

Culvert Inspection

Culverts are the most numerous drainage structures on most road networks, and the larger ones meet the federal definition of a bridge. This course is built on the FHWA Culvert Inspection Manual (FHWA-IP-86-2, July 1986), a supplement to the Bridge Inspector's Training Manual. It covers how culverts differ from bridges, culvert types and materials, how flexible and rigid culverts carry load, durability, the inspection sequence and reporting, and the manual's condition rating guidelines for waterways, corrugated metal, precast concrete, cast-in-place concrete and masonry barrels. The manual predates the Specifications for the National Bridge Inventory (SNBI) and current element inspection, so its SI&A item numbers are historical; the inspection practice it describes remains the backbone of culvert work. Worked numbers are labeled illustrative.

Learning objectives

- Identify culvert types and materials
- Recognize shape distortion and joint defects
- Inspect inlets, outlets and embankments
- Rate culverts consistently

Why culverts need their own inspection approach

The Culvert Inspection Manual opens by noting that the traditional bridge/culvert split is based on span, not function: structures over 20 feet along the roadway are usually called bridges, and smaller ones culverts, even when they carry traffic directly. Many structures longer than 20 feet were designed hydraulically and structurally as culverts, and the manual was written for "structures functioning structurally and hydraulically as culverts regardless of span length."

The manual lists the differences that matter to an inspector:

- **Hydraulic.** Culverts are usually designed to run at peak flow with a submerged inlet. The culvert constricts the stream, water ponds upstream, and the resulting head increases capacity. Bridges are generally not designed to use inlet submergence to the same degree, so flooding of appurtenances, embankments and neighboring property is a bigger part of culvert inspection.
- **Structural.** Culverts are usually buried, so they carry the dead load of the soil plus live load. Live load is generally less significant than dead load unless cover is shallow; box culverts with shallow cover are the example the manual gives where live load matters. The surrounding soil plays an important structural role, and lateral soil pressure enhances the culvert's ability to carry vertical load.
- **Maintenance.** Because culverts constrict flow, debris and sediment blockage are more likely, especially at seasonal streams and at multiple barrels. Routine maintenance is mostly removing obstructions and repairing erosion and scour. Joint leakage matters where the bedding soil is "pipeable."
- **Traffic safety.** A culvert can often be extended so the full roadway section, including a recovery area, runs over it without parapets or rails. Ends close to traffic may need guardrail.
- **Construction.** Bedding, compaction and trench width during installation are critical to structural integrity.
- **Durability.** In hostile environments corrosion and abrasion can deteriorate all commonly available culvert materials.
- **Inspection.** Assessing a culvert requires evaluating not only visible distress but also circumstantial evidence such as roadway settlement, pavement patches and embankment condition.

The manual is candid that culverts "have traditionally received less attention than bridges" because they are out of sight and usually cheaper. But after 1967 many small bridges were replaced with multiple-barrel, box or long-span culverts, and long-span corrugated metal culverts with spans over 40 feet appeared in the late 1960s. A major culvert failure, it warns, can be both costly and hazardous; one of its exhibits shows a failure in which several people died.

Objectives of a culvert inspection

The manual sets out seven tasks the inspector should be able to perform: inspect an existing culvert; evaluate structural adequacy; evaluate hydraulic adequacy and recognize potential flood hazards; rate the condition; document the findings; recognize and document traffic safety conditions; and recommend corrective actions.

It names safety as "the most important reason why culverts should be inspected," and breaks safety into three parts:

- **Structural integrity:** identifying structural and material problems requires careful evaluation of indirect evidence of distress as well as actual deterioration.
- **Hydraulic performance:** inadequate capacity can flood adjacent property, fail the embankment and flood downstream areas, or wash out the roadway.
- **Roadside compatibility:** headwalls and wingwalls above the road or slope surface can be fixed-object hazards, and abrupt drop-offs or steep slopes at culvert ends can roll vehicles.

The manual adds that lack of maintenance is "a prime cause of improper functioning" of culverts, and that regular inspections let minor problems be corrected before they become serious.

Who inspects

Culverts with a total opening over 20 feet are bridges under the National Bridge Inspection Standards (NBIS), so bridge inspectors are the primary audience. The 1986 manual summarizes the NBIS team leader qualifications of the time (a registered or registrable professional engineer, or five years of inspection assignments plus a comprehensive training course). Those qualifications have since been revised in 23 CFR 650 Subpart C, so use the current rule, not the 1986 summary. Smaller culverts were, and often still are, inspected by maintenance staff, and the manual says its guidance generally applies to them too.

