Chapter 11
CULVERTS

MONTANA
Department of Transportation

HYDRAULICS MANUAL

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CULVERTS

11.1 INTRODUCTION

This Chapter addresses MDT's design practices, criteria, and procedures on the hydraulic design of highway culverts. Irrigation facilities are designed using the practices and procedures in Chapter 12, "Irrigation Facilities."

11.1.1 Overview

This chapter provides the following:

- General Considerations, Section 11.2;
- Design Criteria, Section 11.3;
- Design Features, Section 11.4;
- Hydraulic Design, Section 11.5;
- Pipe Material Selection and Structural Requirements, Section 11.6;
- Design Procedure, Section 11.7;
- Documentation, Section 11.8;
- Related Designs (e.g., irrigation facilities, storage routing, tapered inlets, aquatic organism passage, broken back culverts), Section 11.9;
- Design Aids, Section 11.10; and
- References, Section 11.11.

This chapter is based on HDS 5, *Hydraulic Design of Highway Culverts* (1).

11.1.2 Culvert Definition

A culvert is defined as the following:

- A structure that can be designed hydraulically to take advantage of submergence of the inlet to increase hydraulic capacity.

- A structure used to convey surface runoff through embankments. The structure may be a round pipe, box, arch, open-bottom arch, or ellipse, depending on site conditions.

- A structure, as distinguished from bridges, that is usually covered with embankment and is composed of structural material around the entire perimeter, although some culverts are supported on spread footings with the streambed serving as the bottom of the culvert (also known as an open-bottom culvert or a three-sided culvert).

11.1.3 Concepts

The following concepts are important in culvert design:

1. Base Flood. The 100-year event or Q_{100} is also known as the base flood.

2. Critical Depth. In channels with a regular cross section, critical depth is the depth at which the specific energy of a given flow rate is at a minimum. For a given discharge and cross section geometry, there is only one critical depth. At critical depth, the Froude Number = 1.

3. Crown. The crown is the inside top of the culvert.

4. Flow Line. The flow line is the bottom of the channel or the channel grade line. The invert of the pipe may be above or below the flow line.

5. Flow Type. USGS (2) established six culvert flow types, which assist in determining the flow conditions at a specific culvert site. HDS 5 (1) uses seven culvert flow types. Diagrams of these flow types are provided in Section 11.5.3.

6. Free Outlet. Free outlet occurs when the tailwater depth is equal to or lower than critical depth. For culverts with free outlets, lowering of the tailwater has no effect on the discharge or the backwater profile upstream of the tailwater.

7. Inlet Control. Inlet control occurs when the culvert barrel can convey more flow than the inlet will accept. It is a function of the headwater elevation, inlet area, inlet edge configuration, and inlet shape. Factors such as roughness of the culvert, length of the culvert, and slope of the culvert do not affect the capacity of a culvert operating in inlet control.

8. Invert. The invert is the inside bottom of the culvert.

9. Normal Depth. Normal depth occurs in a channel or culvert when the slopes of the water surface and channel bottom are equal and the water depth remains constant. The discharge and velocity are constant throughout the reach. Normal flow will exist in a culvert operating on a constant slope if the culvert is sufficiently long.

10. Outlet Control. Outlet control occurs when the culvert barrel cannot convey as much flow as the inlet opening will accept. It is a function of the headwater elevation, inlet area, inlet edge configuration, inlet shape, roughness of the culvert, area and shape of the barrel, length of the culvert, slope of the culvert, and tailwater elevation.

11. Slope. The measurement of inclination of a pipe, representing the difference in elevation of the inlet and outlet inverts along the centerline of the pipe. A steep slope occurs where the normal depth is less than the critical depth. A mild slope occurs where the normal depth is greater than the critical depth.

12. Subcritical Flow. Subcritical flow occurs when the actual flow depth is greater than critical depth. Water in subcritical flow is impacted by downstream conditions.

13. Submerged. A submerged outlet occurs where the tailwater elevation is higher than the crown of the culvert. A submerged inlet occurs where the headwater is greater than 1.2D, where D is the culvert diameter or barrel height.

14. Supercritical Flow. Supercritical flow occurs when the flow depth is less than critical depth. Water in supercritical flow is impacted by upstream conditions but not downstream conditions.

15. Tapered Inlet. A tapered inlet has an entrance geometry that decreases the flow contraction at the inlet and, thus, increases the capacity of the culvert. These inlets are referred to as either side- or slope-tapered. The side-tapered inlet has a face wider than the culvert. The slope-tapered inlet has both a larger face and increased flow line slope at the entrance. Beveled edges at the culvert face may also improve the hydraulic capacity of a culvert for both conventional and tapered inlets.

11.1.4 Symbols

To provide consistency within this Chapter, the symbols given in Figure 11.1-1 will be used. These symbols have been selected because they are consistent with HDS 5 (1).

Figure 11.1-1 — SYMBOLS, DEFINITIONS, AND UNITS

Symbol	Definition	Units
A	Area of cross section of flow	ft^2
B	Barrel width	in. or ft
D	Culvert diameter or barrel height	in. or ft
d	Depth of flow	ft
d_c	Critical depth of flow	ft
d_n	Normal depth of flow	ft
EGL	Energy grade line	ft
g	Acceleration due to gravity	ft/s^2
H	Head Loss, sum of $H_e + H_f + H_o$	ft
H_e	Entrance head loss	ft
H_f	Friction head loss	ft
H_L	Total energy losses	ft
H_o	Outlet or exit head loss	ft
H_v	Velocity head	ft
h_o	Hydraulic grade line height above outlet invert	ft
HGL	Hydraulic grade line	ft
HW	Headwater depth (f subscript indicates face, t = throat)	ft
HW_a	Headwater allowable	ft
HW_i	Headwater depth (inlet control) above inlet invert	ft
HW_o	Headwater depth (outlet control) above the inlet invert	ft
k_e	Entrance loss coefficient	—
L	Length of culvert	ft
n	Manning's roughness coefficient	—
R	Hydraulic radius (A/P)	ft

Symbol	Definition	Units
R	Resistivity	ohm-meter
S	Slope of culvert	ft/ft
S_o	Slope of streambed	ft/ft
TW	Tailwater depth above outlet invert of culvert	ft
V	Mean velocity of flow with barrel full	ft/s
V_d	Mean velocity in downstream channel	ft/s
V_o	Mean velocity of flow at culvert outlet	ft/s
V_u	Mean velocity in upstream channel	ft/s
γ	Unit weight of water	lb/ft^3

11.2 GENERAL CONSIDERATIONS

11.2.1 MDT Culvert Practices

The following general MDT practices are specific to the design of culverts:

- A completed design of the culvert includes structural, environmental, and hydraulic aspects. This chapter addresses the hydraulic design, choice of culvert materials, and structural design.
- Hydraulically design all mainline culverts 24 in. and greater. Hydraulically design all mainline irrigation crossings 18 in. and greater.
- Follow the criteria defined in Chapter 9, "Hydrology," Section 9.3.2 and Section 11.3.1.1 to select a design flood.
- Align culverts vertically and horizontally with the natural channel to avoid sediment build up. Stream profiles are important to setting the pipe and establishing the correct slope. Use the long profile to set culvert slope, elevation inverts, and flow lines (see Section 11.4.6).
- Weigh the cost savings of combining drainage with special-purpose large culverts (utilities, stock and wildlife passage, and land access) against the advantages of separate facilities (see Section 11.4.10).
- When the culvert barrel needs to accommodate aquatic organism passage, use the culvert design procedures described in Section 11.9.4.
- When site conditions warrant, design culverts to accommodate ice, debris, sediment, Section 11.2.2, and access for maintenance.
- Maintain existing drainage patterns. Consider impacts both upstream and downstream of the culvert crossing.
- When determining appropriate culvert materials, consider the desired service life of the culvert and the site conditions affecting the service life. These include abrasion, corrosion, structural

factors (e.g., height of fill), and replacement cost commensurate with the risk at the site. See Section 11.4.5.

- Locate and design culverts to present a minimum hazard to traffic and people. Include in the design the environmental, aesthetic, political, or nuisance considerations and land-use requirements.
- In the design documentation, include all information required to justify the design. Assemble design data and calculations in an orderly fashion and retain for future reference (see Section 11.8 and 23 CFR 650A).

11.2.2 Site Considerations

11.2.2.1 Structure Type Selection

Culverts may be used where:

- Bridges are not hydraulically required,
- Debris and ice accumulation are tolerable, and
- Bridges are uneconomical.

Culverts may replace a bridge when the above conditions are met and:

- The hydraulic design requirements for a culvert can be met,
- Upstream risk is determined to be acceptable based on a risk assessment Section 9.3.4, and
- Floodplain requirements can be met.

Advantages of a culvert include:

- Can be extended so that guardrail is not required,
- Will generally stop headcuts,
- Can eliminate the need for a detour with staged construction,
- Can eliminate traffic disruptions through use of jack and bore methods,
- Requires less maintenance than a bridge,
- Does not have deck icing issues or deck drainage risks, and
- Reduces the likelihood of snow and sanding material plowed from the roadway reaching the stream; culvert may be extended to further reduce the amount of sand that would enter the culvert.

Disadvantages of a culvert include:

- Can create a scour hole at outlet of pipe,
- May not be adequate for ice or debris, and
- Has a longer imprint on the stream reach.

Bridges are used:

- Where culverts cannot be used hydraulically,
- Where more economical than a culvert,
- To satisfy land use requirements,
- To mitigate environmental harm caused by a culvert,
- To meet floodplain criteria,
- To avoid irrigation canal encroachments on large canals, and
- To accommodate ice and large debris.

Open-bottom culverts:

- MDT does not use open-bottom culverts over waterways due to scour concerns.

11.2.2.2 Ice Condition

Floating ice conditions may be mitigated as necessary by:

- Increasing the culvert crown above the maximum observed ice level,
- Increasing the culvert width to span the channel width, and
- Using concrete edge protection on culverts with diameters larger than or equal to 54 in. or equivalent (see Figure 11.A-4).

Sheet ice conditions may be mitigated by:

- Installing an overflow culvert, and/or
- Increasing the culvert crown above the maximum observed ice level.

11.2.2.3 Debris Control

Per HDS 5, factors that may help to align and pass most floating debris through a culvert are:

- A smooth, well-designed inlet,
- Avoidance of multiple barrels, and
- Avoidance of inlets skewed to upstream flow.

If the debris cannot be controlled with one of the methods above, upsize to a larger structure or bridge.

Where beavers are active, preserve the low flow channel to mitigate the potential for damming. It may be beneficial to oversize the structure to pass debris and to minimize the sound of running water.

11.2.2.4 Sedimentation

Most streams carry a sediment load and deposit this load when their velocities decrease. Therefore, barrel slope less than the natural channel and roughness greater than the channel are key indicators of potential problems at culvert sites. Other important factors in sedimentation processes are the magnitude of the discharge and the characteristics of the channel material.

Culverts that are located on and aligned with the natural channel both vertically and horizontally generally do not have a sedimentation problem. If it is not possible to align the culvert with both the upstream and downstream channel, it is more desirable for sediment passage to align with the upstream channel; however, for culverts with erosion concerns, it may be preferable to align with the downstream channel. See HDS 5 for additional information.

11.2.3 Cleaning Culverts

It may be desirable to include the cleaning of existing culverts with design projects. Follow the guidelines below to determine and document if a culvert is eligible for cleaning on projects involving federal-aid funds:

- Except in special cases, such as difficult to reach culverts, only culverts that are larger than 48 in. are eligible to be cleaned with federal-aid funds. All culverts larger than 48 in. will be individually evaluated for cleaning based on the size, location, severity of the problem, and whether specialized equipment is needed. If culvert cleaning will be addressed by a project, include the culvert locations in the plans and a cleaning special provision.

- Culvert cleaning is not typically included in preventive maintenance projects such as pavement preservation projects.

- A list of smaller culverts (48 in. and smaller), not eligible for federal-aid funds but in need of cleaning, can be submitted to the appropriate MDT Maintenance Division to schedule cleaning activities.

11.3 DESIGN CRITERIA

11.3.1 Culvert Criteria

Culverts must be sized to:

- Pass the design flood event without overtopping the road (see Section 11.3.1.1 on design floods),

- Maintain existing flow patterns without creating unexpected flood hazards both upstream and downstream (see Section 11.3.1.2 on review floods),

- Meet the allowable headwater criteria (see Section 11.3.1.3 on allowable headwater), and

- Follow the risk evaluation criteria in Section 9.3.4.

11.3.1.1 Design Flood

Because it is not economically feasible to design a structure for the maximum runoff a watershed can produce, a design flood frequency is selected. Design flood is a general term to describe the discharge or water level (stage) and associated probability of exceedance that is selected as the standard for designing the capacity or stability of a hydraulic structure. Figure 9.3-1 presents design flood frequencies expressed as return periods adopted by MDT for the various drainage facilities on streets and highways. The design flood criteria and procedures are further described in Section 9.3.2.

11.3.1.2 Review Flood

All proposed structures designed to accommodate the selected design flood frequency must be reviewed using the 100-year (base flood) and the overtopping or the 200-year flood, whichever is smaller, to ensure that there are no unexpected flood hazards. The review flood criteria and procedures are further described in Section 9.3.2.

11.3.1.3 Allowable Headwater

11.3.1.3.1 For Permanent Culvert Installations

Headwater is the depth of water that can be ponded at the upstream end of the culvert. For embedded culverts, hydraulically design the culvert with embedment in place, and use the embedment elevation to measure the headwater depth.

Allowable headwater will be limited by each of the following:

- The allowable headwater criteria in Figure 11.3-1 for the design flow and the 100-year flow for culverts on new alignment or replacement culverts (see Section 11.3.1.3.2 for exceptions);
- The maximum headwater increase allowed for the 100-year flow in Montana is 0.00 ft to 0.50 ft, depending on the site, for National Flood Insurance Program mapped floodplains; or
- When replacing a bridge with a culvert, the allowable headwater used for culvert design is typically the backwater of the existing bridge. Complete a Risk Evaluation per Section 9.3.4 when deciding whether to replace a bridge with a culvert. Where there is no site risk or NFIP floodplain, the backwater may be increased within the limits of Figure 11.3-1 with approval from the State Hydraulic Engineer. See also Section 17.4.2.5.

If increasing headwater over existing conditions at the design, 100-year, or 200-year events, complete a risk evaluation per Section 9.3.4 and document the risk evaluation and results in the hydraulic report.

When sizing mainline and public approach culverts do not exceed the values listed in Figure 11.3-1. For arch pipes, the allowable headwater is based on the rise (R).

Figure 11.3-1 — MAXIMUM ALLOWABLE HEADWATER

Equivalent Pipe Size (in.)	HW @ Design Flow	HW @ 100-Year Flow
≤ 42	< 3.0 D or 3.0 R	< 4.0 D or 4.0 R
48 - 108	< 1.5 D or 1.5 R	< D + 5 ft or R + 5 ft
≥ 120	< D + 2 ft or R + 2 ft	< D + 4 ft or R + 4 ft

Note: For arch pipes and boxes, R is equal to the rise of the pipe; for round pipes, D is the diameter of the pipe. Use the diameter or rise of the pipe; do not reduce the D or R for embedment.

11.3.1.3.2 Headwater Exception Procedure (Previously MDT Procedure Memo 10)

General

This procedure applies only to small rural drainage areas where the preliminary hydrologic/hydraulic analysis does not agree with the historical performance of existing drainage facilities. To use this method, the selected culvert must be 36 in. in diameter or smaller for the RCP option and 42 in. in diameter or smaller for the CMP option.

Procedure

For these crossings, an economic/risk assessment documenting that the selected culvert is appropriate will suffice. The brief assessments rely heavily on sound hydraulic engineering judgment and include three major elements — 1) a hydrologic analysis using the current USGS prediction equations, 2) culvert sizing calculations based upon peak flow, and 3) an indication that the potential for damage is minimal or nonexistent. The remainder of the assessment may include considerations similar to the following examples:

1. The peak flow analysis indicates that a 60-in. RCP is necessary. However, the existing culvert or culverts at crossings of comparably sized drainage areas in the immediate vicinity are 30-in. or 36-in. RCPs and have historically been adequate. Floodwater storage is probably a factor, but survey data is inadequate to allow a routing design and additional survey would be unwarranted. High headwater would result in minimal damage; therefore, specify a 36-in. RCP or consider upsizing by one or two pipe sizes.

2. Peak flow analysis indicates that a 30-in. RCP is adequate. However, field drainage recommendations, historic performance of the existing structure or similar sized structures on comparably sized drainage areas in the immediate vicinity, or erosion evidence indicates that a larger pipe is warranted. A larger culvert, up to a 36 in. in diameter, is recommended.

Optional Pipe Recommendations

For drainage recommendations based on the Headwater Exception Procedure above, use Figure 11.3-2 to specify comparable sizes for the optional pipe materials. For example, an equivalent 30-in. CMP would use an optional 24-in. RCP.

