficiency or to conduct an in-depth review by a qualified Inspector or engineer. Special inspections may also include close-up inspections of one or more members above or below the water surface to identify any deficiencies not readily detectable during routine inspections.

Special inspections are typically triggered by a severe rating identified during a routine inspection, and conducted to determine urgent or emergency corrective action. If the Inspector performing a special inspection is not a professional engineer, the Inspector must be instructed regarding the nature of the deficiency and its relationship to structural performance. Guidelines and procedures for inspection must also be provided and all results must be reviewed by a Professional Engineer.

Special inspections may also be conducted on a non-emergency basis at more frequent intervals to track rates of deterioration or structural deficiency that may reach a severe stage sooner than would be captured under the routine inspection schedule. Other types of special inspections may include research monitoring of new structural materials, types of structures, or structural details being evaluated on a trial basis.

3.5.4—Damage Inspection

Damage inspections are unscheduled, event-driven emergency inspections. These may be conducted to assess damage after flooding, fires, appearance of roadway sinkholes, or traffic accidents. Damage inspections should be conducted by an engineer or an otherwise qualified Inspector.

The purpose of a damage inspection is to document structural or functional damage caused by environmental events or human actions. Damage inspection may be used to determine if emergency restrictions or closures are required on a structure for vehicular traffic safety. Resulting actions may range from preventive maintenance to preserve the life of the structure from more rapid deterioration to critical repairs that must be undertaken immediately to restore service and/or address public safety issues.

3.6 Types of Entry

There are three main types of entry for internal inspection of a culvert or storm drain barrel: person entry, non-entry, and remote entry. Inspection procedures will vary depending on the type of entry. The type of entry appropriate for each structure should be determined by the owner agency in consultation with the Inspector. Person entry is preferred.

3.6.1—Person-Entry Internal Inspection

Person-entry inspection involves physical entry into the structure to perform condition assessment. The component condition rating tables provided in this Guide require close-up inspection and evaluation that is best achieved through person entry. Therefore person entry is the preferred method as it allows for non-destructive evaluation, detailed measurements, photographs, and hands-on inspection of all portions of the structure barrel and footings.

Person-entry inspections require compliance with OSHA and state-specific safety agency confined space entry procedures, and may require following OSHA permit-required confined space entry procedures. Storm drains are closed systems and are therefore typically considered permit required confined spaces. Culverts, although typically open at the ends, may also be permit spaces depending on the size, length, and hazards. The controlling agency should be consulted on when culverts are considered permit-required confined spaces.



Figure 3.6.1-1—Person-entry Inspection of a Masonry Culvert
(Photo courtesy of Ohio Department of Transportation)

3.6.2—Non-Entry Internal Inspection

Non-entry inspection is performed when conditions such as high flows or deep sedimentation do not permit access to the culvert interior. This type of inspection is performed by visually examining the structure from both ends. Non-entry inspection is not as thorough as person-entry inspection and therefore only limited information can be gathered about internal condition. If conditions that prevent person entry are temporary or seasonal, consider inspecting the culvert at a later date when person entry is permissible.

If distress is noted during a non-entry inspection, the Inspector should recommend further investigation through person-entry inspection or remote-entry inspection. The Inspector should also note in the report if portions of the barrel cannot be viewed sufficiently to assess the barrel from the ends of the structure.

For non-entry inspection, use a high-powered flashlight or mirror to examine as much of the structure interior as possible from the inlet and outlet, if accessible. Although joints may not be observed closely, significant problems can often be inferred by the appearance of joint offsets or the accumulation of backfill soil that has infiltrated at the joint locations (see Table 4.14.1-1). Additionally, serious joint problems can be detected by the presence of holes or depressions in the road embankment above the culvert. Abrasion problems are typically most prominent near the outlet therefore outlet observations are likely representative of the worst-case conditions.



Figure 3.6.2-1—Non-entry Inspection of a Corrugated Metal Culvert

(Photo courtesy of Simpson Gumpertz & Heger Inc.)

3.6.2.1—Remote-Entry Internal Inspection

Remote-entry inspection is used in cases where internal inspection is necessary but person entry into the pipe is not practical, such as small diameter (including deep sedimentation), internal hazards, significant water depth, or closed-end conduit systems. Remote-entry inspection is performed using specialized equipment that is inserted into the pipe and operated remotely to record video and other measurements such as diameter, slope, wall deformation, crack width, etc. for the purposes of condition assessment. This equipment is controlled by operators from outside the pipe without making entry. Due to the relatively small diameter and typical closed-end configuration of storm drain pipe, remote-entry video inspection is commonly used to perform internal condition assessment. More information on remote-entry video inspection technology is provided in Article 3.8.

3.7 Inspector Role and Training

The primary responsibility of the Inspector is to conduct thorough inspections to identify distressed conditions and monitor culvert and storm drain functional performance throughout the service life. The Inspector is responsible for maintaining accurate inventory and inspection records using a system that yields consistent and repeatable data. To fulfill this role, Inspectors must be trained to understand system performance and to recognize components that are critical to maintain roadway safety and those that can be maintained to avoid the need for costly replacement.