Its advice on attitude is short: "The inspector should approach each inspection with the expectation of finding serious defects." It also recommends at least two people per team for safety, measuring and documentation.

Tools, equipment and safety

The manual's standard kit includes tapes, rules, feeler gauges, calipers, plumb bob, protractor and sounding line; a geologist's hammer, chisel, scraper, wire brush, ice pick and probing rods; shovel and brush hook for debris; a hat-mounted light (preferred over a hand-held flashlight) and mirror; camera; marking devices including keel (lumber crayon); field books and forms; and personal protective and traffic control equipment.

Specialized equipment includes ladders, a small boat for large pipes with constant flow, rope for steep culverts, a level or transit for shape surveys of long spans, mechanical ventilation and pre-entry air testing for confined spaces, coring equipment with plugging kits, pH meters or kits, and soil resistivity meters. The manual says pH and resistivity tests "are not hard to perform, and this information should be collected" because it helps analyze long-term durability.

Hazards specific to culverts

- **Confined space.** Culverts with poor ventilation, such as one end blocked by debris or long urban drainage runs, may lack oxygen or collect toxic or combustible gases (the manual names hydrogen sulphide, carbon monoxide and methane). Test before entry where air quality is in doubt, ventilate continuously while occupied, use harness and lifeline where required, and keep one person outside. Follow current OSHA and agency confined-space rules.
- **Drowning.** Scour holes can leave deep water that looks shallow at low flow; probe with a rod before wading. Flash floods can reach peak flow in small culverts very quickly, sometimes before rain falls at the site.
- **Traffic.** Use traffic control conforming to the MUTCD or the state manual.
- **Steep embankments, toxic spills, animals and insects.** Brambles hide footing, streams occasionally carry spilled chemicals or gasoline, and drift piles can hide snakes and rodents. Watch for poison ivy, ticks and stinging insects.

Culvert shapes and materials

The manual stresses that shape selection is often not critical hydraulically, because equivalent openings can be made with several shapes; cover depth, headwater limits, debris, a natural bottom and structural needs usually decide it.

- **Circular:** the most common pipe shape, hydraulically and structurally efficient. It narrows the stream at low flow and may clog as the free surface shrinks above mid-height. Very large corrugated metal pipes need careful backfill to keep uniform curvature.
- **Pipe arch and elliptical:** used where cover is limited or a wider low-flow section is wanted. Less structurally efficient than circular and also prone to clogging as flow deepens.
- **Arches:** less obstruction and can keep a natural bottom where the bed resists erosion. Footing foundations must be adequate; riprap is often used for scour protection.
- **Box sections:** adaptable to low-profile sites but, with flat sides and top, less structurally efficient.
- **Multiple barrels:** give capacity under low fills or wide waterways but can trap debris between barrels, and barrels outside the dominant channel tend to fill with sediment.

For multiple barrels, the manual notes that opening length includes the distance between barrels when that distance is less than half the opening of the adjacent barrels, which is why groups of fairly small pipes can meet the bridge definition.

Materials

- **Precast concrete pipe** in six standard shapes (circular, arch, horizontal ellipse, vertical ellipse, pipe arch and box), and, except for boxes, up to five strength classes. The manual lists standard circular and elliptical sizes to 144 inches and precast arches on cast-in-place footings to 40-foot spans.
- **Cast-in-place concrete,** usually multi-cell boxes or arches, designed for the site but slower to build.
- **Corrugated steel,** as factory pipe (round or pipe arch, annular or helical corrugations, riveted, spot-welded, bolted, welded or lock seams) or field-bolted structural plate with 6 by 2 inch corrugations. Structural plate is described in units of $N = 3\pi = 9.6$ inches; the manual's example is a 60-inch pipe with a 20N circumference assembled from four 5N plates. Steel boxes and long spans (typical spans about 19 to 40 feet) use stiffened plate.
- **Corrugated aluminum,** as factory pipe or structural plate with 9 by 2.5 inch corrugations, plus rib-reinforced boxes and long spans.
- **Masonry** stone or brick, common before the 1920s, durable with good foundations; also timber, cast iron, stainless steel, terracotta, asbestos cement and plastic.

The manual points out that each long-span structure is to some extent a custom design, so the inspector should check dimensions against the design or as-built plans rather than standard tables.