Figure 11.3-2 — OPTIONAL PIPE EQUIVALENTS FOR HEADWATER EXCEPTION PROCEDURE

RCP or RCPA	CMP or CMPA
24″ or 28″ × 18″	30″ or 35″ × 24″
30″ or 36″ × 22″	36″ or 42″ × 29″
36″ or 44″ × 27″	42″ or 49″ × 33″

11.3.1.3.3 For Temporary On-Site Traffic Detour Culverts

Use Figure 9.3-3 to determine the design frequency for culverts used for temporary on-site traffic detours for Interstate highways and for any other facility that is considered essential to maintain during most flood events. For other locations, the design frequency can be determined using the procedure in Appendix 9A. At the detour design frequency, size the culvert to have a headwater depth less than or equal to the diameter or rise of the culvert.

11.3.1.4 Tailwater Elevation

For the culvert analysis, determine the tailwater elevation based on normal depth from downstream channel geometry, a downstream control, or field observations.

11.3.1.5 Outlet Velocity and Energy Dissipation

If the velocity at the culvert exit exceeds 10 ft/s at the 10-year return period flow, dissipate the energy as follows:

- Culverts with a 48-in. diameter and less (or equivalent area; see Figure 11.A-4), use the riprap Standard Drawing *Culvert Outlet Riprap for Culverts with FETS.*
- Culverts with greater than an equivalent 48-in. diameter (or equivalent area; see Figure 11.A-4), follow the procedures in HEC 14 *Hydraulic Design of Energy Dissipators for Culverts and Channels* (4) and compare the results to the size of the existing scour hole and use engineering judgment to temper the size of the riprap apron.
- If a culvert has an existing scour hole at the outlet, keep the hole for energy dissipation if possible and line the hole with appropriately sized riprap.
- Additional guidance on energy dissipators may be found in Appendix 11C and HEC 14 (4).

11.3.1.6 Minimum Pipe Size

The minimum size for all new mainline drainage pipes is 24 in. in diameter. The minimum size for all new mainline irrigation pipes is 18 in. in diameter. Pipes located underneath public road approaches must be at least 24 in. in diameter, while pipes located underneath private approaches and farm field approaches must be at least 18 in. in diameter. Equivalent area arch pipes may be used; see Figure 11.A-4. If an approach pipe also carries irrigation water, the hydraulic engineer determines the appropriate pipe size.

11.3.1.7 Storage (Temporary or Permanent)

Storage is normally not considered in culvert design. If storage is being assumed upstream of the culvert, see Section 11.9.2 and Chapter 15, "Storage Facilities." Also consider:

- Limiting the total area of flooding;
- Performing unsteady flow (routing) analysis; and
- Recommending that the storage area will remain available for the life of the culvert, in areas of possible development, through the purchase of right-of-way or easement, if the culvert design depends on this storage.

11.3.1.8 Buoyancy

Buoyancy is more serious with steep culvert slopes, depth of the headwater, flatness of the upstream fill slope, height of fill, large culvert skews, or mitered ends. Cutoff walls, concrete edge protection, and limiting head water, or other means of anchoring to provide buoyancy protection will be considered for all culverts that are 54 in. in diameter and larger (or equivalent area; see Figure 11.A-4). Culvert end treatments are discussed further in Section 11.4.7.3 and are shown in Figure 11.10-2. Allowable headwater criteria are shown in Figure 11.3-1.

11.3.1.9 Sediment Transport

In perennial streams where there is significant bedload, sediment control can be an issue. To ensure sediment passage, size the culvert to have minimal backwater at the 1.5-year event. For perennial streams with bedload, consider setting the pipe invert 10% to 20% below the channel flow line.

MDT does not generally use a detailed design procedure to analyze sediment deposition. Locations where sediment is a concern can generally be analyzed using the maximum permissible velocity criteria in *Open-Channel Hydraulics*, by Ven Te Chow (5). Locations where there are known sedimentation problems that are high risk may require a more detailed analysis using hydraulic software; see Chapter 8, "Hydraulics Software" and HEC 20 (6).

11.3.2 Service Life

The hydraulic engineer will use service life to determine the required wall thickness, type of coating, and any special requirements for new pipes. For each project, the hydraulic engineer will evaluate the corrosive soil report, as provided by the Materials Bureau, to determine design service life and the allowable pipe materials. The remaining service life of existing culverts will guide the decision to either retain or replace the culvert.

MDT assumes that, during construction, soils from any location in a project may be relocated to another location within the project limits. Therefore, develop one culvert material strategy for the entire project based on all soil and water sample results and the condition of the existing culverts. Additionally, consider site-specific factors such as those listed below and in Section 11.6.

The culvert service life will comply with the following criteria:

- The minimum design service life for new or replacement culverts will be:
    - 100 years for Interstates,
    - 100 years for fill heights over 15 ft,
    - 100 years for storm drains,
    - 100 years for siphons,
    - 100 years for non-pressurized irrigation pipes,
    - 75 years for mainline pipes and public approaches, and
    - 40 years for non-public approach pipes (approach pipes will not receive any coating unless specifically recommended).
- The remaining design service life for in-place culverts on pavement preservation projects will be 20 years for all in-place culverts.
- The remaining design service life for in-place pipes on projects other than pavement preservation projects will be 25 years; however, where any of the following apply, the remaining design service life for in-place culverts is 50 years:
    - Fill heights are over 15 ft,
    - Average daily traffic (ADT) is greater than 5000 vehicles per day,
    - Grade raises are over 5 ft,
    - The facility is a 4-lane roadway,
    - Extensions are greater than 50% of the in-place length of the culvert, or
    - The project is a major rehabilitation or reconstruction.

See Section 11.6.2 for service life calculations.

11.4 DESIGN FEATURES

11.4.1 Culvert Shape and Material Selection

When selecting allowable culvert shapes and materials, evaluate the following:

- Durability (service life),
- Structural strength,
- Hydraulic roughness,
- Constructability,
- Initial/replacement cost,
- Bedding conditions,
- Passage of fish and aquatic organisms,
- Abrasion and corrosion resistance, and
- Water-tightness requirements.

In general, these considerations are addressed in the physical properties of the culvert shape and material. Physical properties are detailed in:

- Section 11.4.7 for pipe culverts, and
- Section 11.4.8 for box culverts.

Pipes may be fabricated from many different types of material, and each of these materials presents different structural properties in response to both live loads and earth loads. The hydraulic engineer will provide information for the different pipe material options, including wall thickness, size of corrugations, and class of concrete for all culverts. MDT practice is to specify alternate or optional pipe materials where they can be used; the basic bid item for optional pipe is steel.

Pipes have different structural capabilities depending on the pipe size, both in terms of diameter and material thickness. In general, the smaller the diameter of the pipe and/or the thicker the pipe material, the more load the pipe can withstand.

11.4.2 Common Culvert Materials

The pipe materials in Figure 11.4-1 are commonly used by MDT. Pipe material selection for mainline culvert crossings, approach culverts, irrigation facilities, and storm drains is based on design criteria such as service life, site conditions, and the intended use. The pipe materials in Figure 11.4-1 are not intended to be all inclusive; therefore, a proper engineering analysis is required for all installations.

For projects where existing pipes can be used in place and require lengthening, the additional length of pipe usually will be constructed of the same material and thickness as the existing pipe. Pipes to be lengthened will be identified in the hydraulic engineer's recommendations.

Figure 11.4-1 — COMMON PIPE MATERIALS

Pipe Material	Abbreviation	MDT Specification
Corrugated Steel Pipe*	CSP	709.02
Corrugated Steel Pipe Arch*	CSPA	709.02
Structural Steel Plate Pipe	SSPP	709.03
Structural Steel Plate Pipe Arch	SSPPA	709.03
Reinforced Concrete Pipe	RCP	708.01.2
Reinforced Concrete Pipe Arch	RCPA	708.01.3
Reinforced Concrete Box	RCB	Standard Special Provision 603-3
Corrugated Aluminum Pipe	CAP	709.07
Aluminum Box Culvert	ALBC	Special Provision
Steel Casing Pipe	SCP	709.01.2 & Special Provision 603-1
Corrugated Polyethylene Pipe	HDPE	708.07
Solid Wall Polyethylene Pipe	HDPE	708.08.2
Large Diameter PVC Pipe (18″-48″)	PVC	708.05.3
Profile Wall PVC Pipe (4″-36″)	PVC	708.05.4
PSM PVC Pipe (15″ or Less)	PVC	708.05.2
PVC Pressurized Pipe	PVC	708.06

* *Acceptable Coatings:*
- *Type 2 Aluminized:* *MDT Standard Specification 709.12*
- *Pre-Coated Polymeric:* *MDT Standard Specification 709.05*

11.4.3 Optional Pipe Materials (Basic Bid Item)

The hydraulic engineer determines which pipe materials are acceptable for each project based on service life, fill height, etc. The acceptable pipe materials are shown in the plans as optional pipe. During construction, the contractor may select which option to use.

The basic bid item for optional pipe is steel. If steel pipe is not an option in the design, then reinforced concrete pipe (RCP) will be the basic bid item. Only the basic bid items are shown in the plans and cross sections. The allowable optional pipe materials for the project are listed in the culvert summary frame.

11.4.4 Alternate Bids

Alternate bids will be used when the area of the opening is greater than a 10-ft diameter round pipe and the use of both materials is appropriate. Alternate bids can be provided for small structures if the design team elects to do so. All alternate bid items are shown in the plans, summaries, and cross sections. The hydraulic engineer will determine and document which materials are appropriate for a project.

11.4.5 Culvert Material Selection Guidelines

MDT practice is to specify alternate or optional pipe materials where they can be used. To qualify for selection, optional pipe materials must meet the following criteria:

- Provide adequate hydraulic capacity.
- Withstand the forces of the weight of fill over the pipe (meet the fill height requirements).
- Withstand the forces of traffic loads and construction equipment during pipe installation and under post construction conditions (meet fill height requirements and construction specifications).
- Withstand hydrostatic pressure to prevent fluid from leaking out of the pipe into the surrounding bed materials.
- Provide adequate service life in relation to the Culvert Service Life Guidelines (Section 11.6.2).
- Withstand corrosion caused by the fluids conveyed by the pipe and the soil surrounding the pipe, especially in areas of standing water or irrigation wastewater.
- Withstand abrasion from sediment carried by the flow.
- Withstand impacts from the high application rates of salt and sand, such as on mountain passes.
- Withstand fire and combustion.
- Be constructible within the constraints of the site.
- Provide desired Aquatic Organism Passage (AOP) characteristics and meet other project based environmental requirements.
- Consider local government preferences.
- Fulfill the need for experimental installations and/or Materials Bureau product review process.
- Culverts, storm drains, or other installations must be studied on a case-by-case basis to determine if the optional materials satisfy these requirements.

11.4.5.1 Pipe Materials

MDT uses the common pipe materials in Figure 11.4-1 as appropriate for mainline culvert crossings, approach culverts, irrigation facilities, and storm drains. For guidelines on the selection and use of optional pipe materials for specific applications, see Figure 11.4-2. The list of factors to be considered is not intended to be all inclusive; therefore, a proper engineering analysis is required for all installations.

Figure 11.4-2 — GUIDELINES FOR OPTIONAL PIPE MATERIAL SELECTION

Application	Factors to be Considered	Materials to be Considered
Interstate Crossings: Design Service Life = 100 Years **Mainline Drainage & Public Approaches:** Design Service Life = 75 Years **Approach Drainage:** Design Service Life = 40 Years	• Service Life • Soil / Water Corrosivity • Fill Height • Bed Load Abrasion • Active Channel Width • AOP	• CSP & CSPA • RCP & RCPA • CAP • RCB • SSPP & SSPPA • ALBC (See Note 7) • SCP (Jack & Bore) • HDPE (Non-public approaches only)
Pipe Extensions: Remaining Service Life = 25 or 50 Years	• Review Remaining Pipe Service Life Criteria in Section 11.3.2	• Match Existing Material & Thickness/Class
Non-Pressurized Irrigation Facilities: Design Service Life = 100 Years	• Service Life • Soil / Water Corrosivity • Watertight Joints • Fill Height • Bed Load Abrasion • Channel Width • Ditch Burning & Maintenance Practices	• CSP-IRR & CSPA-IRR • RCP-IRR & RCPA-IRR • CAP-IRR • PVC (See Note 8) • RCB • SSPP & SSPPA • ALBC (See Note 7)
Storm Drain Trunkline and Laterals: Design Service Life = 100 Years **Siphons:** Design Service Life = 100 Years	• Service Life • Soil / Water Corrosivity • Watertight Joints • Hydraulic Capacity • Abrasion • Maintenance Responsibility • Owner Preference • ADT • Surfacing Type	• RCP-IRR & RCPA-IRR • RCB • PVC (See Note 8)

1. *The materials listed for each application in this table are a preliminary estimate of possible optional materials.* ***Not all of the materials may be feasible in all situations, and additional engineering criteria may require evaluation.***

2. *Some materials may not have adequate hydraulic capacity, service life, corrosion and abrasion resistance, structural capacity, or resistance to fire damage, or they may not satisfy environmental requirements or the preferences of local jurisdictions.*

3. *The use of a specific pipe product may be used if documented properly in the Hydraulic Report in accordance with these guidelines and the Culvert Service Life Guidelines. To fully document the optional pipe material selection, include the following in the Hydraulic Report as appropriate:*

    a. *An individual hydraulic analysis for each culvert, storm drain, irrigation line, or siphon. Separate analyses may be necessary if optional pipes have different roughness values.*

    b. *Results from the corrosive soil and water testing that determine the applicable pipe materials, gages, and coatings that provide an adequate service life for the application.*

    c. *Verification that the minimum and maximum fill height for each optional pipe material and shape is applicable to each crossing.*

    d. *A determination if abrasion protection is required based on the channel bed material and estimated flow velocity.*

    e. *Documentation of any special site or environmental requirements such as aquatic organism passage (AOP), wildlife access, stream bank width restrictions, or floodplain or overtopping risk.*

4. *The Culvert Service Life Criteria 11.3.2 and Guidelines 11.6.2 will be utilized to the extent possible and in combination with 23 CFR 635.411 (b) when specifying pipe products on MDT projects.*

5. *The fill height tables for various pipes are provided in Appendix 11A. These tables must be used to determine the applicability of the various optional pipe materials, shape, gage, and wall thickness.*

6. *Do not use plastic pipe, or polymeric coated metal pipe if maintenance practices such as ditch burning are anticipated near the pipe.*

7. *ALBCs: Headwater at the 100-year event cannot exceed the crown of the pipe.*

8. *PVC: Maximum size allowable is 36 in. Allowed only in applications where no part of the pipe is exposed to direct sunlight.*

9. *For RCP-IRR and RCPA-IRR specify pipe with watertight joints used for storm drains and irrigation. Concrete arch pipe is not available with a gasketed and grooved joint; therefore, when watertight concrete arch pipe is necessary, work with the precast concrete pipe manufacturer to obtain a watertight joint. Typically, this is achieved with double ramneck gaskets inside the joint and joint wrap around the exterior of the joint.*

11.4.6 Culvert Skew, Slope, Embedment, and Length

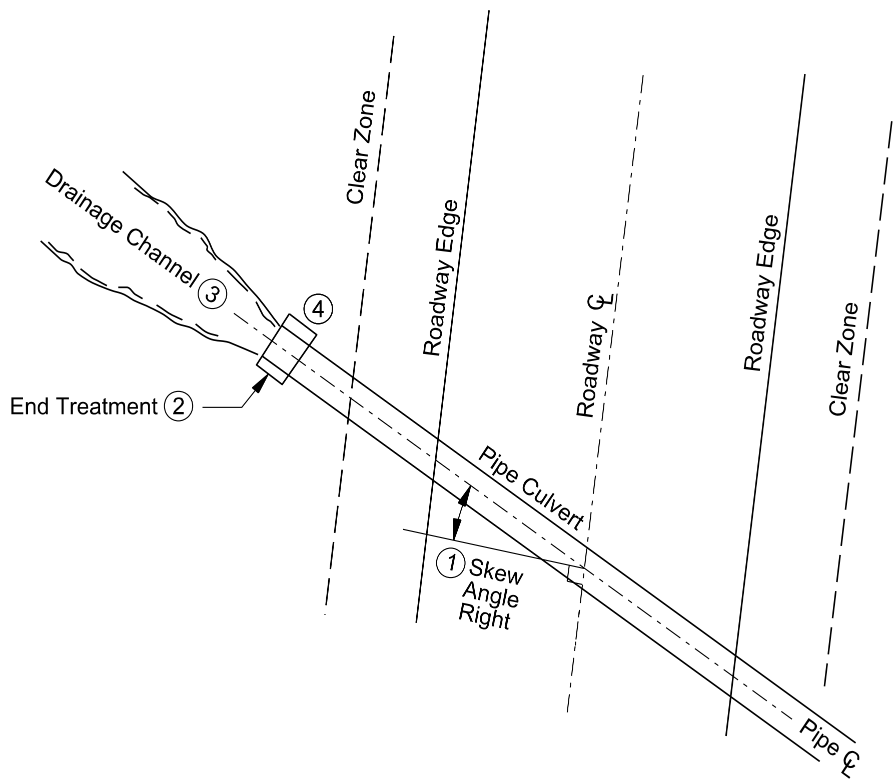
Set the culvert skew, slope, and length for culverts to fit the existing topography. If necessary, skew the culvert to align with the angle of the stream; see Section 11.4.6.1. Match the culvert slope with the overall slope of the thalweg; see Section 11.4.6.2.