If any inspection reveals an immediate danger to the public, the Inspector should alert their manager so that appropriate actions can be taken, up to and including roadway closure.

3.7.1—Inspector

There are no specific federal guidelines for qualifications of culvert and storm drain system Inspectors. The following information provides a framework to consider for culvert and storm drain system Inspectors.

Role

Inspectors perform the routine inspections, including assignment of component condition ratings using the tables in Section 4.

Qualifications

Inspectors should complete an agency inspection training and be familiar with the provisions of this Guide.

3.7.2—Training

Inspection training should be provided by the Owner or inspection agency. Training should include an educational seminar based on this Guide and on-the-job experience. Training should prepare the Inspector with the following skills:

- Basic familiarity and understanding of culvert structural behavior.
- Basic familiarity and understanding of culvert and storm drain system function, including hydraulic performance.
- Understanding of failure modes, critical inspection points, and the condition rating system described in this Guide.
- Ability to read and interpret plans, construction documents, and inspection reports.
- Basic hand-drafting capabilities to sketch system features for inventory records and distress identification.
- Working knowledge of inspection tools, their use, application, and limitations.
- Appropriate training in agency safety requirements for site access and culvert entry.

3.7.3—Physical Ability

Inspection of culverts and storm drains requires physically strenuous activity. The inspection team must be capable of working under demanding conditions, including cramped spaces, rugged terrain, steep embankments, elevated surfaces, and in and around water. In addition, the inspection team will often be traversing this terrain carrying tools and equipment adding difficulty to their work. These challenges should be understood and conveyed to inspection team members.

3.8 Inspection Equipment

This Article discusses standard inspection tools and equipment, nondestructive inspection equipment, and remote-entry inspection equipment. Several factors determine the type of equipment needed for an inspection, including barrel material, barrel size, presence and depth of water, type of inspection, and type of entry. Review of the structure inventory and past inspection data during inspection planning will allow Inspectors to identify and bring the appropriate equipment, reducing the risk of repeat site visits or inability to conduct a thorough inspection.

The type of entry (person entry, non-entry, or remote entry) and type of inspection (initial, routine, special, or damage) dictate the type of equipment required. The standard tools are appropriate for person entry to conduct initial and routine inspections. A reduced set of the standard tools is necessary for non-entry inspection, though it is typical to carry all standard tools in the inspection site access vehicle. Remote entry for initial and routine inspection requires equipment specially designed to travel through a structure and collect data via remote control.

This Guide provides a set of guidelines based on those developed for highway bridges but adapted here for culvert and storm drain systems. The focus of this Guide is on inventory and routine inspections; however, the Inspector should be aware of tools available for special or damage inspections. Special or damage inspections typically require the use of specialized equipment during person-entry inspection and may be performed by the same Inspectors as the routine inspection, depending on their qualifications and the specific system distress. Specialized equipment includes nondestructive inspection equipment and destructive inspection equipment intended to provide additional information about structure or material condition that is used to assess a specific identified poor or severe distress condition.

3.8.1—Standard Inspection Tools and Equipment

Standard tools are discussed in this Article and grouped into six basic categories. All equipment should be ruggedized and waterproof or water-resistant.

- Tools and equipment for access
- Tools for cleaning
- Tools for inspection and measurement
- Tools for visual aid
- Tools for documentation of condition
- Miscellaneous tools and equipment

This list does not include personal protective equipment (PPE), which is required for safe access during inspection. The PPE may differ depending on the structure, location, and type of inspection conducted and should comply with all OSHA, state, and agencies/employer requirements. A typical set of PPE includes steel-soled boots, safety glasses, gloves, a reflective vest, a hard hat, and a dust mask.

Tools and Equipment for Access

Access to conduct the inspection starts with the use of geographic information systems (GIS), mapping programs, and site photographs to identify site conditions.

- Inspection vehicle for travel to the jobsite and for hauling tools and equipment.
- GPS (Global Positioning System) device should be used for locating culvert and storm drain system features and for confirming and updating inventory records. Most smartphones and some digital cameras are GPS enabled. Devices with geotagging capabilities are readily available which add geographical identification metadata to photographs, electronic notes, voice memos, etc., which can be very useful for condition recording. Ensure that tools intended for use onsite, such as GPS and mapping systems, function without cellular signal or other data access.
- Ladders, for accessing higher reaches of a structure or to gain access through a manhole. Stepladders allow close inspection of top slab or pipe crowns.
- Rubber boots and waders are needed for wading into shallow streams.
- Probes should be used to check for voids beneath the water surface for safe footing.
- Rope and carabiners should be used for securing items and lowering tools down grade separations.
- Small boat may be needed during inspection of a large pipe with constant flow.
- Manhole lid hook for removal of manhole covers.