Hydraulics an inspector needs

The manual divides culvert hydraulics into hydrology (how much runoff reaches the culvert) and hydraulics (whether the culvert can pass it). The inspector usually does not compute runoff but should recognize what changes it.

- **Land use** is the factor most likely to change over a culvert's life. Paved surfaces shed nearly all their rain, while undeveloped land sheds much less.
- **Time of concentration**, the time for water to reach the culvert from the most remote part of the drainage area, can shorten when streams are straightened or enclosed, upstream undersized pipes are replaced, or land is paved. Because shorter storms have higher intensities, shorter times of concentration can significantly raise peak runoff.
- Drainage areas are sometimes altered and flow diverted between watersheds.

Capacity depends on headwater depth, tailwater depth, inlet geometry, barrel slope and barrel roughness, which combine into two conditions:

- **Inlet control:** water can flow out of the barrel faster than it can enter, so headwater and inlet geometry govern. The manual says most culverts outside flat terrain are designed to operate under inlet control at peak flow, so small changes at the inlet, such as stream approach alignment, edge condition or headwalls, can significantly change capacity.
- **Outlet control:** water can enter faster than the barrel can carry it, so tailwater and barrel slope, length and roughness also matter. These culverts are usually on flat slopes or have high tailwater; added tailwater or debris in the barrel reduces capacity.

The manual also warns that unprotected inlet ends of flexible pipe can fail from **buoyant forces**, that high outlet velocity scours and undermines endwalls, wingwalls and barrels and causes end-section drop-off in rigid sectional pipe, and that **piping**, seepage along the outside of the barrel or through open joints, removes supporting soil. Piping is controlled with watertight joints, sometimes anti-seep collars, and good, well-compacted backfill.

BR-CU02 covers inlet and outlet control and HDS-5 performance curves in detail.

How flexible and rigid culverts carry load

The manual's structural chapter explains loads simply. Dead load is the soil over the culvert plus any surcharge; live load is traffic. The manual uses 120 pounds per cubic foot as a typical soil unit weight. Live load spreads with depth, and with more than about 2 feet of cover the manual describes a wheel load spread over a square whose sides are 1.75 times the cover depth. The practical consequence is the one an inspector needs: with shallow cover, live load is significant and may cause visible movement; with deep cover, dead load dominates and live load becomes minor.

Flexible culverts

Corrugated metal culverts are flexible. Under load the pipe deflects slightly, the vertical diameter shortens, the horizontal diameter lengthens, and the sides push outward into the backfill. The resisting side pressure is what lets the thin wall carry load. The wall itself works mainly in **ring compression**, a thrust around the circumference, and carries very little bending. The manual states the thrust with the simple relation $C = P \times S / 2$, where P is the vertical pressure on top of the pipe and S is

the span. It treats the culvert wall as a liner whose job is to carry that thrust and to keep water from washing out the soil envelope.

Illustrative example (not from the manual): for a 6-foot span under a vertical pressure of 1,800 psf, $C = 1,800 \times 6 / 2 = 5,400$ pounds per foot of pipe length. The number matters less than the concept: the thrust can only be carried if the curvature is maintained and the soil holds the sides. If the curvature flattens and the soil keeps yielding, the wall can buckle inward or reverse curvature, and that leads to partial or total failure.

Rigid culverts

Concrete pipe and boxes are rigid. They rely mainly on the structural strength of the barrel, and because they are stiffer than the surrounding soil they carry a substantial portion of the load. Vertical load creates zones of tension and compression in the wall, and reinforcing steel is placed in the tension zones (except in non-reinforced circular pipe). The manual warns that shear in the haunch area can be critical for heavily loaded rigid pipe on hard foundations, especially with inadequate haunch support. Unlike flexible pipe, rigid pipe does not deflect appreciably before it cracks, so shape measurement tells the inspector little; cracking pattern and alignment tell a great deal.

Installation

The manual contrasts trench and embankment installations. In a narrow trench the backfill settles more than the undisturbed soil beside it, and friction against the trench sides helps support the backfill, reducing the load on the pipe. As trench width increases that benefit shrinks; in a trench that is too wide, poor compaction can increase the dead load. Pipe bedded on original ground and covered by embankment behaves like a very wide trench. That is why trench widths should be on the plans and not exceeded without the designer's approval, and why good backfill and compaction are critical for flexible pipe and important for rigid pipe. Culverts under high fills are sometimes laid with **camber** so they settle to the intended grade; do not mistake an intentional camber or broken-back grade for distress.