11.4.6.1 Culvert Skew

The skew is defined as the angle measured left or right from a line which is perpendicular to the roadway centerline. See Figure 11.4-3 for a general illustration of pipe skew in relation to the roadway orientation.

For skewed installations, concrete pipes have square ends and cannot be cut at a skew. For steel pipes, the beveled end section can be cut at a skew to match the embankment slope. Cutting the beveled section at an angle is referred to as a skew bevel. Round pipes have a step bevel and arch pipes have a bevel; see the MDT *Detailed Drawings*.

Figure 11.4-3 — PIPE SKEW



① *A skew angle right is one where the pipe centerline is to the right of a line extended perpendicular from the roadway centerline. A skew angle left is one where the pipe centerline is to the left of a line extended perpendicular from the roadway centerline.*

Avoid skew angles greater than 35°.

② *End treatments for all single concrete pipe and corrugated steel pipe installations with diameters 48 in. or less will be installed perpendicular to the centerline of the pipe regardless of pipe skew, unless specified otherwise by the hydraulic engineer.*

The following will apply to installations of corrugated steel pipe diameters 54 in. diameter equivalent or greater:

- *For skew angles 0° to 15°, the end treatment is perpendicular to the centerline of the pipe.*
- *For skew angles 16° to 35° and fill height 10 ft or less, the end treatment is skew step beveled or skew beveled.*
- *For skew angles 16° to 35° and fill height greater than 10 ft, the end treatment is perpendicular to the centerline of the pipe and the fill warped to the pipe ends.*

- *Avoid skew angles greater than 15° for structural steel plate pipe culverts.*

③ *Consider channel realignment changes where appropriate, with consideration of potential environmental impacts, to limit pipe skew.*

④ *Extend the pipe so that the near corner of the edge protection catches the fill slope beyond the clear zone.*

Consider the following for metal pipe end treatments with skewed installations for pipe diameters of 54-in. diameter equivalent or greater:

- Multiple-pipe installations will use the same end treatment as single-pipe installations except that, for skews from 16° to 35°, the end treatment will be skew-beveled regardless of fill height.
- Skew-bevel or skew step-bevel end sections are cut parallel to the centerline of the roadway.
- If it is determined to be necessary to skew-bevel or skew step-bevel a pipe end, provide concrete edge protection and cutoff walls on both ends.
- The type of bevel and the amount of skew must be identified in the culvert summary.

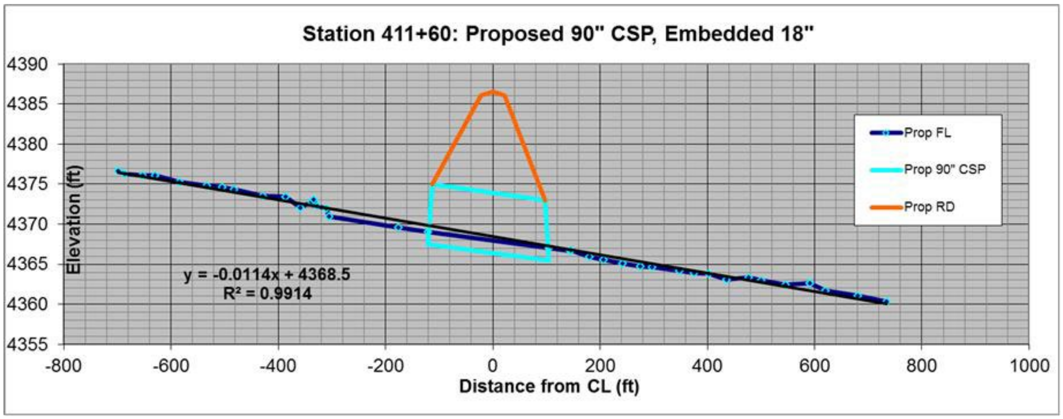
11.4.6.2 Culvert Slope

Culvert slope (S) is established by considering the natural streambed slope (S_o) and the required culvert invert embedment. Figure 11.4-4 illustrates how slope is established. The stream bottom is plotted to the extents of the thalweg survey or for at least 500 ft upstream and downstream. An average streambed slope (S) is established by eye or computation (see the Prop FL line in Figure 11.4-4). The large culvert in this case is embedded 18 in. below the proposed flowline.

11.4.6.3 Culvert Embedment

Embed culverts 54 in. and larger a minimum of 10% of the diameter or rise. Culverts also may be embedded greater than 10% to address abrasion concerns and for Aquatic Organism Passage (AOP) design. See Sections 11.9.4 for AOP and 11.3.1.9 for sediment transport. On the plans, cross-sections, and/or details, clearly label both the culvert invert and embedment flow lines at each end of the culvert.

Figure 11.4-4 — DETERMINING THE CULVERT SLOPE



11.4.6.4 Culvert Length

Hydraulics provides a preliminary pipe length, and Road Design determines the final pipe lengths for all pipes except box culverts. For box culverts, Hydraulics determines the final length based on the box segment lengths. The culvert length shown in the plans includes the end treatments. Chapter 13 of the MDT *Road Design Manual* provides additional information on measuring and quantifying pipe lengths.

When designing the pipe, the culvert may need to be lengthened so that either the top of the pipe (48 in or less) or all the concrete edge protection (54 in or greater) is beyond the clear zone. If it isn't possible to extend the pipe beyond the clear zone, safety end sections or guardrail may be required.

Box lengths are measured along the culvert flow line. Sloped end sections and wing walls are considered a part of the pipe length and are measured along the culvert flowline. Most box culvert sections come in 6 ft lengths, but larger box culverts may come in 4 ft lengths. Layout the box culvert so the total length is divisible by the length of the box sections for the specified box size. If the length is not divisible by the box section length, increase the culvert length.

11.4.7 Pipe Culvert Physical Properties

This section describes MDT practices for pipe culvert physical properties. Box culvert physical properties are described in Section 11.4.8.

11.4.7.1 Structural Requirements

The structural requirements are based principally on the size and shape of the culverts, the amount of cover over the pipe and, in some cases, the class of bedding and type of backfill. MDT structural requirements are further discussed in Section 11.6. Structural requirements are primarily addressed via fill height tables, which are provided in Appendix 11A.

In addition to culvert size and length, include the following data on the plans to identify strength requirements:

1. Reinforced Concrete Pipe Culverts. Indicate class of pipe 2, 3, 4, or 5.

2. Concrete Arch Pipe Culverts. Indicate class of pipe 3 or 4.

3. Corrugated Steel Pipe including CSP, CSPA, SSPP, and SSPPA. Provide the gage of metal and the size of corrugations. Also note any coating requirements.

4. Corrugated Aluminum Pipe Culvert. Provide the gage of metal and the size of corrugations.

11.4.7.2 Bedding, Foundation Material, and Backfill

Bedding is required for all pipe installations per the MDT *Detailed Drawings*. For pipes 48-in. in diameter or less, bedding is paid for within the cost of the pipe and does not need to be shown in the culvert summary. For pipes 54-in. or larger in diameter, granular bedding must be quantified and paid for separately and specified in the culvert summary in accordance with the MDT *Standard Specifications for Road and Bridge Construction* and the MDT *Detailed Drawings*.

When foundation material is specified, it will be placed below the granular bedding or bedding material. Foundation material must be quantified and paid for separately and specified in the culvert summary in accordance with the MDT *Standard Specifications for Road and Bridge Construction* and the MDT *Detailed Drawings*.

Backfill requirements are described in the MDT *Standard Specifications for Road and Bridge Construction* and the MDT *Detailed Drawings*.

11.4.7.3 Pipe Culvert End Treatments

Special treatments are typically required for the ends of culvert installations. Figure 11.4-5 provides criteria for determining the proper end treatments for cross drain structures based upon pipe type and size; the following subsections identify the application considerations for each type. The end treatment criteria apply to both single- and multiple-pipe installations. Refer to Chapter 9 of the MDT *Road Design Manual* for detailed information on the proper use and installation of culvert end treatments in relation to roadside safety best practices. See the MDT *Detailed Drawings* for the standard pipe culvert end treatments.

Example photos of the culvert end treatment types are shown in Figure 11.10-2. In addition, when modeling culverts, select the inlet coefficient (k_e) from Figure 11.10-2.

Consider safety when selecting an end treatment. When possible, extend the pipe so that the near corner of the edge protection catches the fill slope beyond the clear zone. Where extending the culvert is impractical due to site conditions, evaluate other end treatments, such as shielding with a roadside barrier, flattening the slope to provide a recoverable slope, use of a modified end treatment (safety end section), or requesting an exception to leave the obstacle. Section 11.2.4 and 11.2.7 of the MDT *Road Design Manual* presents the criteria for the selection of an end treatment type for pipe culverts based on safety considerations.

Figure 11.4-5 — CULVERT END TREATMENT DETERMINATION

Pipe Type and Size	End Treatment	Cutoff Walls②	Inlet/Outlet Concrete Edge Protection
RCP/RCPA ≤ 48″ (Eq)	FETS	No	No
RCP/RCPA ≥ 54″ (Eq) and ≤ 90” (Eq)	FETS	Yes	No
CMP/CMPA ≤ 48″ (Eq)	FETS	No	No
CMP ≥ 54″	Step Bevel①	Yes	Yes
CSPA or SSPPA ≥ 54″	Bevel①	Yes	Yes
SCP ≤ 48″	FETS	No	No
SCP ≥ 54″	Square③	Yes	Yes
RCB	Sloped End ④	Yes	Yes
RCB	Wingwalls ④	Yes	No

CMP = Corrugated Metal Pipe (CSP, CAP, or SSPP)
FETS = Flared End Terminal Section

Notes:

① *Type of bevel will be identified on the plans and culvert summary frame (e.g., 2H:1V step bevel, 2H:1V bevel). 2H:1V step bevel and 2H:1V bevel are typically used; 1.5H:1V and 2.5H:1V are used rarely.*

② *Cutoff wall dimensions are shown on MDT Detailed Drawings. The cutoff walls are typically used on both ends of a culvert and extend a minimum of 3 ft deep or 1 ft below the bottom the foundation material to prevent piping under the culvert.*

③ *In special situations, square ends may be specified by the hydraulic engineer. For square ends on culverts ≤ 48 in. in diameter or equivalent area (Figure 11.A-4), extend the culvert length 2 ft beyond the toe of the fill slope. For square ends on culverts ≥ 54 in. in diameter or equivalent area, add cutoff walls and concrete edge protection to the inlet and outlet.*

④ *Sloped end sections are typically used on box culverts for drainage crossings. Wingwalls are typically used for irrigation crossings. See Section 11.4.8.4 for additional information.*

11.4.7.3.1 Flared End Terminal Section (FETS)

Flared end terminal section (FETS):

- Are available for both corrugated metal and concrete pipe;
- Decrease embankment erosion and incur less damage from maintenance; and
- May improve projecting metal pipe entrances by increasing hydraulic efficiency, reducing the accident hazard, and improving their appearance.

11.4.7.3.2 Bevels and Step Bevels with Concrete Edge Protection

Bevels and step bevels with concrete edge protection:

- Increase the efficiency of metal pipe,
- Provide embankment stability,
- Provide embankment erosion protection,
- Provide protection from buoyancy, and
- Reduce maintenance damage.

11.4.7.3.3 Square Ends (Projecting Inlets or Outlets)

Square ends (projecting inlets or outlets):

- Extend 2 ft beyond the embankment of the roadway,
- Are susceptible to damage during roadway maintenance and automobile accidents, and
- Have poor hydraulic efficiency for thin materials ($k_e = 0.9$).

11.4.7.3.4 Safety End Sections and RACETs

When culvert end sections are within the clear zone, use one of the end treatments listed below to make the culvert opening more traversable by an errant vehicle.

Use Safety Slope End Sections (see MDT Standard Hydraulic Drawing) on culverts that cross under the mainline, and the culvert ends are:

- Within the clear zone, and
- Greater than 30" span.

Use Road Approach Culvert End Treatments (RACETs) (MDT Detailed Drawings 603-12 & 603-13) on all approach culvert end sections that are located within the clear zone. Generally, these culverts are oriented parallel to traffic on the mainline. These end sections have a 6:1 slope.

Use Precast Median U-Turn Cross Drain End Sections (MDT Detailed Drawing 603-17) on culverts under Interstate crossovers and median turn-around locations. These end sections have a 10:1 slope.

11.4.7.3.5 Outlet Protection/Aprons

Outlet protection/aprons are constructed using riprap, vegetated concrete block, or gabions. Consult Section 11.3.1.5 and Appendix 11C, "Energy Dissipators" for other outlet protection considerations.

11.4.7.4 Multiple Pipes

It may be necessary to install two or more adjacent culverts at one location to provide adequate conveyance. Multiple pipe installations are identified as a "double" or a "triple" installation at the station representing the center of the installation. Typically, a single pipe crossing is preferred to multiple pipe installations.

The spacing between outside faces of adjacent pipes normally will be a minimum of 4 ft but may be increased to a maximum of 8 ft to aid in installation and backfill. If FETS are used, specify at least 2 ft between the outside ends of adjacent terminal sections.

Multiple barrel culverts must fit within the natural dominant channel with minor widening of the channel to avoid conveyance loss through sediment deposition in some of the barrels. Where minor widening will not accommodate the multiple barrels, place one pipe in the channel and additional pipes at a higher elevation (typically the bankfull elevation). Avoid placing multiple culverts in the following locations:

- The approach flow is high velocity, particularly if supercritical (these sites require either a single barrel or special inlet treatment to avoid adverse hydraulic jump effects).
- In irrigation canals or ditches (unless approved by the canal or ditch owner).
- Aquatic Organism Passage (AOP) is required.
- A high potential exists for debris and/or ice problems (clogging of culvert inlet).
- At a river bend because the inside culvert will infill with sediment.

11.4.7.5 Culverts in Deep Fills

The replacement of culverts in deep fills (i.e., 15 ft or more) can be very costly and can cause severe disruption to traffic. These circumstances require that viable alternatives for rehabilitation or special installations be investigated before specifying the traditional remove and replace option (see Section 11.4.12).

Appendix 11B presents guidance for pipe replacement/rehabilitation options for culverts with fill heights greater than 15 ft. The guidance serves as a checklist for options to consider when replacing pipes in high fills as either a culvert replacement or reconstruction project.

When specifying a replacement pipe size in fill heights greater than 15 ft, enlarge replacement concrete culverts by 18" and corrugated metal culverts by 24" to allow room for future rehabilitation.

In some situations, it may be advantageous for culverts in deep fills to provide options on the plans for culvert replacement, jack and bore, and/or culvert rehabilitation. Additionally, it may be advantageous to provide options for rehabilitation methods rather than specifying a single method.

11.4.7.6 Soil Conditions

Soil and water conditions can have a significant impact on the service life of culverts. At each site, take soil samples to be analyzed for:

- pH
- Marble pH
- Percent sulfates
- Resistivity

MDT has developed a spreadsheet to analyze and determine the impacts of soil conditions on pipe life and when pipe materials or coatings are appropriate. The spreadsheet uses the methodology described in Section 11.6.2, "Service Life."

11.4.8 Box Culvert Physical Properties

11.4.8.1 Box Culvert Size

MDT has not adopted standardized designs for box culverts. The project contract documents provide basic information on the culvert site (e.g., the length of the culvert) and stipulate that the contractor's manufacturer is responsible for the structural design of the box culvert. Typically, these are precast concrete boxes. When site conditions allow, MDT bids:

- A CSP/CSPA steel option if the steel culvert is less than a 10-ft diameter (or equivalent area), or
- A SSPP/SSPPA steel alternate if the steel culvert is a 10-ft diameter or larger (or equivalent area).

11.4.8.2 Multiple Barrels

To avoid conveyance loss through sediment deposition in some of the barrels, multiple-barrel box culverts must fit within the natural dominant channel with only minor channel widening. Avoid using multiple-barrel culverts where:

- The approach flow has a high velocity, particularly if supercritical (these sites require either a single barrel or special inlet treatment to avoid adverse hydraulic jump effects).

- Irrigation canals or ditches are present unless approved by the canal or ditch owner.

- Fish passage is required unless special treatment is provided to ensure adequate low flows (commonly one barrel is lowered).

- A high potential exists for debris and/or ice problems (clogging of culvert inlet).

- A meander bend is present immediately upstream.

11.4.8.3 Embedding Box Culverts

MDT practice is to embed the inverts of box culverts below the streambed a minimum of 10% of the rise and potentially more for Aquatic Organism Passage (AOP) culverts or for abrasion (see Section 11.9.4 for AOP and Section 11.3.1.9 for sediment transport). On the plans, cross-sections, and/or details, clearly label both the culvert invert and embedment flow lines at each end of the culvert.

11.4.8.4 End Treatment (Inlet or Outlet)

The following are end treatment types and features for reinforced box culverts:

1. Sloped End. 2H:1V sloped ends with edge protection is the standard edge protection for box culverts. Sloped end sections are typically used on drainage crossings. See the MDT Standard *Drawing*: Sloped End RCB Detail.

2. Wingwalls. Wingwalls are typically used on box culverts in irrigation canals. Wingwalls may also be used on drainage crossings where sloped end sections do not tie into the bank lines, if the channel banks are unstable, or if needed to reduce the length of a box culvert. Wingwalls provide the best hydraulic efficiency if the flare angle is between 30° and 60°.

   Standard wingwall angles are 30°, 45°, 60°, and 90°; alternate angles may be considered if necessary for design. In addition, standard wingwalls have a flat top, however wingwalls with sloped tops may be considered if necessary for design. Coordinate with the precast manufacturers for non-standard design.

3. Cutoff Walls. Use cutoff walls on both ends of all box culverts to prevent piping under the culvert. The cutoff walls extend either a minimum of 3 ft below the outside bottom of the box culvert or to 1 ft below the bottom of the foundation material (if required by Geotech). See the MDT Standard Drawing: Sloped End RCB Detail.

4. Concrete Edge Protection. Concrete edge protection is constructed on both the inlet and outlet for sloped end sections. The concrete edge protection protects the inlet and outlet of the culvert during high flow events.

Use Figure 11.10-2 to select the inlet coefficient (k_e). As shown on the hydraulic standard drawings, the top edge of the box culvert is beveled to improve hydraulics.

11.4.9 Siphon (Sag Culverts)

Siphons (sometimes called inverted siphons, sag culverts, or sag lines) are used to convey water by gravity under roads, railroads, other structures, various types of drainage channels, and depressions. A siphon is a closed conduit designed to run full and under pressure. Typically, MDT avoids siphons for drainage crossings; however, they may be used in irrigation. Further discussion on siphons is included in Chapter 12, "Irrigation Facilities."

11.4.10 Special-Purpose Large Culverts

Large culverts frequently are used for purposes other than to accommodate drainage. They may serve as stockpasses, wildlife underpasses, vehicular underpasses with surfacing, or pedestrian/bicycle underpasses. The following criteria present guidance for special-purpose large culverts.

11.4.10.1 Stockpasses

A standard metal pipe may be designed to serve as a stockpass by using the treatment shown in the MDT *Detailed Drawings*. Specify stockpasses when justified by right-of-way negotiations. The primary purpose of this structure is to serve as a stockpass, but stockpasses may also act as cross drains. Where possible, separate stockpasses from drainage culverts, and set the stockpass invert elevation to avoid water flow. Adjacent, lower elevation culverts may also be provided for drainage when necessary.

The same fill height requirements and bedding for drainage culverts also apply to stockpasses. See Appendix 11A for fill height tables and the detailed drawings for the bedding requirements.

11.4.10.2 Wildlife Underpasses

Wildlife underpasses are intended to provide connectivity across highways while reducing collisions between vehicles and animals. The size and structure type will vary in accordance with the size and type of animal species to be accommodated and potentially by the crossing length. When a culvert is used, it is typically sunk and backfilled with natural soil and used in conjunction with wildlife exclusionary fencing. The design team will coordinate with the hydraulic engineer because the culvert will often function as both a wildlife crossing and a drainage culvert.

11.4.10.3 Vehicular Underpasses

Vehicular underpasses can be either round structural steel pipes or reinforced concrete box culverts. Details for steel vehicular underpasses are shown in the MDT *Detailed Drawings*.

The same fill height requirements and bedding for drainage culverts also apply to vehicular underpasses. See Appendix 11A for fill height tables and the standard hydraulic drawings for the bedding requirements.

11.4.10.4 Pedestrian/Bicycle Underpasses

Pedestrian and bicycle underpasses are typically designed using a 10 ft × 10 ft equivalent opening. These structures may include lighting, special grouting, or paving to meet ADA guidelines. All pedestrian and bicycle underpasses must be ADA-compliant up to and through the underpass from both directions. Consider placing a curb around the top of the pipe to direct drainage/snowmelt away from the culvert face.

11.4.11 Encasement Pipe

11.4.11.1 Purpose

The following provides a general guideline for material selection when the Hydraulics Section is requested to specify an encasement pipe for pressure irrigation lines, sanitary sewers, water lines, etc. This request generally is in the form of a landowner request or possibly at the request of a municipality for a future water or sanitary sewer line.

Encasement pipes may be required for the following reasons:

- To prevent damage to structures caused by soil erosion or settlement in case of pipe failure or leakage,
- To permit economical pipe removal and placement in the future,
- To accommodate regulations or requirements imposed by public or private owners of property in which the pipe is installed, and
- To permit boring rather than excavation where open excavation would be impossible or prohibitively expensive.

11.4.11.2 Encasement Pipe Materials

When installation of an encasement pipe is warranted, the following encasement pipe materials may be considered.

- Corrugated Steel Pipe (CSP),
- Reinforced Concrete Pipe (RCP),
- Steel Casing Pipe (SCP),
- PVC Pipe:
  - Large Diameter PVC Pipe,
  - Profile Wall PVC Pipe, and
  - PSM PVC Pipe, and
- Solid Wall Polyethylene Pipe (HDPE).

11.4.11.3 Special Considerations

Consider the following when designing an encasement pipe:

- Cost.
- As the insert becomes larger, the requirement for a smooth interior encasement becomes more important.
- Use steel casing pipe when a pressurized line will be inside the encasement.

- When sizing the encasement pipe, allow enough space for the outside diameter, including the bells, of the inserting pipe.

11.4.11.4 Guidelines

The following guidelines, which are available online, provide additional information:

1. *Steel Pipe--A Guide for Design and Installation*, American Water Works Association (AWWA) No. M11
2. *A Guide for Accommodating Utilities Within Highway Right-of-Way*, AASHTO
3. *PVC Pipe-Design and Installation*, AWWA No. M23
4. *Accommodation of Utility Plant within the Rights of Way of Urban Streets and Highways*, State of the Art and Manual of Improved Practice, FHWA RD-75-8 and 75-9
5. MDT *Utilities Manual*

11.4.12 Culvert Rehabilitation Versus Replacement

Many culverts are reaching the end of their design life. In many cases, replacement of these culverts can be very costly and cause severe disruption to traffic. These circumstances require that viable alternatives for rehabilitation or special installations be investigated before specifying the traditional remove and replace option. Appendix 11B presents guidance for pipe replacement vs. rehabilitation options.

Options typically considered include:

- Keep existing pipe,
- Install new pipe,
- Jack & bore new pipe,
- Insert new pipe into existing pipe,
- Cured in place pipe (CIPP),
- Spray-on liner, and
- Invert paving.

11.4.12.1 Excavation Requirements

MDT practice is to use an open-trench replacement if the depth of existing cover is approximately 15 ft or less or if the new roadway alignment is offset. Consider trenchless methods where existing fill heights are approximately 15 ft or greater. Trenchless methods become economically viable for deep fill replacements due to the traffic disruption and the cost of detours associated with open-trench replacement.

11.4.12.2 Guidelines

The following guidelines, which are available online, provide additional information:

1. *Culvert Rehabilitation to Maximize Service Life while Minimizing Direct Costs and Traffic Disruption*, NCHRP Project Number 14-19.

2. *FHWA FLH Culvert Assessment and Decision-Making Procedures Manual for Federal Lands Highway*, Publication No. FHWA-CFL/TD-10-005

11.4.13 Detour Culverts

The Hydraulics Section determines the type of temporary drainage structure(s) that are required for detours. Design frequency for detours is discussed in Appendix 9A. Detour guidelines for bridges are described in Section 17.8.

11.5 HYDRAULIC DESIGN

11.5.1 General

An exact theoretical analysis of culvert flow is extremely complex because the following is required:

- Analyzing non-uniform flow with regions of both gradually varying and rapidly varying flow;
- Determining how the flow type changes as the flow rate and tailwater elevations change;
- Applying backwater and drawdown calculations, energy, and momentum balance;
- Applying the results of hydraulic model studies; and
- Determining if hydraulic jumps occur and if they are inside or downstream of the culvert barrel.

MDT typically uses the software HY-8 to design culverts, and most of the above issues are addressed in HY-8 (see Chapter 8, "Hydraulics Software").

11.5.2 MDT Standard Practice

MDT uses procedures for the hydraulic design of highway culverts that are based on HDS 5. Typically, the hydraulic engineer will use HY-8 or other software that is consistent with the equations provided in HDS 5 to analyze culverts. However, the hydraulic engineer also has the option of manually designing the culverts using the equations or nomographs in HDS 5. Large culverts that function hydraulically more like bridges and culverts that have high entrance velocities may be more appropriately sized using HEC-RAS. Design irrigation culverts that need a backwater analysis in HEC-RAS.

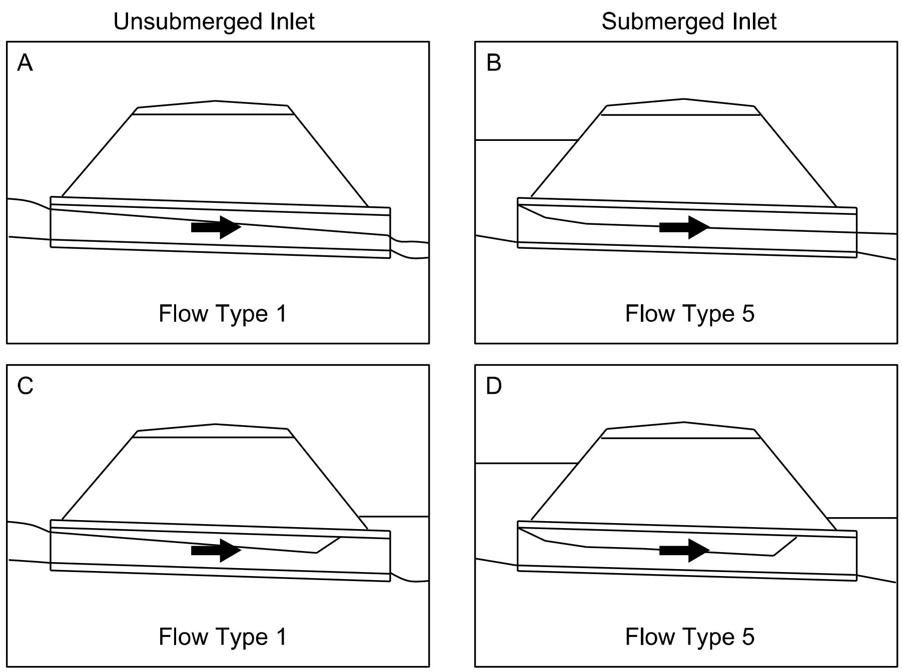
11.5.3 Types of Flow Control

Inlet and outlet control are the two basic types of flow control. The basis for the classification system is the location of the control section. The hydraulic control section is the location where there is a unique relationship between the flow rate and the upstream water surface elevation. Inlet control is governed by the inlet geometry. Outlet control is governed by a combination of the culvert inlet geometry, the barrel characteristics, and the tailwater or critical depth. The characterization of pressure, subcritical, and supercritical flow regimes has an important role in determining the location of the control section and, thus, the type of control. The hydraulic capacity of a culvert depends upon a different combination of factors for each type of control.

11.5.3.1 Inlet Control

Figure 11.5-1 illustrates the types of inlet control flow. Inlet control flow type depends on the submergence of the inlet and outlet ends of the culvert. In these examples, the control section is at the inlet end of the culvert. Depending on the tailwater, a hydraulic jump may occur downstream of the inlet.

Figure 11.5-1 — TYPES OF INLET CONTROL



Source: HDS 5 (1)

11.5.3.1.1 Factors Influencing Inlet Control

Because the control is at the upstream end, only the headwater and the inlet factors affect the culvert performance:

1. Headwater Depth. Headwater depth is measured from the inlet invert to the surface of the upstream pool.

2. Inlet Area. Inlet area is the cross-sectional area of the face of the culvert. Generally, the inlet face area is the same as the barrel area. For tapered inlets (Section 11.9.3), the face area is enlarged, and the control section is at the throat.

3. Inlet Configuration. Inlet configuration describes the entrance type. Some typical inlet configurations are mitered, square edges in a headwall, and beveled edge.

4. Inlet Shape. Inlet shape is usually the same as the shape of the culvert barrel; however, it may be enlarged as in the case of a tapered inlet. Typical shapes are rectangular, circular, arch, and elliptical. When the inlet face is a different size or shape than the culvert barrel, the possibility of an additional control section within the barrel exists.

5. Barrel Slope. Barrel slope influences inlet control performance, but the effect is small. Inlet control nomographs assume a slope of 2% for the slope correction term (0.5S for most inlet types). This results in lowering the headwater required by 0.01D. In the computer program HY-8, the actual slope is used as a variable in the calculation.

11.5.3.1.2 Inlet Control Hydraulics

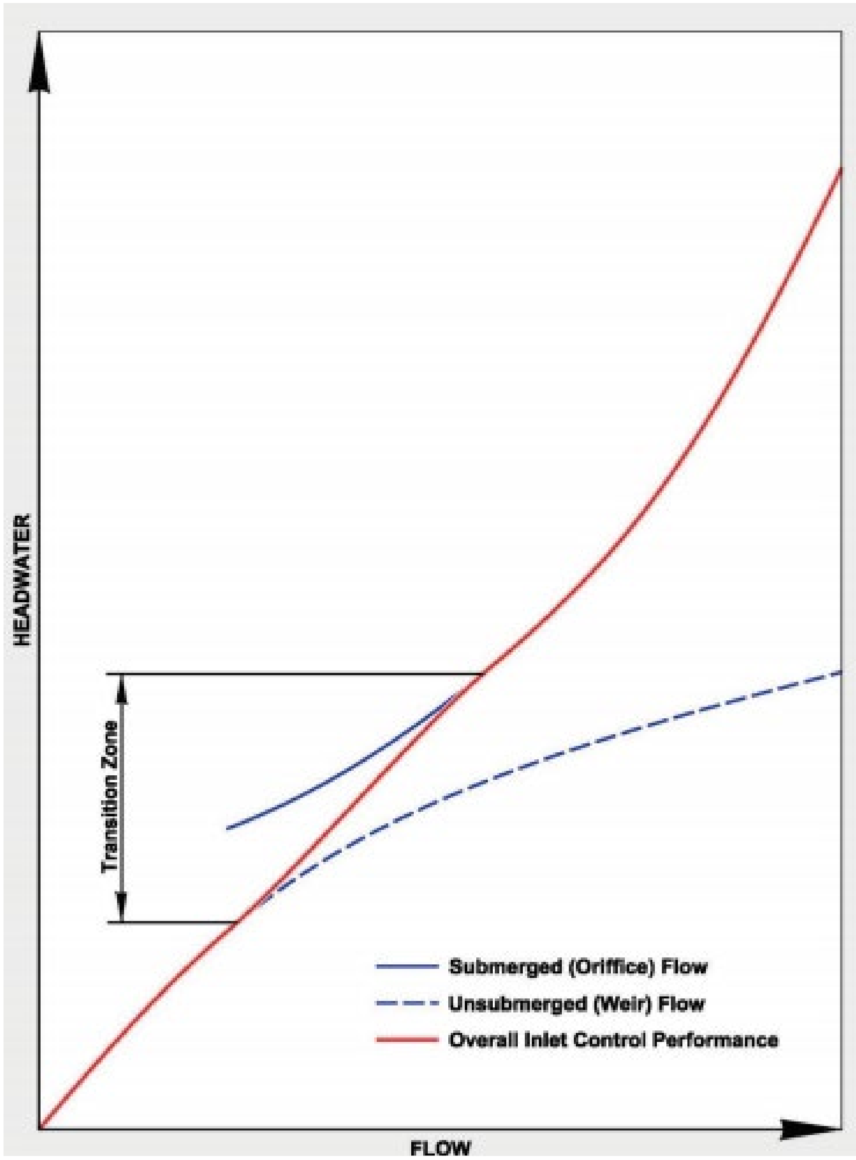
Inlet control performance is defined by the three regions of flow shown in Figure 11.5-2 — unsubmerged, transition, and submerged. For low headwater conditions, as shown in Figure 11.5-1(A) and Figure 11.5-1(C), the entrance of the culvert operates as a weir. A weir is an unsubmerged flow control section where the upstream water surface elevation can be predicted for a given flow rate. The relationship between flow and water surface elevation must be determined by model tests of the weir geometry or by measuring prototype discharges. These tests or measurements are then used to develop equations for unsubmerged inlet control flow. HDS 5, Appendix A (1) contains the equations that were developed from the National Bureau of Standards (NBS) and other model test data.

For headwaters submerging the culvert entrance, as shown in Figure 11.5-1(B) and Figure 11.5-1(D), the entrance of the culvert operates as an orifice. An orifice is an opening, submerged on the upstream side and flowing freely on the downstream side, which functions as a control section. The relationship between flow and headwater can be defined based on results from model tests (see HDS 5 (1)).

The flow transition zone between the low headwater (weir control) and the high headwater (orifice control) flow conditions is poorly defined. This zone is approximated by plotting the unsubmerged and submerged flow equations and connecting them with a line tangent to both curves, as shown in Figure 11.5-2.