Durability: corrosion and abrasion

The manual identifies durability problems as the most common reason pipe culverts are replaced. Two mechanisms dominate:

- **Corrosion**, the electrochemical or chemical deterioration of metal. Steel corrodes rapidly in salt water and in strongly acidic soil or water. Aluminum resists salt water reasonably well but corrodes rapidly in highly alkaline environments, especially where iron or copper or their salts are present.
- **Abrasion**, the wearing away of the invert by sand, gravel and rock carried in the flow. It is worst on steep streams with heavy bedload and can strip coatings and accelerate corrosion. The manual notes that the abrasive power of flow rises steeply with velocity; it gives doubling of velocity as roughly quadrupling abrasive power.

The manual describes pH 5.5 or less as strongly acidic and 8.5 or more as strongly alkaline, and it reports FHWA and industry guidance of its era: plain galvanized steel generally suited to roughly pH 6 to 10 with resistivity of at least about 3,000 ohm-cm, and aluminum to roughly pH 4 to 9 with resistivity of at least about 500 ohm-cm. Concrete exposed to pH of about 5.0 or lower needs protection. Many agencies set their own pH and resistivity limits from local performance, and later FHWA and AASHTO guidance has refined these ranges, so treat these figures as the manual's historical guidance rather than current design limits.

Protective measures the manual lists include extra thickness of concrete or metal; bituminous coating (the most common measure on corrugated steel, vulnerable to handling damage and abrasion); bituminous paved inverts, usually at least 1/8 inch

thick over the inner crests and generally only in the lower quadrant; other coatings such as polymeric, epoxy, fiberglass, clay and concrete field paving; and metallic coatings, of which galvanizing is the most common, with aluminum and aluminum-zinc also used. Very aggressive sites may call for special materials such as vitrified clay, stainless steel or plastic. An inspector should note the type of coating and its condition, because a failed coating usually means accelerated wall loss where it failed.

Testing in the field

When heavy corrosion is found by observation or sounding, the manual recommends pH testing, resistivity measurement and cores from the pipe wall. It also recommends considering a routine pH and resistivity program because the tests are easy and the data help estimate remaining life. A geologist's pick hammer is the inspector's main tool: scraping removes the thick scale that forms even from shallow steel corrosion, and striking the wall with the pick end locates unsound metal; under severe corrosion the pick will dent or punch through.

Reporting, records and measurement locations

Chapter 4 of the manual covers inspection procedures and documentation. At the time, NBIS required inspection of bridge-length culverts at intervals not exceeding two years. The manual suggests more frequent attention where conditions warrant, and it recommends inspecting new culverts annually for the first two years, since installation problems such as poor backfill tend to show up early.

Documentation the manual expects:

- The **inventory** and the **structure file**: plans, design data, previous inspection reports, maintenance and repair history, and hydraulic data.
- The **inspection report form** with condition and appraisal ratings.
- **Sketches** of plan and cross section, defect locations, and measured shapes.
- A **narrative** describing defects, their extent and location, and recommended actions.
- **Photographs** keyed to the report, including overall views of both ends, the waterway and the roadway, plus close-ups of defects.

Locating what you see

Changes can only be tracked if the same points are checked each time. The manual's convention is to number locations from the **outlet as station 1** and to give positions around the barrel by **clock position, looking upstream**. For structural plate, the manual recommends using joints, seams and plates as the reference grid because paint and scribe marks are lost over time, and measuring all dimensions to the inside crest of the corrugation, at the center of a longitudinal seam where possible. Long-span culverts should normally be measured at the ends and at 25-foot intervals, more often where shape changes are found.

For a flattened area, record the arc length and the length of culvert affected, and measure a **chord and its middle ordinate**. From those the actual radius can be computed and compared with the design radius; if the actual radius is larger, the curve is flatter than designed. *Illustrative example (not from the manual)*: with chord $C = 6.0$ ft and middle ordinate $M = 0.30$ ft, $R = C^2/(8M) + M/2 = 36/2.4 + 0.15 = 15.15$ ft. On a pipe whose design crown radius is 5 ft, that is a markedly flat crown. The manual's exhibit gives the chord and middle ordinate geometry; the formula above is the standard circular-segment relationship.

The rating scale and urgency

The manual uses the 0-to-9 Coding Guide scale and pairs it with a maintenance-urgency interpretation adapted from NCHRP Report 251 (its Exhibit 40, a maintenance rating scale), so that each rating corresponds to a level of maintenance or repair action; check your agency's current version before using it. The key rules it repeats: select the lowest rating that matches actual conditions as a starting point, use judgment, and do not average component ratings to get an overall rating.