The inlet control flow versus headwater curves, which are established using the above procedure, are the basis for constructing the inlet control design nomographs in HDS-5 and for developing equations used in software. The original equations for computer software were generally 5th order polynomial, curve-fitted equations that were developed to be as accurate as the nomograph solution (plus or minus 10%) within the headwater range of 0.5D to 3.0D. These equations are used in HY-8 but have been supplemented with a weir equation from 0.0D to 0.5D and an orifice equation above 3.0D.

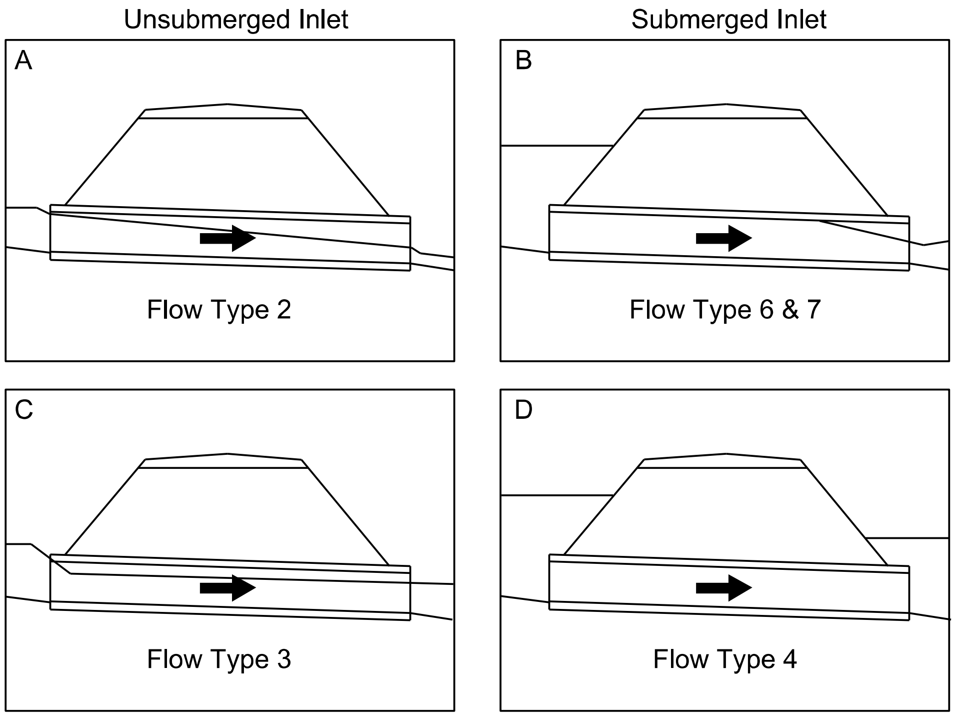
Figure 11.5-2 — INLET CONTROL CURVES



11.5.3.2 Outlet Control

Figure 11.5-3 illustrates the types of outlet control flow. The outlet control flow type depends on the submergence of the inlet and outlet ends of the culvert. In all cases, the control section is at the outlet end of the culvert or further downstream. For the partly full flow situations, the flow in the barrel is subcritical.

Figure 11.5-3 — TYPES OF OUTLET CONTROL



Source: HDS 5 (1)

11.5.3.2.1 Factors Influencing Outlet Control

Because the control is at the downstream end, the headwater is influenced by all of the culvert factors. The factors influencing the performance of a culvert in inlet control also influence culverts in outlet control (see Section 11.5.3.1). In addition, the barrel characteristics and the tailwater elevation affect culvert performance in outlet control as described below:

1. Barrel Roughness. Barrel roughness is a function of the material used to fabricate the barrel. Typical materials include concrete, corrugated metal, and plastic. The roughness is represented by a hydraulic resistance coefficient (e.g., Manning's n value). Typical Manning's n values used for designing culverts are shown in Figure 11.10-1.

2. Barrel Area. Barrel area is a function of the culvert dimensions. A larger barrel area will convey more flow.

3. Barrel Shape. Barrel shape is a function of culvert type and material. Based on the location of the center of gravity for a given area, a box is the most efficient shape, then the arch shape, followed by the circular shape.

4. Barrel Length. Barrel length is the total culvert length from the entrance to the exit of the culvert. Because the design height of the barrel and the slope influence the actual length, an approximation of barrel length is usually necessary to begin the design process.

5. Barrel Slope. Barrel slope is the actual slope of the culvert barrel. The barrel slope is often the same as the natural stream slope. However, when the culvert inlet is raised or lowered, the barrel

slope is different from the stream slope. The slope is not a factor in calculating the barrel losses for Flow Types 4, 6, and 7, but is a factor in calculating Flow Types 2 and 3 when a water surface profile is calculated.

6. Tailwater Elevation. Tailwater elevation is based on the downstream water surface elevation. Backwater calculations from a downstream control, a normal depth approximation, or field observations are used to define the tailwater elevation.

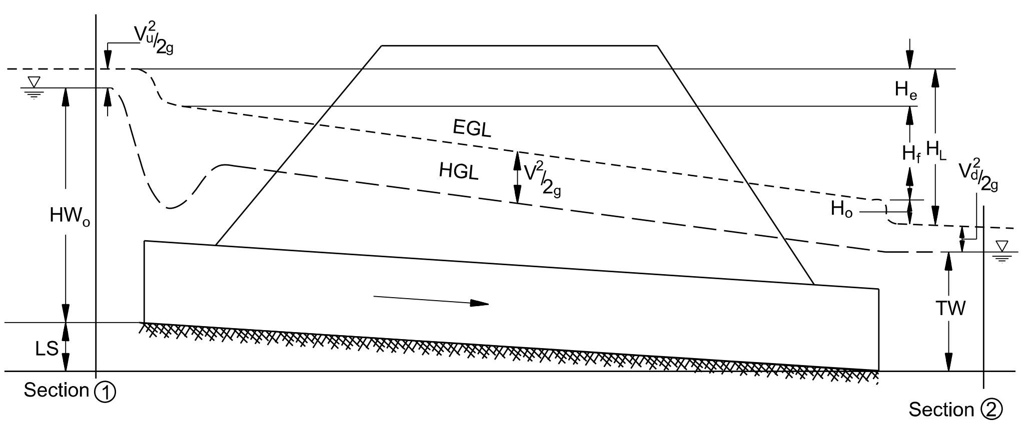
11.5.3.2.2 Outlet Control Hydraulics (Full Barrel Flow)

Full flow in the culvert barrel, as depicted in Figure 11.5-3(D), is the best flow type for describing the hand computation of outlet control hydraulics. Outlet control flow conditions can be calculated based on an energy balance from the tailwater pool to the headwater pool. The losses are discussed in Chapter 3 of HDS 5.

11.5.3.2.3 Energy Grade Line and Hydraulic Grade Line

Figure 11.5-4 depicts the energy grade line (EGL) and the hydraulic grade line (HGL) for full flow in a culvert barrel. The energy grade line represents the total energy at any point along the culvert barrel. The headwater depth, HW_o is the depth from the inlet invert to the energy grade line; however, most culvert designs assume that a still pool is upstream of the culvert and that the velocity head is negligible. The hydraulic grade line is the depth to which water would rise in vertical tubes connected to the sides of the culvert barrel. In full flow, the energy grade line and the hydraulic grade line are parallel straight lines separated by the velocity head, except in the vicinity of the inlet where the flow passes through a contraction. The headwater and tailwater conditions and the entrance, friction, and exit losses are also shown in Figure 11.5-4.

Figure 11.5-4 — FULL FLOW ENERGY AND HYDRAULIC GRADE LINES



Source: HDS 5 (1)

Note: The total available upstream headwater (HW_o) includes the depth of the upstream water above the inlet invert and the approach velocity head. In most instances, the approach velocity is low and the approach velocity head is neglected. However, it can be considered to be a part of the available headwater and used to convey the flow through the culvert.

Equation 11.5-1 shows the energy equation applied between Sections 1 and 2 below:

$$HW_o + LS + \frac{V_u^2}{2g} = TW + \frac{V_d^2}{2g} + H_L \qquad \text{Equation 11.5-1}$$

Where:

HW_o	=	headwater depth above the inlet invert, ft
V_u	=	approach velocity, ft/s
TW	=	tailwater depth above the outlet invert, ft
V_d	=	downstream velocity, ft/s
H_L	=	sum of all losses, ft
LS	=	drop through the culvert, ft

Likewise, the velocity downstream of the culvert (V_d) is usually neglected. When both approach and downstream velocities are neglected, Equation 11.5-1 becomes:

$$HW_o = TW + H_L - LS \qquad \text{Equation 11.5-2}$$

11.5.4 Outlet Velocity

Because a culvert often constricts the available channel area, flow velocities in the culvert may be higher than in the channel. These increased velocities can cause streambed scour and bank erosion in the vicinity of the culvert outlet. Minor problems can occasionally be avoided by increasing the barrel roughness. When a culvert is operating under inlet control and the culvert barrel is not operating at capacity, it is often beneficial to flatten the barrel slope or add a roughened section to reduce outlet velocities (see broken-back culverts, Section 11.9.5). Energy dissipaters and outlet protection devices are sometimes required to avoid excessive scour at the culvert outlet. See Section 11.3.1.5 for outlet velocity criteria.

11.5.5 Overtopping

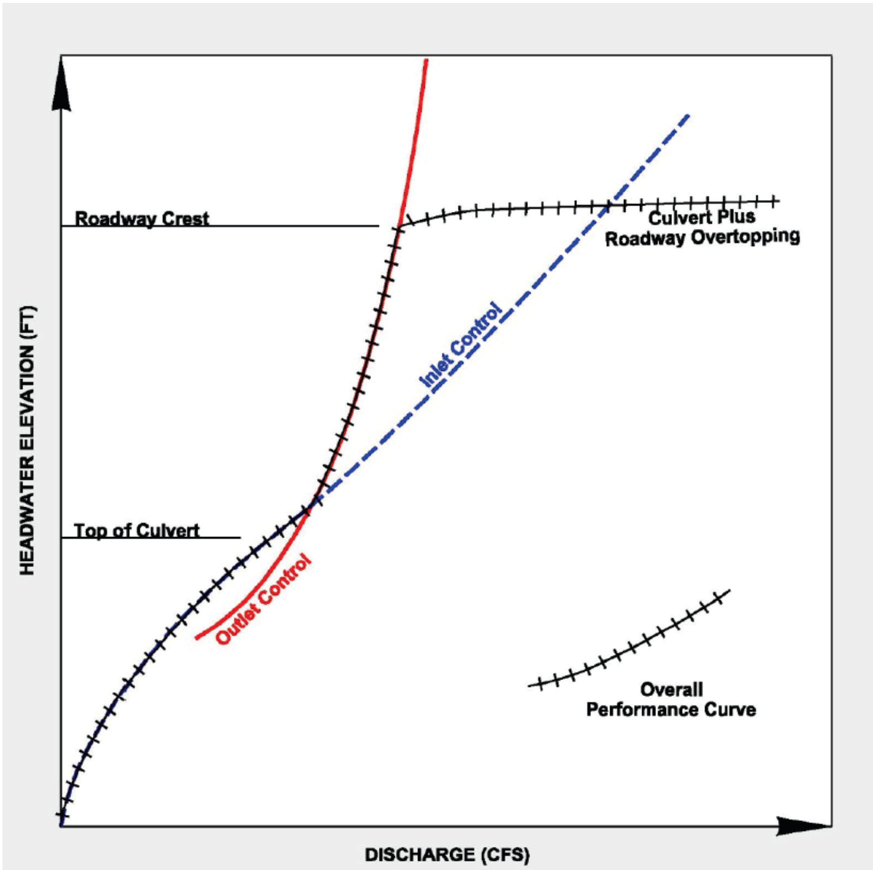
Overtopping can occur at either the roadway, an approach road, or a basin divide, whichever is lowest. The hydraulic engineer will determine the overtopping location and will calculate the overtopping flow accordingly.

Roadway overtopping will begin when the headwater rises to the high point elevation of the roadway (center of the road for a standard crown or the high side for a superelevated road). The overtopping elevation will be used in HY-8 to calculate the start of weir flow over the road. The overtopping will usually occur at the low point of a sag vertical curve on the roadway and might not be located directly above the culvert. The flow will be similar to flow over a broad-crested weir. Flow coefficients for flow overtopping roadway embankments are found in HDS 5.

11.5.6 Performance Curves

Performance curves are plots of flow rate versus headwater depth or elevation, velocity, or outlet scour. The culvert performance curve consists of the controlling portions of the individual performance curves for the control sections in Figure 11.5-5.

Figure 11.5-5 — OVERALL PERFORMANCE CURVE



11.6 PIPE MATERIAL SELECTION & STRUCTURAL REQUIREMENTS

As part of the material selection discussed in Section 11.4.5, complete the following steps when determining allowable pipe materials, coating, and pipe wall properties:

1. Determine the abrasion level for the site.
2. Using the soil and water sample results, determine which pipe materials are appropriate for the project based on the allowable environmental limits (pH and resistivity) for each pipe material. Consultants: Follow testing procedures in the MDT *Materials Manual*.
3. Calculate the appropriate pipe gage/class/coating for the soil conditions.
4. Increase the pipe gage/class for structural requirements/fill height as necessary.

11.6.1 Abrasion

The FHWA abrasion levels from NCHRP 474 (7) (see Figure 11.6-1) are intended as guidance for the hydraulic engineer to consider the impacts of bedload wear on the invert of pipe materials. Sampling of the streambed materials is not required, but visual examination and documentation of the size of the materials in the streambed and average slope of the channel will give the hydraulic engineer guidance on the expected level of abrasion. Where existing culverts are in place in the same drainage, the conditions of inverts could also be used as guidance. Estimate abrasion potential based on the pipe velocity during the 2-year flood.

Figure 11.6-1 — FHWA ABRASION LEVELS

Level 1	Non-Abrasion	No bed load regardless of velocity or storm sewer applications.
Level 2	Low Abrasion	Minor bed loads of sand and gravel and velocities of 5 ft/s or less.
Level 3	Moderate Abrasion	Bed loads of sand and small stone or gravel with velocities between 5 ft/s and 15 ft/s.
Level 4	Severe Abrasion	Heavy bed loads of gravel and rock with velocities exceeding 15 ft/s.

Note: Velocities are based on a 2-year event.

An estimate of the potential for abrasion is required at each pipe location to determine the need for invert protection. Where velocity is less than 5 ft/s (Level 2 or less), the abrasion potential is low, and no special considerations are warranted. Where the velocity is greater than 5 ft/s (Level 3 or greater) and there is a coarse gravel bed material, there is some potential for abrasion.

Do not use polymeric coated pipe if the abrasion level exceeds Level 2. For other pipe materials, if the abrasion level listed below in the environmental limitation figures (Figures 11.6-3 through 11.6-5 and 11.6-7) is exceeded or if the existing pipe shows signs of abrasion:

- Provide concrete invert paving (through abrasion Level 3), or
- Embed the culvert and provide appropriately sized riprap invert protection through the culvert (through abrasion Level 4). On the plans, cross-sections, and/or details, clearly label both the culvert invert and embedment flow lines at each end of the culvert.

11.6.2 Service Life

11.6.2.1 General

Soil and water samples are taken at representative culvert locations in a project. These samples are sent to a lab to analyze pH, marble pH, conductivity, resistivity, and percent sulfates. When MDT completes these analyses, the lab provides Hydraulics with a spreadsheet of the results. These values are used by the hydraulic engineer to calculate the service life and to determine the allowable pipe materials and pipe properties for the project using the methods below.

See Section 11.3.2 for service life criteria.

11.6.2.2 Metal Culverts

11.6.2.2.1 Corrugated Metal Pipe (CMP/CMPA) Approach Pipe and Mainline

MDT uses the modified AISI chart for estimating the average service life in years of corrugated steel pipe and corrugated aluminum pipe.

Where the pH of the environment is greater than or equal to 7.3, use the following equation:

$$\text{Years} = 2.94\,R^{0.41} \qquad \text{Equation 11.6-1}$$

Where:

R = resistivity (ohm-cm)

Where the pH of the environment is less than 7.3, use the following equation:

$$\text{Years} = 27.58\,[\text{Log}_{10}R - \text{Log}_{10}(2160 - 2490*\text{Log}_{10}pH)] \qquad \text{Equation 11.6-2}$$

Where:

R = resistivity (ohm-cm)
pH = soil pH or water pH

The formulas above calculate the service life for a 16-gage pipe. Thicker gage pipe may be used to increase the service life. To determine the service life for thicker gages of pipe, multiply the calculated service life (years) by the appropriate factor from Figure 11.6-2.

Figure 11.6-2 — CMP/CMPA PIPE LIFE MULTIPLIERS

Thickness (in.)	0.064	0.079	0.109	0.138	0.168
Gage	**16**	**14**	**12**	**10**	**8**
Galvanized[1]	1.0	1.3	1.6	2.2	2.8
Type 2 Aluminized[2]	1.5	1.8	2.1	2.7	3.3
Aluminum[3]	2.6	2.9	3.2	3.8	4.4

[1] *Galvanized factors are from the AISI method but are shifted so that 16 is the minimum gage and has the factor of 1.*

[2] *MDT assumes a 50% increase in the service life for Type 2 aluminized coating over the calculated galvanized service life. (Type 2 Aluminized Multiplier = Galvanized multiplier + 0.5)*

[3] *MDT assumes a 160% increase in the service life for aluminum pipe over the calculated galvanized service life. (Aluminum Multiplier = Galvanized multiplier + 1.6)*

The corrugated metal culvert environmental limitations are shown in Figure 11.6-3.

Figure 11.6-3 — CORRUGATED METAL CULVERT (ENVIRONMENTAL LIMITATIONS)

Material Type	Maximum FHWA Abrasion[1]	Appropriate pH Range[2] (Check with Calculator)[3]									Resistivity (ohm-cm)	
		3	4	5	6	7	8	8.5	9	10	Minimum[3]	Maximum
Galvanized Steel[4]	Level 2				■	■	■	■			Use Calculator	10,000
Type 2 Aluminized Steel	Level 2			■	■	■	■	■			Use Calculator	N/A
Polymeric Coated	Level 2		■	■	■	■	■	■	■		Use Calculator	N/A
Aluminum Alloy	Level 2		■	■	■	■	■	■	■		Use Calculator	N/A

1. *Maximum FHWA Level without providing invert protection.*
2. *i.e., Appropriate pH range for Galvanized Steel is 6.0 to 8.5.*
3. *Use the pipe life calculator to determine if the site-specific pH and Resistivity meet the service life requirements.*
4. *If the marble pH is higher than the pH by 0.2 or more, galvanized pipe must have either Type 2 aluminized or polymeric coating.*

11.6.2.2.2 Pipe Coating Options

Polymeric and aluminized pipe coatings are available to extend the service life of galvanized steel culverts for certain environmental conditions. Use Figure 11.6-3 to determine the environmental conditions allowed for the coating.

To determine the service life for Type 2 aluminized steel, use the service life calculator for galvanized pipe and then use the appropriate multiplier from Figure 11.6-2.

To determine the service life for polymeric coated steel pipe, use the service life calculator for galvanized pipe and then add an additional 10 years to the service life. For example, if a 75-year service life is required, the pipe calculator would need to calculate at least a 65-year life, and then 10 years would add on to reach the 75-year service life.

Coating options are not available for all steel pipe thicknesses. The limitations are as follows:

- Polymeric coating is available on pipe thicknesses from 0.064 in. to 0.109 in. (16 gage to 12 gage) for corrugated steel pipe up to 108 in. diameter or equivalent.
- Type 2 aluminized steel is available on pipe thicknesses from 0.064 in. to 0.109 in (16 gage to 12 gage) for corrugated steel pipe up to 108 in. diameter or equivalent.

11.6.2.2.3 Thickness Limitations

Steel and aluminum pipes are not available in all sizes and thicknesses. See the fill height tables in Appendix 11A for allowable gage and corrugation combinations. In general, use the thinnest gage allowable when all site requirements are considered (abrasion, corrosion, and fill height).

11.6.2.3 Concrete Pipe

If the RCP meets the environmental factors in Figure 11.6-4 and uses the necessary wall thicknesses mentioned below, MDT assumes RCP has a minimum service life of 100 years.

Figure 11.6-4 — CONCRETE PIPE (ENVIRONMENTAL LIMITATIONS)

Material Type	Maximum FHWA Abrasion[1]	Allowable pH Range[2]									Resistivity (ohm-cm)	
		3	4	5	6	7	8	8.5	9	10	Minimum	Maximum
Concrete[3]	Level 3										300	N/A

[1] Maximum FHWA Level without providing invert protection.

[2] Class B wall RCP is recommended when the soil or water pH is equal to or higher than 6. Use Class C wall RCP when soil or water pH is less than 6.

[3] If sulfate content is over 2.00%, use an alternate pipe material or contact precast concrete pipe manufacturer for concrete mix design and testing requirements.

11.6.2.4 Thermoplastic Pipe

If the thermoplastic pipe meets the environmental factors in Figure 11.6-5, MDT assumes thermoplastic pipe has a minimum service life of 100 years. Thermoplastic pipe refers to the plastic pipe materials listed in Figure 11.4-1.

Figure 11.6-5 — THERMOPLASTIC PIPE (ENVIRONMENTAL LIMITATIONS)

Material Type	Maximum FHWA Abrasion[1]	Allowable pH Range[2]									Resistivity (ohm-cm)	
		3	4	5	6	7	8	8.5	9	10	Minimum	Maximum
Thermoplastic	Level 2										N/A	N/A

[1] Maximum FHWA Level without providing invert protection.

[2] i.e., Appropriate pH range for Thermoplastic Pipe is 3.0 to 10.0.

11.6.2.5 Structural Plate Pipe

Based on guidance from the steel industry, MDT uses the California Method for estimating the average service life in years of structural plate pipe.

Where the pH of the environment is greater than or equal to 7.3, use the following equation:

$$\text{Years} = 1.47\,R^{0.41} \qquad \text{Equation 11.6-3}$$

Where:

R = resistivity (ohm-cm)

Where the pH of the environment is less than 7.3, use the following equation:

$$\text{Years} = 13.79[\text{Log}_{10}R - \text{Log}_{10}(2160 - 2490 * \text{Log}_{10}\text{pH})] \qquad \text{Equation 11.6-4}$$

Where:

R = resistivity (ohm-cm)
pH = soil pH or water pH

The formulas above calculate the service life for a 16-gage pipe, which is not an available gage of structural plate pipe but is used in the base calculation. To determine the service life for gages of SSPP, multiply the calculated service life (years) by the appropriate factor from Figure 11.6-6.

Figure 11.6-6 — SSPP/SSPPA PIPE LIFE MULTIPLIERS

Thickness (in.)	**0.109**	**0.138**	**0.168**	**0.188**	**0.218**	**0.249**	**0.280**	**0.318**	**0.380**
Gage	**12**	**10**	**8**	**7**	**5**	**3**	**1**	**5/16″**	**3/8″**
Structural Plate	2.2	2.8	3.4	3.7	4.3	4.9	5.5	6.2	7.4

Note: Multipliers are for the California Method and were extrapolated for 5/16 in. and ⅜ in. gages.

The structural plate pipe culvert environmental limitations are shown in Figure 11.6-7.

Figure 11.6-7 — STRUCTURAL PLATE PIPE CULVERT (ENVIRONMENTAL LIMITATIONS)

Material Type	**Maximum FHWA Abrasion[1]**	**Allowable pH Range (Check with Calculator[3])**									**Resistivity (ohm-cm)**	
		3	**4**	**5**	**6**	**7**	**8**	**8.5**	**9**	**10**	**Minimum[3]**	**Maximum**
Galvanized Steel SSPP & SSPPA	Level 2										Use Calculator	10,000[2]

1. *Maximum FHWA Level without providing invert protection.*
2. *Use the pipe life calculator to determine if the site-specific pH and Resistivity meet the service life requirements.*

3. *If the soil resistivity and pH exceed the environmental limits, structural plate culvert may still be an option with the use of non-corrosive backfill as described in Section 11.6.2.5.1. However, if the water resistivity exceeds 10,000 ohm-cm and/or the water pH is outside the allowable range in the Figure above, do not use steel at the site.*

11.6.2.5.1 Non-Corrosive Special Backfill

Structural Steel Plate Pipe Culverts
Non-corrosive special backfill is required around all structural steel plate pipe culverts and arches. Geotech and Hydraulics will work together to define the non-corrosive properties and special back fill requirements for a special provision that would correspond to the selected pipe gage.

If the soil resistivity and pH exceed the environmental limits shown in Figure 11.6-7, non-corrosive backfill may be used as a buffer to the natural soils with the approval of the state hydraulic engineer and the following conditions:

- The minimum structural plate gage is 7.
- Increase the structural plate pipe culvert gage as necessary to meet the service life requirements for the water sample results.
- If the water resistivity or the water pH is outside the allowable range in Figure 11.6-7, do not use steel at the site even with non-corrosive special backfill.
- Extend the non-corrosive special backfill limits to the surface to avoid placing corrosive soils above the special backfill where it can infiltrate down to the culvert.

MDT Standard Drawings show the minimum special backfill extents for structural steel plate pipes.

Reinforced Concrete Box Culverts
If the soil resistivity and pH exceed the environmental limits shown in Figure 11.6-4, non-corrosive backfill may be used as a buffer to the natural soils with the approval of the state hydraulic engineer and the following conditions:

- If the water resistivity, pH, or sulfates are outside the allowable ranges in Figure 11.6-4, contact precast concrete pipe manufacturer to determine if the precast design can be modified to allow concrete at this site.
- Extend the non-corrosive special backfill limits to the surface to avoid placing corrosive soils above the special backfill where it can infiltrate down to the culvert.

MDT Standard Drawings show the minimum special backfill extents for reinforced concrete box culverts.

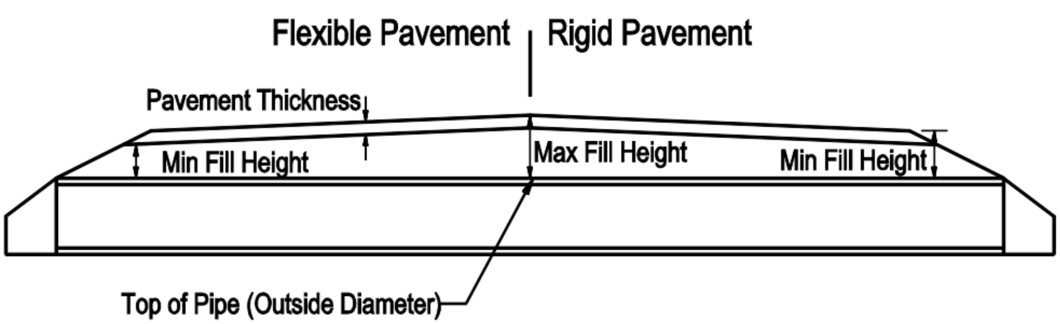
11.6.3 Structural Requirements

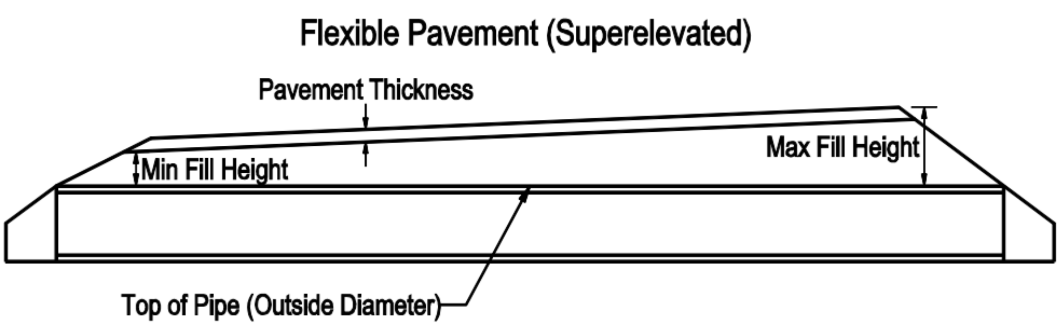
The following sections discuss the characteristics of each culvert material and indicate the appropriate figure to use in Appendix 11A.

11.6.3.1 Measurement of Fill Height

Structural requirements for pipes are based primarily upon live-load and earth-load conditions. Maximum fill heights are set to protect the pipe structure from the earth load, and minimum fill heights are set to protect the pipe structure from live loads. Figure 11.6-8 illustrates the measurement of maximum and minimum fill heights for both flexible (asphalt) and rigid pavement (concrete) sections. Maximum fill height is measured from the top of the pipe to the point of maximum cover, including the total surfacing thickness. Minimum fill height is measured from the top of the pipe to the top of the rigid pavement or to the bottom of the flexible (plant mix) pavement. The controlling fill height (minimum or maximum) for pipe material-type/gage/class selection is listed in the culvert summary frame. Where the minimum fill height cannot be provided using the basic bid pipe, consider specifying reinforced concrete pipe, equivalent sized arch pipe, or multiple smaller pipes Appendix 11A presents the maximum and minimum allowable fill heights for pipe culverts.

Figure 11.6-8 — MEASUREMENT OF MAXIMUM AND MINIMUM FILL HEIGHTS





11.6.3.2 Reinforced Concrete Pipe (RCP)

Reinforced concrete pipes (RCP) are identified by "class" numbers, depending on their respective strength characteristics. Four classes are available — Classes 2, 3, 4, and 5; the higher the number, the stronger the pipe. Figure 11.A-1 provides maximum fill heights for RCP embankment installations. Figure 11.A-2 provides maximum fill heights for RCP trench installation. Figure 11.A-3 provides RCP minimum fill heights, which apply to either installation condition.

The MDT standard pipe wall thickness is B-wall pipe, which is the diameter in feet converted to inches plus 1 in. For example, a 48-in. pipe is 4 ft in diameter and will have a pipe wall thickness of 4 in. + 1 in. = 5 in. C-wall pipe is used in low pH conditions to add additional concrete thickness over the rebar. To determine the C-wall pipe thickness, add 1.75 in. to the diameter in feet converted to inches.

For reinforced concrete pipe arches (RCPA), use the fill height requirements for the equivalent diameter RCP. Figure 11.A-4 provides the equivalent RCP diameters for RCPA. RCPA is only available in Classes 3 and 4.

To avoid damage during construction, do not allow the top of the pipe to extend into the base course. Although not desirable, pipes may extend into the subbase/subgrade if necessary.

11.6.3.3 Corrugated Steel Pipe (CSP) and Corrugated Steel Pipe Arches (CSPA)

Metal thickness and soil support are the principal measures of strength in corrugated steel pipe (CSP) and corrugated steel pipe arches (CSPA). The required metal thickness depends on the following factors:

- Height of fill over pipe,
- Size of pipe,
- Dimensions of corrugations,
- Shape of pipe,
- Soil compaction,
- Corner bearing pressure, and
- Soil corrosiveness.

Figures 11.A-5 through 11.A-7 illustrate some of the relationships among these factors. The exhibits show the minimum and the maximum permissible fill heights for each combination of pipe size and metal thickness. Per the culvert fill height tables, placed pipes a minimum of 0.3 ft to 1.0 ft below the surfacing subgrade. Although not desirable, pipes may extend into the subbase/subgrade if necessary due to constraints. See the fill height exhibits for additional information.

Normally, for steel pipe installations up to 120 in. in diameter, CSP will be specified for installation. The fill heights for these pipes must fall within the limits of the fill height exhibits.

The following corrugation sizes will be specified for corrugated steel pipe:

- 2⅔ in. × ½ in.
- 3 in. × 1 in.
- 5 in. × 1 in.

Note that Manning's n values change between corrugation sizes. See Figure 11.10-1.

Most culvert installations will be round pipe. Pipe arches are specified where cover is limited or where local conditions make the shape of the pipe arch more effective for carrying the water. Figures 11.A-8 and 11.A-9 present structural requirements for corrugated steel pipe arch (CSPA) culverts.

11.6.3.4 Structural Steel Plate Pipes (SSPP) and Structural Steel Plate Pipe Arches (SSPPA)

Normally, for culvert installations larger than 120 in., structural steel plate pipe (SSPP) culverts will be specified. Figure 11.A-10 provides SSPP criteria for minimum and maximum fill heights permitted with various combinations of pipe size and metal thickness. Structural steel plate pipe arch (SSPPA) culverts are used occasionally for new installations or pipe extensions. The hydraulic engineer will specify adequate metal thickness for each installation of SSPP or SSPPA. The dimensions of SSPP and SSPPA will be called out in feet and inches. Figures 11.A-11 and 11.A-12 present the structural requirements for structural steel plate pipe arch (SSPPA) culverts.

11.6.3.5 Corrugated Aluminum Pipe (CAP)

When corrugated aluminum pipe (CAP) is specified or permitted as an option based on soil/water conditions, determine the metal thickness requirements from Figures 11.A-13 or 11.A-14 for the specific conditions of pipe diameter and height of fill.

11.6.3.6 Steel Casing Pipe (SCP)

Steel casing pipe (SCP) is typically installed by jacking and boring methods. To accommodate jacking pressures and fill heights, thicker pipe walls will be necessary as the pipe diameter increases. Jack-and-bore installations are most commonly used on projects with high existing fills and/or to avoid impacting the roadway cross section. Figure 11.A-15 provides minimum pipe thicknesses for SCP based upon the pipe diameter. The contractor will need to determine if this minimum thickness is structurally sufficient for the proposed jacking and/or boring loads and increase pipe thickness if necessary.

11.6.3.7 Plastic Pipes

High-density polyethylene (HDPE) pipe is limited for use underneath private approaches. Solid-wall or profile-wall polyvinyl chloride (PVC) pipe may be specified for irrigation if the pipe is not exposed to sunlight and ditch burning is not used in the area. Solid-wall or profile-wall polyvinyl chloride (PVC) pipe may be specified for storm drain applications provided the structural requirements are met. Figure 11.A-16 presents structural requirements for plastic pipes.