The inspection sequence

The manual recommends a consistent order so nothing is missed:

1. **Review available information** before going to the site: plans, prior reports and photos, maintenance records, and any hydraulic or overtopping history.
2. **Observe overall condition** on arrival, before entering the channel: general alignment, ponding, debris, obvious distress.
3. **Inspect the approach roadway and embankment:** sags, dips, cracking, patches, guardrail sight lines, slope slips and erosion.
4. **Inspect the waterway** upstream and downstream: channel alignment, scour, sediment, debris and high water marks.
5. **Inspect the end treatments:** headwalls, wingwalls, aprons, cutoff walls, mitered ends; use a plumb bob to check walls for tipping, a hammer to sound concrete, and a probing bar to find undermining and scour holes that have refilled; look for piping and voids around the barrel ends.
6. **Inspect the barrel:** shape (flexible culverts) or cracking (rigid), alignment, joints and seams, wall deterioration, footings and inverts.

The manual's reasoning for inspecting the roadway first is that approach defects are circumstantial evidence. Depressions, pavement cracks and patches should alert the inspector that structural problems might exist in the barrel, and the barrel inspection should look for the cause.

Approaches and end treatments

Approach roadway. Settlement is common and usually comes from poorly compacted embankment, but it can also come from culvert settlement in soft foundation material, displacement of soft soil, or piping along the barrel. Look for dips, sags, cracks and patches; cracks will usually run parallel to the barrel. Sighting along guardrail, pavement edges or pavement markings reveals sags well. The manual notes how pavement type changes the evidence: rigid pavement bridges over minor voids and cracks, while flexible pavement settles irregularly. Flexible culverts that lose side support usually produce settlement directly over the culvert; poorly compacted backfill beside rigid pipe usually produces settlement beside it. Vertical ellipses, pear shapes and arches tend to peak up in the center, so the settlement shows beside the culvert. Repeated patching over the same culvert suggests progressive settlement.

Where box culvert top slabs carry traffic directly, cracks and defects in the slab must be evaluated structurally as well as as pavement. Approach changes such as new guardrail or Jersey barrier, or a raised grade, can change how overflow sections work and increase upstream flooding hazard.

The functional evaluation looks at roadway width over the culvert relative to the approach, alignment and sight distance, signing (advance warning, weight limit, narrow bridge), and fixed-object or drop-off hazards at the ends. Common safety

treatments are moving ends away from traffic, guardrail or barrier, matching ends to the slope, and traversable grates; grates need cleaning and repair and may increase upstream flooding.

End treatments. The manual describes projecting ends, mitered (beveled) ends usually with slope paving, skewed ends, prefabricated pipe end sections, and headwalls and wingwalls, plus appurtenances such as flumes, side ditches, aprons with cutoff walls, and energy dissipators. What to look for:

- **Projecting ends:** erosion and undercutting around the barrel, slope deterioration, drift and debris, and damage from debris impact and mowing equipment. Use a probing bar to find the real depth of scour holes that refill with sediment as flows drop. Watch for piping voids around the pipe, end-section drop-off at outlets of rigid sectional pipe, and inlet ends of corrugated metal pipe turned up by buoyant forces.
- **Mitered and skewed ends** of corrugated metal: the cut end can no longer act as a ring in compression and behaves like a cantilevered retaining wall, so check for deformation, slope erosion and undercutting, and confirm that headwalls, cutoff walls, slope paving, tie-backs or riprap are holding the end.
- **Headwalls and wingwalls:** undermining and settlement shown by cracking, tipping, or separation from the barrel. A separation that exposes fill "can be particularly serious and should be reported for special attention." For metal headwalls, check for voids behind the wall, toe-out at the base (scour) and outward movement at the top (anchor rods).
- **Aprons:** undermining (probe along the edges), settlement (cracks and movement at the headwall joint), displaced riprap, and wire-enclosed baskets that are displaced, partly empty or corroded. A scour hole with a downstream mound often forms in riprap aprons and the manual says it should generally not be disturbed; add rock if scour has penetrated the riprap.

Waterway: channel and adequacy

The manual rates the channel (then SI&A item 61, channel and channel protection) and the waterway adequacy (then item 71) with separate guideline exhibits.