11.6.3.8 Road Approach Pipes

Pipes located underneath public road approaches must be at least 24 in. in diameter and meet the structural requirements of the pipe material specified. Pipes located underneath private approaches and farm field approaches must be at least 18 in. in diameter and meet the structural requirements in Figure 11.A-17. See Section 11.2.8 of the MDT *Road Design Manual* for safety end treatments.

11.7 DESIGN PROCEDURE

The following design procedure provides the general guidelines, steps, and documentation necessary for drainage culvert design. This procedure is not all inclusive; it is up to the hydraulic engineer to ensure the accuracy and completeness of the design. For each roadway drainage crossing requiring design, the hydraulic engineer will perform a hydrologic and hydraulic analysis on a site-by-site basis. Irrigation culvert/system replacements demand a higher level of accuracy in the survey and design and are covered in Chapter 12, "Irrigation Facilities." Additionally, the procedure does not address the effect of storage, which is discussed in Section 11.9.2 and Chapter 15, "Storage Facilities." Other related designs are discussed further in Section 11.9.

Design each culvert to match the unique conditions of the site. Be familiar with the culvert design equations in HDS 5 before using these procedures. Following the design method without an understanding of culvert hydraulics can result in an inadequate, unsafe, or costly structure.

Deviations from MDT manuals, procedures and/or guidelines need to be documented and rationalized.

Step 1: Assemble site data and project file in addition to the material collected for the LHSR (see Chapter 5).

a. The minimum data are:

- LHSR;
- As-built plans;
- Project and hydraulic survey data;
- Culvert Inspection Report;
- Topographic mapping;
- Aerial and ground photographs;
- Proposed roadway alignment, profile, and cross sections; and
- Design data at nearby structures.

b. Studies by other agencies including:

- Floodplains — FEMA, DNRC, NRCS, independent community floodplain studies, USACE;
- Canals — DNRC, USBR, BIA, or private irrigation districts;

- Small dams — DNRC, NRCS, private dam owners, USACE, BLM; and
- Storm drains — local or private.

c. Historical performance of existing culvert:

- Contact MDT Maintenance, county/state/federal officials, local road maintenance, landowners, and/or residents concerning historical flooding problems, culvert sufficiency, roadway overtopping, previous channel alterations, erosion, debris, ice, sediment, etc., to determine if there is a problem with any existing culvert capacity or operations. This information, in addition to flood photos and aerials (if available), may identify problems with the existing culvert and can be utilized to help calibrate the existing culvert model.

d. Environmental constraints including:

- Commitments contained in environmental documents, and
- Aquatic organism and wildlife passage as defined in the Biological Resources Report.

e. Design criteria:

- Review Section 11.3 for applicable criteria, and
- Complete risk evaluation as described in Section 9.3.4 if needed.

Step 2: Determine hydrology.

a. See Chapter 9, "Hydrology."

b. Minimum data are the drainage area map, a flood frequency discharge table, and the design flood frequency.

c. Hydrology may have been developed during the Preliminary Hydraulic Evaluation (Activity 356).

Step 3: Determine downstream channel condition.

a. Use survey data to determine channel geometry and slope.
b. Use aerials, site photos, or site visit to determine appropriate Manning's n.
c. Develop a rating curve for the channel.

Step 4: Determine existing condition overtopping elevation and location.

a. Overtopping can occur at either the roadway, an approach, or a basin divide, whichever is lower.

Step 5: Determine the existing culvert capacity and historical adequacy.

a. Use survey data and as-builts for culvert and roadway information.

b. Select appropriate entrance loss from Figure 11.10-2 and Manning's n from Figure 11.10-1.

c. Calculate the headwater and overtopping flows of existing culverts using the selected hydrology. Hydrology may have been completed in the Preliminary Hydraulic Evaluation (Activity 356).

Step 6: Determine allowable pipe materials to use for analysis.

a. Determine the abrasion level for the site.

b. Compute the culvert service life based on obtained water and soil samples; see Sections 11.3.2 and 11.6.2.

c. Determine a culvert material strategy for the entire project based on:

- The service life analysis results, and
- The material selection guidance in Section 11.4.

d. Use the selected materials for the following hydraulic analysis.

Step 7: Determine proposed overtopping elevation and location (if different than existing).

a. Overtopping can occur at either the roadway, an approach, or a basin divide, whichever is lower.

b. A ditch block in new construction may be used to improve the performance of the proposed culvert by increasing the basin divide overtopping elevation.

c. Where possible, design the ditch block to be below the base course but above the culvert crown.

Step 8: Determine proposed culvert skew, slope, and length per Section 11.4.6.

a. Determine the culvert skew. See Section 11.4.6.1.

b. Determine culvert slope. See Section 11.4.6.2.

- Use the available survey to create a profile of the channel thalweg, roadway, and existing and proposed culverts to determine the overall channel slope.

- Set the proposed culvert to match the overall channel slope unless site conditions prevent matching, which may include heavy sediment conditions, head cuts, or right of way restrictions, or if excessive ditch work is required outside of the right of way.

c. Determine proposed culvert invert elevations.

- Generally, culverts 48 in. (equivalent) and smaller are not embedded.
- Embed culverts 54 in. and larger approximately 10% of the diameter. See Section 11.4.6.3.
- AOP culverts require additional embedment. See Section 11.9.4.
- On the plans, cross-sections, and/or details, clearly label both the culvert invert and embedment flow lines at each end of the culvert.

d. Determine initial culvert length. See Section 11.4.6.4.

- For hydraulic design, set the length where the stream intersects the roadway embankment toes.
- Length will be adjusted after a size is selected to ensure that top of culvert and edge protection, if present, are located outside of the clear zone.

Step 9: Calculate proposed culvert headwater and determine culvert size.

a. Using HY-8 or HEC-RAS, determine the headwater elevations for the design flow and the 100-year flow and the magnitude of the overtopping flow.

b. Compare headwater to the allowable headwater criteria in Figure 11.3-1. Size the culvert so that roadway overtopping does not occur at flows less than or equal to the design flow.

c. Compare proposed headwater to the existing culvert headwater for the same flow. If the headwater increases over the existing, evaluate whether the proposed headwater is allowable based on the site risk.

d. For fill heights greater than 15 ft, upsize the pipe. See Section 11.4.7.5.

e. Complete computations for each allowable pipe material.

Step 10: Check that the proposed alternative(s) meets the design criteria including:

a. Does the culvert meet the headwater criteria?

b. Does the culvert material meet the cover requirements in Appendix 11A?

c. Check exit velocity at the 10-year event.

- If exit velocity is less than 10 ft/s and the site does not have a history of scour, no protection is needed.
- If exit velocity is greater than 10 ft/s or the site has a history of scour, provide outlet protection.

d. Check the 2-year velocity to determine if the abrasion assumption in Step 6a is still appropriate for the selected pipe materials.

e. Do the modeled end sections fit the site?

Step 11: Determine the required gage and corrugation or class of the allowable pipe materials.

a. Select the appropriate pipe gage/class/coating for the soil conditions.

b. Increase the pipe gage and corrugation or class for structural requirements/fill height as necessary. (Note that Manning's n values change between corrugation sizes. See Figure 11.10-1.)

Step 12: Document all assumptions and results from the steps above.

a. See Section 11.8.

11.8 DOCUMENTATION

11.8.1 Drainage and Culvert Recommendation Memo and Report

Use the template provided in Appendix 11D to document design assumptions and decisions.

11.8.2 Hydraulic Data Summary Sheet

11.8.2.1 General

The *Federal Aid Policy Guide* (FAPG) 23 CFR 650A has established requirements for design and for presenting hydraulic data on the plans for federal-aid highway projects. For MDT projects, this will be accomplished with a separate plan sheet, HYDRAULIC DATA SUMMARY SHEET, which will contain the required data for all appropriate bridges and culverts. This sheet has been developed to provide a uniform system for showing the data required by Section 650.117 in 23 CFR 650A for encroachment locations.

The hydraulic data summary sheet is used to summarize the hydraulic data for drainage culverts and approach culverts greater than or equal to 30 in. in diameter and bridges over waterways. When optional culverts are used, the base bid option will be shown on the hydraulic data summary sheet. This sheet is prepared by the Hydraulics Section, and the design team is responsible for incorporating the sheet into the plans. Complete the Hydraulic Data Summary sheet and include the sheet with the Culvert Recommendation Memo. Update the hydraulic data summary sheet as necessary as the project progresses. If the crossing contains both irrigation and drainage water, only include the crossing on the Hydraulic Data Summary sheet. If the crossing just contains irrigation water, document irrigation design data using the Irrigation Data Summary sheet described in Section 12.6.3.

11.8.2.2 Applicability

A. Bridges

- Provide hydraulic data for all new bridge installations over waterways.

B. Culverts

1. Lengthening in-place drainage culverts.

   - Generally, do not need to show data for culvert installations involving lengthening due to roadway slope flattening or minor widening.

   - When lengthening a culvert and modifying the overtopping elevation, show the updated hydraulic data.

2. Lining in-place drainage culverts.

   - Show data for lined culverts when the overtopping event becomes more frequent after lining the culvert.

3. New drainage culverts.

   - Provide hydraulic data for all new culvert installations greater than or equal to 30 in. in diameter.

C. Headwater Exception Procedure

- The hydraulic data shown on the Hydraulic Data Summary Sheet for culverts recommended under the Headwater Exception Method procedure (see Section 11.3.1.3.2) shall include design flow, high water elevations, and overtopping flood information using the selected hydrology for the project. Design floods for this procedure shall be in accordance with Chapter 9, "Hydrology."

11.9 RELATED DESIGNS

11.9.1 Irrigation Facilities

Irrigation facilities are designed using the practices and procedures in Chapter 12 "Irrigation Facilities."

11.9.2 Storage Routing

11.9.2.1 Introduction

Significant storage capacity behind a highway embankment can attenuate a flood hydrograph. Because of the reduction of the peak discharge associated with this attenuation, the required capacity of the culvert and its size can be reduced. This section briefly outlines how to complete hydrologic routing. Detailed information on routing is provided in Chapter 15, "Storage Facilities," HEC 22 (8), and HDS 5 (1).

Although the calculation is not difficult and is readily completed with the FHWA Hydraulic Toolbox or other software, most culvert designs do not consider attenuation upstream of the embankment but, rather, consider it part of the safety factor in the design (see HDS 5 (1)).

11.9.2.2 Design Procedure

Flood routing through a culvert may be accomplished with the FHWA Hydraulic Toolbox or other software (see Chapter 8, "Hydraulics Software"). The design procedure is the same as for reservoir routing:

- Obtain the site data including storage data and roadway geometry (see Chapter 5, "Location Hydraulic Study").
- Include a hydrograph in the hydrologic analysis (see Chapter 9, "Hydrology").
- Estimate a trial culvert size, and route the hydrograph.

Before attempting to design a culvert to take advantage of storage, review the culvert storage routing design process included in HDS 5, Chapter 5 (1). The triangular Hydrograph method in the Chapter 15, "Storage Facilities" can be used to estimate storage results and determine if a storage design is viable.

11.9.2.3 Routing

After the input hydrograph has been determined, it is necessary to determine the stage-storage relationship of the temporary upstream pond. Detailed contour maps / terrain data will be needed to complete this modeling.

The next step is to develop a stage-discharge relationship of the proposed pipe. This is done using one of the approved methods of culvert analysis in this chapter.

The stage-storage and stage-discharge relationships are then input into the routing software, along with the hydrograph. The program then computes the routing, with output consisting of an outflow hydrograph, the volume stored and the maximum stage.

11.9.3 Tapered Inlets

A tapered inlet is a flared culvert inlet with an enlarged face section and a hydraulically efficient throat section. A tapered inlet may have a throat depression incorporated into the inlet structure or located upstream of the inlet. The depression is used to exert more head on the throat section for a given headwater elevation. Therefore, tapered inlets improve culvert performance by providing a more efficient control section (the throat). Tapered inlets are not recommended for use on culverts flowing in outlet control because the simple beveled edge is of equal benefit.

Tapered inlets are used in very specific applications. They can be used for retrofitting steep culverts where increased capacity is necessary. More information on their design is included in HDS 5.

11.9.4 Aquatic Organism Passage

Replicating the natural stream bottom conditions in a culvert is the most desirable design option to accommodate aquatic organisms or to provide for the transport of large bed material. MDT sizes AOP culverts to match upstream and downstream velocities by using oversized embedded culverts to provide a natural bottom.

The process of sizing an embedded culvert is provided in HEC 26 (9). The premise of HEC 26 is:

- To match the velocity through the culvert to the velocities upstream and downstream of the culvert, and
- To include the natural transport of streambed material through the culvert and a larger diameter rock layer at the bottom of the culvert to provide roughness that will retain and recruit natural streambed material.

To address the HEC 26 design, MDT practice is to:

1. Size the culvert to pass the design flood and meet the headwater criteria in Section 11.3.1.3.
2. Upsize the culvert to span the bank full width if necessary.
3. As needed, increase the culvert size to match the velocities through the culvert to the natural stream velocities upstream and downstream of the culvert at the 2-year return event flow.
4. Depress the culvert inverts below the stream bed and provide a layer of Class I riprap and:
    a. A layer of streambed material or infill material on the riprap and to fill the riprap voids, or
    b. No infill to allow riprap to recruit streambed material.
5. Add a low flow channel or opposing rock clusters inside the culvert to maintain the seasonal low-flow channel depths upstream and downstream of the culvert.

Each culvert presents unique properties and will require a site-specific design. Engineering judgment is required to adjust the design to fit the site. Reinforced box culverts and structural steel plate pipe culverts may be used for AOP culverts. Do not use polymeric-coated pipes for AOP culverts, because the coating is damaged during the installation of the interior infill material.

11.9.5 Broken-Back Culverts

An alternative to installing a steeply sloped culvert is to break the slope into a steeper portion near the inlet followed by a flatter horizontal runout section. This configuration is referred to as a broken-back culvert. When used appropriately, a broken-back culvert configuration can influence and contain a hydraulic jump. However, there must be sufficient tailwater, friction, and length in the culvert to create a hydraulic jump inside the culvert. See HDS 5 for more information and a design procedure.

11.10 DESIGN AIDS

This section includes the following culvert design aides:

1. Manning's n Values. Manning's n values that have been determined in the laboratory are provided in Figure 11.10-1 with the recommended design n value. Culvert materials are either treated as smooth or as corrugated. In this way, alternative materials can be substituted for a given structure.

Figure 11.10-1 — MANNING'S n VALUES FOR CULVERTS

Type of Conduit	Wall Description	Manning's n Laboratory(1)	Design Value(2)
Concrete Pipe	Smooth	0.010-0.011	0.013
Concrete Boxes	Smooth	0.012-0.015	0.013
Corrugated Metal Pipe, Pipe-Arch and Box	2⅔ in. × ½ in. Annular	0.022-0.027	0.024
	2⅔ in. × ½ in. Helical	0.011-0.023	0.024
	6 in. × 1 in. Helical	0.022-0.025	0.024
	5 in. × 1 in.	0.025-0.026	0.027
	3 in. × 1 in.	0.027-0.028	0.027
	6 in. × 2 in. Structural Plate	0.033-0.035	0.035
	9 in. × 2½ in. Structural Plate	0.033-0.037	0.035
Steel Casing Pipe	Smooth	-	0.013
Corrugated Polyethylene	Smooth	0.009-0.015	0.013
Polyvinyl Chloride (PVC)	Smooth	0.009-0.011	0.013
Cured In Place Pipe Liner	Smooth	-	0.013

Source: HDS 5 (1)

(1) These n values were measured in a laboratory. Actual field values may vary depending on the effect of abrasion, corrosion, and joint conditions.

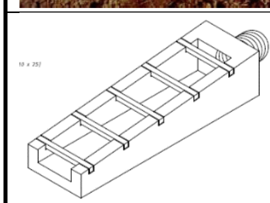
(2) The values indicated in this table are MDT's recommended Manning's n values for new culverts. Actual field values for older existing pipes may vary depending on the effects of abrasion, corrosion, deflection, and joint conditions.

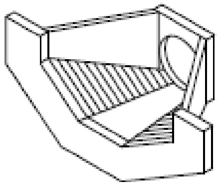
2. Entrance Loss Coefficients. Entrance loss coefficients (k_e) are provided in Figure 11.10-2.