- **Horizontal alignment:** abrupt bends at the ends retard flow, erode the outside of the curve and deposit sediment on the inside. Document alignment with sketches and photos.
- **Vertical alignment:** culverts much flatter than the natural stream tend to collect sediment; moderate and steep culverts run faster than the stream and tend to scour at the outlet. Barrels set higher or lower than the bed also cause problems.
- **Scour:** local scour, usually at the outlet, and general scour along the stream, including **head cutting**, an abrupt drop that migrates upstream during floods and can threaten the culvert from downstream.
- **Sediment and debris:** blockage reduces capacity, causes ponding, can redirect the channel, and increases the risk of buoyant failure. Some culverts are deliberately designed with fill in the bottom to create a natural bed for fish, which should not be mistaken for unwanted sedimentation.

For adequacy, the manual asks for **high water marks** (several, for consistency). Marks inside the barrel, in the drawdown area near the inlet or in turbulence at the outlet are generally misleading. Drift on fences and trees and residents' accounts help. Overtopping, excessive ponding or flooding of property should be investigated: an obvious cause such as a blocked inlet goes to maintenance; an unexplained one goes to a hydraulic specialist. The inspector should also note watershed changes, such as clearing, development, channel work, removal of upstream dams or sediment basins, or replacement of an upstream culvert with a larger one, which can send more water sooner.

The manual's channel exhibit runs from 9 (good alignment, no scour, no obstructions) through, for example, 5 (alignment beginning to change, significant scour requiring investigation, moderate restriction) and 2 (structure or roadway weakened,

danger of collapse with the next flood, culvert blocked by drift) to 0 (washed out). Scour that undermines footings or threatens the embankment connects culvert work to the scour courses (BR-H01).

Corrugated metal barrels: shape and defects

Shape is the direct indicator of whether the soil envelope is doing its job. The design cross section is the standard; if it is unknown, compare the unloaded ends with sections under the roadway or deep fill. Symmetry and uniform curvature are the critical factors. For shallow-cover structures, the manual recommends watching a few live loads pass; discernible movement may indicate instability.

Round and vertically elongated pipe. These deflect slightly during construction, and round pipe is sometimes elongated about 5 percent on purpose. At minimum, measure the horizontal diameter; measure chords and middle ordinates of flattened areas; and if the horizontal diameter exceeds design by more than 10 percent, measure the vertical diameter. Flattening of the top arc indicates possible distress; minor invert flattening is common on pipe not laid on shaped bedding, but severe bottom flattening is a concern. In shallow cover, side pressures can exceed the fill load and push the sides in, so side curvature matters.

- **Good to fair shape:** shape matches design with smooth, symmetrical curvature; horizontal span within 10 percent of design.
- **Marginal:** fair or marginal appearance, distortion in the upper half, severe flattening in the lower half, or horizontal span 10 to 15 percent over design.
- **Poor to critical:** shape does not match design or has obvious deformations; severe upper-half distortion; horizontal diameter more than 15 to 20 percent over design; or a crown flattened to a radius of about 20 to 30 feet or more. The manual stresses that pipe with less than 15 to 20 percent deflection may still be critical because of poor shape appearance.

The manual's rating guidelines tell the inspector to treat the shape criteria as a group, to give the most weight to shape in flexible culverts, and to evaluate significant change since the last inspection carefully even when the structure still looks fairly good.

Barrel defects

- **Misalignment:** sags trap water and debris; because most highway culvert joints are not watertight, ponded water can saturate the soil around the pipe.
- **Joints** (factory pipe): look for backfill infiltration and water exfiltration; probe open joints for voids; surface sinkholes over the line are a sign. Good condition has no open joints; fair has a few open joints without soil infiltration; marginal to poor shows soil infiltration.
- **Seams:** helical lock seams carry little ring thrust but should not crack or open. Riveted or spot-welded longitudinal seams carry the full thrust. On structural plate, check for open seams, cracking at bolt holes, plate distortion, bolt tipping, cocked and cusped seams, and fastener corrosion. Cracks 3 inches long on each side of the bolts indicate very poor to critical condition. Steel plate bolts can be checked by tapping; the manual cites 125 to 150 ft-lb torque for aluminum plate seam bolts.
- **Circumferential seams** do not carry ring thrust; distress there usually means embankment slippage or foundation movement pulling the structure apart.
- **Dents and local damage** matter if extensive; check the back of dents in steel for cracked or disbonded coating.

- **Wall deterioration** is rated with the manual's metal condition table: for steel, 8 is superficial rust with no pitting, 6 fairly heavy rust with moderate pitting and slight thinning, 4 pronounced thinning with deflection or penetration when struck with a pick, 3 scattered perforations, 2 extensive perforations, 1 invert completely deteriorated, 0 partial or complete collapse. Aluminum is rated by corrosion and attack of the core alloy. Culverts with lost inverts may still act as arches but are highly vulnerable to bedding erosion.
- **Footings and inverts** of arches and boxes: differential settlement shows as cracking or crushing across the footing and compressed or stretched corrugations; check for undermining and rotation where there is no invert slab, and for spalls, open cracks and missing portions in concrete inverts.

Concrete and masonry barrels

Precast concrete pipe. Plant manufacture gives uniform, dense concrete, and burial protects it from temperature swings and deicing salts, so concrete culverts generally resist surface deterioration better than bridge elements. Because rigid pipe does not deflect appreciably before cracking, shape inspection is of little value; focus on:

- **Misalignment:** sags, faulting and heaving at joints. Some pipe is laid with camber or a broken-back grade on purpose. If undermining is the cause, notify maintenance because damage will continue.
- **Joints:** exfiltration (water leaking out into bedding, which can start piping), infiltration (groundwater carrying fines in, shown by staining, soil deposits in the invert or depressions above), joint cracks and separation. Some agencies design open joints to act as subdrains, so check criteria before calling every leak a defect.
- **Longitudinal cracks:** under 0.01 inch, note only; 0.01 to 0.1 inch, describe and list as possible maintenance; over 0.1 inch may indicate overloading or poor bedding. For cracks over 0.1 inch, measure fill height and horizontal and vertical diameters so the design can be checked, and photograph for monitoring.
- **Transverse cracks:** a broken bell across the bottom where bell holes were not provided, or a broken back across the top over hard spots in the foundation.
- **Spalls and delaminations:** sound with a hammer along crack edges to find hollow areas.
- **Slabbing:** large slabs peeling from the sides as the reinforcing cage straightens; a serious condition that may occur under high fills.
- **Durability:** acid attack (for example mine drainage) and abrasion; surface loss under 1/4 inch is noted, deeper loss is a maintenance candidate, and a completely deteriorated invert warrants immediate notification.
- **End-section drop-off** from outlet erosion.

The precast rating exhibit puts, for example, cracks open more than 0.12 inch with efflorescence and spalling at numerous locations, heavily corroded exposed bars and invert scaling over 0.5 inch at rating 4, and extensive cracking with minor slabbing at 3.

Cast-in-place boxes and frames. Inspect walls, floor, top slab and joints; sound concrete with a hammer. Find sags at low flow by deeper water or sediment, or by top-slab profile elevations. Check that expansion joint filler is present and joints are not packed with incompressible material (spalls along joint edges suggest this). Longitudinal cracks in the top slab may indicate flexure or shear; transverse cracks may indicate differential settlement; wall cracks may come from settlement or earth pressure. The bottom of the top slab, the invert and the waterline on the walls are the most likely places for deterioration. Probe exposed footings for undermining, and check weep holes: no flow where flow used to appear, or fines on the floor, suggests they are not working.

Masonry. Usually stone or brick arches or boxes, dry, pointed or cemented. Tap units and mortar with a geologist's hammer; look for displaced, cracked, crushed or missing units and deteriorated mortar, especially where units have moved. Masonry

arches work in compression, so flattened curvature or bulging walls may indicate unstable soil. Many have no floor, so probe footings for undermining.

Overall ratings, load capacity and remaining life

The manual's final section ties the components together. In the SI&A coding of the time, item 62 (culvert and retaining walls) covered the structural and hydraulic components (alignment, settlement, barrel, end treatment, embankment), while item 67 (structural condition) also reflected load-carrying capacity. A sound culvert with capacity below current standards could therefore rate high on 62 and low on 67.

The overall rating is not an average. A low rating for one component very often controls, but the inspector should consider each component: is it functioning, could it threaten safety or cause property damage, will it cause more extensive damage if not repaired, and is the needed work maintenance or rehabilitation?

Load capacity items in the manual (operating rating, inventory rating and safe load capacity against state legal loads) are to reflect the culvert's condition at the time of inspection, which is why inspectors must record section loss, cracking, shape and cover depth carefully. BR-CU03 covers culvert load rating.

Remaining life is the inspector's estimate of years before major rehabilitation or replacement, based on the design life of the barrel material, years in service, current condition and the material's performance at similar sites; pH and resistivity help where durability governs.

Today. National Bridge Inventory coding has moved from the SI&A items to the SNBI, and many agencies also collect AASHTO element data. The 1986 item numbers in this course are historical. The field practice, the defect definitions and the logic of the rating guidelines (match the lowest description that fits, weigh shape most heavily on flexible culverts, do not average) carry over, but always code with your agency's current manual. BR-S01 introduces the SNBI.

Illustrative scenario (not from the manual): a 10-foot corrugated steel pipe under 6 feet of fill measures 11.2 feet horizontally, a 12 percent increase over design, with a flattened crown and moderate cracking at bolt holes on one seam. Using the shape guidance alone, that combination points to the marginal range, and the change since the last measurement decides how urgent follow-up is. If the previous report showed 10.6 feet two years earlier, the shape is still changing, the backfill is not stable, and the culvert should be referred for engineering evaluation rather than simply re-rated.

Field checklist and common mistakes

The checklist below condenses the manual's guidance into the order you would use it on site. It is a study aid, not a replacement for your agency's forms.

Before the visit

- Pull plans or as-builts, design shape and dimensions, cover depth, material and coating, prior reports, photos, shape measurements, and maintenance and flooding history.
- Check the weather and upstream rainfall; small culverts can flash flood quickly.
- Plan traffic control, confined-space testing and ventilation, and a two-person team.

On site

- Look at the whole site first: ponding, debris, alignment, roadway sags.

- Walk the approaches and embankment; sight along guardrail and pavement edges.
- Walk the channel upstream and downstream; record high water marks away from the inlet drawdown and outlet turbulence; note watershed changes.
- At each end, plumb the walls, sound the concrete, probe for scour and undermining, and look for piping voids and separations at the barrel-headwall joint.
- In the barrel, measure the same reference points as last time, record defects by station from the outlet and clock position looking upstream, and test pH and resistivity where corrosion is found.

Mistakes the manual's guidance helps avoid

- **Reading one shape survey as proof of stability.** Corrugated pipe can be off its design shape and still be stable; the trend over time is what matters.
- **Averaging.** A good barrel does not offset an undermined headwall or a scoured outlet.
- **Trusting apparent scour depth.** Scour holes refill as floods recede; probe.
- **Missing circumstantial evidence.** Repeated patches, sinkholes over joints and dips in guardrail often show a barrel problem before the barrel does.
- **Taking marks you cannot find again.** Paint and scribe marks fade; use seams, joints and plate numbers.
- **Treating intentional features as defects.** Camber, broken-back grades, open subdrain joints and fish-passage bed material can all be by design; check the records.
- **Mistaking a riprap apron's scour hole for failure.** The manual says a scour hole with a downstream mound often forms and should generally be left alone unless scour has gone through the riprap.

Key takeaways

- A culvert works with the soil around it and usually runs with a submerged inlet, so embankment, roadway and waterway evidence is as important as the barrel itself.
- Flexible (corrugated metal) culverts depend on a stable soil envelope; shape and curvature, and their change over time, are the key measurements.
- Rigid (concrete) culverts do not deflect appreciably before cracking, so inspection focuses on alignment, joints, cracks, spalls, slabbing and durability.
- Use the 1986 manual's guidance of 0.01 inch and 0.1 inch for concrete pipe crack significance, and measure fill height and diameters when cracks exceed 0.1 inch.
- Select the lowest rating that matches actual conditions and do not average component ratings; one bad component usually controls.
- Test the air before entering poorly ventilated culverts, probe scour holes before wading and leave when storms approach.
- Record exact measurement locations (outlet as station 1, clock positions looking upstream, seams and joints) so changes can be tracked between inspections.

References

1. FHWA, Culvert Inspection Manual, FHWA-IP-86-2, 1986
2. FHWA, Bridge Inspector's Reference Manual (BIRM), FHWA-NHI-12-049, 2012 (as revised)
3. AASHTO, Manual for Bridge Element Inspection, 2nd Edition, 2019

4. FHWA, Culvert Inspection Manual, Report No. FHWA-IP-86-2, Supplement to the Bridge Inspector's Training Manual, July 1986 (archived; FHWA lists the BIRM, the FLH Culvert Assessment and Decision-Making Procedures Manual and the AASHTO Culvert and Storm Drain System Inspection Guide as its successors).

Study text only; the final quiz is taken online. Verify all references against the edition your agency has adopted.