Figure 11.10-2 — MDT ENTRANCE LOSS COEFFICIENTS (Outlet Control, Full or Partly Full)[1]

Entrance loss: $H_e = k_e \left[\frac{V^2}{2g}\right]$

Entrance Image	MDT Description *MDT Detailed Drawing Number is listed, where applicable*	k_e[1,2]	HY-8 Inlet Configuration
	CMP Flared End Terminal Section (FETS) *603-02*	0.5	Square Edge with Headwall
	CMP in Headwall (with or without wingwalls)	0.5	Square Edge with Headwall
	CMP or SSPP Step Bevel for Circular Metal Pipe Culvert (Shown with Concrete Edge Protection) *603-32*	0.7	Mitered to Conform to Slope
	CMP Thin Edge Projecting	0.9	Thin Edge Projecting
	CMPA Bevel *603-34*	0.7	Mitered to Conform to Slope
	RCP Square End (Grooved End Projecting)	0.2	Grooved End Projecting
	RCP Square End (Cut end)	0.5	Square Edge with Headwall

Entrance Image	**MDT Description** ***MDT Detailed Drawing Number is listed, where applicable***	**k_e[1,2]**	**HY-8 Inlet Configuration**
	RCP Flared End Terminal Section (FETS) *603-08*	0.5	Square Edge with Headwall
	RCP Square End with Headwall	0.5	Square Edge with Headwall
	RCPA Flared End Terminal Section (FETS) *603-10*	0.5	Square Edge with Headwall
	RCB[3] Sloped End (Shown with Concrete Edge Protection)	0.5	Square Edge (90°) Headwall
	RCB[3] Wingwalls (top of wingwall is level)	0.2	1:1 Bevel (45° Flare) Wingwall
	RCB[3] Tapered Wingwalls (top of wing wall tapers down)	0.2	1:1 Bevel (45° Flare) Wingwall
	Safety Slope End Section	0.7	Mitered to Conform to Slope
	RACET/ Precast Median U-Turn Cross Drain End Sections	0.7	Mitered to Conform to Slope

Entrance Image	**MDT Description** *MDT Detailed Drawing Number is listed, where applicable*	**k_e[1,2]**	**HY-8 Inlet Configuration**
	Irrigation Inlet Transition	0.2	1:1 Beveled Edge

1. *For additional entrance loss conditions, see HDS 5* (1).
2. *Embedding culverts will change k_e. See HY-8 User Manual for additional information.*
3. *RCB options all assume that top (crown) edge is beveled. If there is a square edge at crown, the entrance loss coefficient is 0.7.*

11.11 REFERENCES

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8. **FHWA.** *Urban Drainage Design Manual, Hydraulic Engineering Circular No. 22, Third Edition.* Washington, DC : Federal Highway Administration, 2009, updated 2013. FHWA-NHI-10-009.

9. —. *Culvert Design for Aquatic Organism Passage, Hydraulic Engineering Circular No. 26, 1st Edition.* Washington, DC : Federal Highway Administration, 2010. FHWA-HIF-11-008.

Appendix 11A — MDT CULVERT FILL HEIGHT TABLES

The following list provides an index to the tables in Appendix 11A. The tables are also available in the MDT *Road Design Manual*:

- Figure 11.A-1 — Maximum Fill Heights for RCP – Embankment Installation
- Figure 11.A-2 — Maximum Fill Heights for RCP – Trench Installation
- Figure 11.A-3 — Minimum Fill Heights for RCP
- Figure 11.A-4 — RCPA – Equivalent Diameters
- Figure 11.A-5 — Structural Requirements for CSP (Welded or Lock Seam) (2⅔″ × ½″ Corrugations)
- Figure 11.A-6 — Structural Requirements for CSP (Welded or Lock Seam) (3″ × 1″ Corrugations)
- Figure 11.A-7 — Structural Requirements for CSP (Welded or Lock Seam) (5″ × 1″ Corrugations)
- Figure 11.A-8 — Structural Requirements for CSPA (2⅔″ × ½″ Corrugations)
- Figure 11.A-9 — Structural Requirements for CSPA (3″ × 1″ or 5″ × 1″ Corrugations)
- Figure 11.A-10 — Structural Requirements for SSPP (6″ × 2″ Corrugations)
- Figure 11.A-11 — Structural Requirements for SSPPA (6″ × 2″ Corrugations, 18″ Corner Radius)
- Figure 11.A-12 — Structural Requirements for SSPPA (6″ × 2″ Corrugations, 31″ Corner Radius)
- Figure 11.A-13 — Structural Requirements for CAP (Lock Seam Aluminum) (2⅔″ × ½″ Corrugations)
- Figure 11.A-14 — Structural Requirements for CAP (Lock Seam Aluminum) (3″ × 1″ Corrugations)
- Figure 11.A-15 — Minimum Thicknesses for SCP
- Figure 11.A-16 — Structural Requirements for Plastic Pipes
- Figure 11.A-17 — Structural Requirements for Private Approach Pipes

Figure 11.A-1 — MAXIMUM FILL HEIGHTS FOR RCP – EMBANKMENT INSTALLATION

Pipe Diameter (in.)	RCP Maximum Fill Height* (ft) Embankment Installation			
	Pipe Class			
	Class 2	Class 3	Class 4	Class 5
12	**	**	**	33
18	**	15	22	33
24	**	15	22	33
30	11	15	22	33
36	11	15	22	33
42	11	15	22	33
48	11	15	22	33
54	11	14	22	33
60	10	14	21	33
66	10	14	21	32
72	10	14	21	32
78	10	14	21	32
84	10	14	21	32
90	10	14	21	32
96	10	14	21	32

* *Maximum fill height is measured from the outside top of the pipe (see Note 5 below) to the point of maximum cover, including the total surfacing thickness.*

** *This class of pipe is not available in the sizes indicated.*

Notes:

1. *Embankment installation based on MDT Detailed Drawings 603-18 and 603-19.*
2. *This fill height table was developed using the indirect design method detailed in the ACPA Concrete Pipe Design Manual, Version 19. This table applies only to pipes having "B" wall thickness.*
3. *Special design is required when fill heights exceed Class 5 fill heights shown in table above.*
4. *For RCPA, use maximum fill heights for equivalent RCP diameter (see Figure 11.A-4) listed above. RCPA is only available in Classes 3 and 4.*
5. *MDT's standard pipe wall thickness is B-wall pipe, which is the diameter in feet converted to inches plus 1 in. For example, a 48-in. pipe is 4 ft in diameter and will have a pipe thickness of 4 in.+1 in. = 5 in. C-wall pipe is used in low pH conditions to add additional concrete thickness over the rebar. To determine the C-wall pipe thickness, add 1.75 in. to the diameter in feet converted to inches. 12" pipes do not follow this formula and have C-walls that are 3" thick.*

Figure 11.A-2 — MAXIMUM FILL HEIGHTS FOR RCP – TRENCH INSTALLATION

Pipe Diameter (in.)	RCP Maximum Fill Height* (ft) Trench Installation			
	Pipe Class			
	Class 2	Class 3	Class 4	Class 5
12	**	**	**	33
18	**	15	22	33
24	**	15	22	33
30	11	15	22	33
36	11	15	22	33
42	11	15	22	33
48	11	15	22	33
54	12	17	29	33
60	12	17	29	33
66	12	17	29	32
72	12	17	29	32
78	12	17	29	32
84	12	17	29	32
90	12	17	29	32
96	12	17	29	32

* *Maximum fill height is measured from the outside top of the pipe (see Note 6 below) to the point of maximum cover, including the total surfacing thickness.*

** *This class of pipe is not available in the sizes indicated.*

Notes:

1. *Trench installation based on bedding material placed to the spring line of the pipe and trench width; equal to the outside pipe diameter, plus 3 ft.*
2. *This fill height table was developed using the indirect design method detailed in the ACPA Concrete Pipe Design Manual, Version 19. This table applies only to pipes having "B" wall thickness.*
3. *Special design is required when fill heights exceed Class 5 fill heights shown in table above.*
4. *Class 5 fill heights are based on embankment conditions due to constructability.*
5. *For RCPA, use maximum fill heights for equivalent RCP diameter (see Figure 11.A-4) listed above. RCPA is only available in Classes 3 and 4.*
6. *MDT's standard pipe wall thickness is B-wall pipe, which is the diameter in feet converted to inches plus 1 in. For example, a 48-in. pipe is 4 ft in diameter and will have a pipe thickness of 4 in.+1 in. = 5 in. C-wall pipe is used in low pH conditions to add additional concrete thickness over the rebar. To determine the C-wall pipe thickness, add 1.75 in. to the diameter in feet converted to inches. 12" pipes do not follow this formula and have C-walls that are 3" thick.*

Figure 11.A-3 — MINIMUM FILL HEIGHTS FOR RCP

Pipe Diameter (in.)	RCP Minimum Fill Height* (in.)			
	Pipe Class			
	Class 2	Class 3	Class 4	Class 5
12	**	**	**	6
18	**	18	6	6
24	**	12	6	6
30	24	6	6	6
36	6	6	6	6
42	6	6	6	6
48	6	6	6	6
>48	6	6	6	6

* *Minimum fill height is measured from the outside top of the bell if present, otherwise is measured from the top outside of pipe (see Notes 3 & 4 below) to the top of the rigid pavement or to the bottom of the flexible (plant mix) pavement at the lowest point of the paved portion of the cross section.*

** *This class of pipe is not available in the sizes indicated.*

Notes:

1. *For RCPA, use minimum fill heights for equivalent RCP diameter (see Figure 11.A-4) listed above. RCPA is only available in Classes 3 and 4.*
2. *To avoid damage during construction, do not allow the top of the pipe to extend into the base course. Although not desirable, pipes may extend into the subbase/subgrade if necessary.*
3. *Note that some RCP/RCPA pipe has bell sections where the pipes connect. Measure the minimum cover from the outside top of the bell when present.*

MDT's standard pipe wall thickness is B-wall pipe, which is the diameter in feet converted to inches plus 1 in. For example, a 48-in. pipe is 4 ft in diameter and will have a pipe thickness of 4 in.+1 in. = 5 in. C-wall pipe is used in low pH conditions to add additional concrete thickness over the rebar. To determine the C-wall pipe thickness, add 1.75 in. to the diameter in feet converted to inches. 12" pipes do not follow this formula and have C-walls that are 3" thick.

Figure 11.A-4 — RCPA – EQUIVALENT DIAMETERS

Span (in.)	Rise (in.)	Equivalent Diameter (in.)
22	13½	18
28½	18	24
36¼	22½	30
43¾	26⅝	36
51⅛	31 5/16	42
58½	36	48
65	40	54
73	45	60
88	54	72
102	62	84

Table values are from AASHTO Materials, Standard Specifications for Reinforced Concrete Arch Culvert, Storm Drain, and Sewer Pipe, M206.

Figure 11.A-5 — STRUCTURAL REQUIREMENTS FOR CSP (Welded or Lock Seam) (2 ⅔″ × ½″ Corrugations)

2 ⅔″ × ½″ Corrugations ①, ② *Welded or Lock-Seam Steel Pipe*						
Pipe Diameter (in.)	**Minimum Fill Height* (in.)**	**Maximum Fill Height* (ft)**				
		Metal Thickness (in.)				
		0.064	**0.079**	**0.109**	**0.138**	**0.168**
12	18	207	259			
18	18	138	172			
24	18	103	129	181		
30	18	82	103	145		
36	18	68	86	120	155	
42	18	58	73	103	133	163
48	18	51	64	90	116	142
54	18		57	80	103	126
60	18			72	93	114
66	18				84	103
72	18				77	94
78	18					84
84	18					72

* *Minimum fill height is measured from the top of the pipe to the top of the rigid pavement or to the bottom of the flexible (plant mix) pavement. For private approaches, see Figure 11.A-17 for alternate minimum fill heights. Maximum fill height is measured from the top of the pipe to the point of maximum cover, including the total surfacing thickness.*

For all pipes less than 84 in., locate the top of the pipe a minimum of 0.3 ft below the bottom of the surfacing subgrade. For all pipes 84 in. and larger, locate the top of the pipe a minimum of 1.0 ft below the surfacing subgrade.

Fill heights are based on the AASHTO LRFD Specifications.

Notes:

① *Fill heights are based on suitable backfill (granular material) and foundation conditions. Consult the Geotechnical Section for special backfill/foundation requirements when wet and/or unsuitable in-place soil conditions exist.*

② *For a given fill height, compare the wall thicknesses for both the 2 ⅔″ × ½″ and the 3″ × 1″ corrugations, and use the corrugations that allow the use of the thinner wall if it still meets the service life requirements.*

Figure 11.A-6 — STRUCTURAL REQUIREMENTS FOR CSP (Welded or Lock Seam) (3″ × 1″ Corrugations)

3″ × 1″ Corrugations ①② *Welded or Lock-Seam Steel Pipe*						
Pipe Diameter (in.)	**Minimum Fill Height* (in.)**	**Maximum Fill Height* (ft)**				
		Metal Thickness (in.)				
		0.064	**0.079**	**0.109**	**0.138**	**0.168**
54	18	52	65	92	119	146
60	18	47	59	83	107	131
66	18	42	53	75	97	119
72	18	39	49	69	89	109
78	18	36	45	63	82	101
84	18		42	59	76	93
90	18		39	55	71	87
96	18			51	66	81
102	18			48	62	77
108	18			46	59	72
114	18				56	68
120	18				53	65

* *Minimum fill height is measured from the top of the pipe to the top of the rigid pavement or to the bottom of the flexible (plant mix) pavement. Maximum fill height is measured from the top of the pipe to the point of maximum cover, including the total surfacing thickness.*

For all pipes less than 84 in., locate the top of the pipe a minimum of 0.3 ft below the bottom of the surfacing subgrade. For all pipes 84 in. and larger, locate the top of the pipe a minimum of 1.0 ft below the surfacing subgrade.

Fill heights are based on the AASHTO LRFD Specifications.

Notes:

① *Fill heights are based on suitable backfill (granular material) and foundation conditions. Consult the Geotechnical Section for special backfill/foundation requirements when wet and/or unsuitable in-place soil conditions exist.*

② *For a given fill height, compare the wall thicknesses for both the 2 ⅔″ × ½″ and the 3″ × 1″ corrugations, and use the corrugations that allow the use of the thinner wall.*

Figure 11.A-7 — STRUCTURAL REQUIREMENTS FOR CSP (Welded or Lock Seam) (5″ × 1″ Corrugations)

5″ × 1″ Corrugations ①② *Welded or Lock-Seam Steel Pipe*						
Pipe Diameter (in.)	Minimum Fill Height* (in.)	Maximum Fill Height* (ft) Metal Thickness (in.)				
		0.064	0.079	0.109	0.138	0.168
54	18	46	58	82	106	129
60	18	42	52	74	95	116
66	18	38	47	66	86	106
72	18	35	43	61	79	97
78	18	32	40	56	73	89
84	18		37	52	68	83
90	18		34	49	63	77
96	18			46	59	72
102	18			43	55	68
108	18			40	52	64
114	18				50	61
120	18				47	58

* *Minimum fill height is measured from the top of the pipe to the top of the rigid pavement or to the bottom of the flexible (plant mix) pavement. Maximum fill height is measured from the top of the pipe to the point of maximum cover, including the total surfacing thickness.*

For all pipes less than 84 in., locate the top of the pipe a minimum of 0.3 ft below the bottom of the surfacing subgrade. For all pipes 84 in. and larger, locate the top of the pipe a minimum of 1.0 ft below the surfacing subgrade.

Fill heights are based on the AASHTO LRFD Specifications.

Notes:

① *Fill heights are based on suitable backfill (granular material) and foundation conditions. Consult the Geotechnical Section for special backfill/foundation requirements when wet and/or unsuitable in-place soil conditions exist.*

② *5″ × 1″ corrugations are not typically used; however, in some instances, manufacturers may recommend 5″ × 1″ corrugations to provide polymeric coating on thicker gage pipes.*

Figure 11.A-8 — STRUCTURAL REQUIREMENTS FOR CSPA (2 ⅔″ × ½″ Corrugations)

2 ⅔″ × ½″ Corrugations ***Steel Pipe Arch (All Seam Fabrications)***							
Pipe Dimensions Span x Rise (in.)	**Equiv. Diameter (in.)**	**Minimum Fill Height* (in.)**	**Maximum Fill Height* (ft)①**				
			Minimum Metal Thickness (in.)②				
			0.064	**0.079**	**0.109**	**0.138**	**0.168**
21 × 15	18	24	12				
28 × 20	24	24	12				
35 × 24	30	30	12				
42 × 29	36	30	12				
49 × 33	42	36		12			
57 × 38③	48	24			12		
64 × 43③	54	24			12		
71 × 47③	60	24				12	
77 × 52③	66	24					12
83 × 57③	72	24					12

* *Minimum fill height is measured from the top of the pipe to the top of the rigid pavement or to the bottom of the flexible (plant mix) pavement. Maximum fill height is measured from the top of the pipe to the point of maximum cover, including the total surfacing thickness.*

For all pipe 2 ²/₃″ x ¹/₂″ corrugations, locate the top of the pipe a minimum of 0.3 ft below the surfacing subgrade.

Fill heights are based on the AASHTO LRFD Specifications.

Notes:

① *Based upon load modification factor of 1, a soil density of 120 pcf, and 4000 psf corner bearing pressure.*

② *Thicknesses above the heavy line will not be used unless specified by the hydraulic engineer.*

③ ***Do not use these sizes unless site conditions preclude the use of arches with 3″ × 1″ corrugations.***

Figure 11.A-9 — STRUCTURAL REQUIREMENTS FOR CSPA (3″ × 1″ or 5″ × 1″ Corrugations)

3″ × 1″ or 5″ × 1″ Corrugations *Steel Pipe Arch (All Seam Fabrications)*							
Pipe Dimensions Span × Rise (in.)**	**Equiv. Dia. (in.)**	**Minimum Fill Height* (in.)**	**Maximum Fill Height* (ft) ① Minimum Metal Thickness (in.)**				
			0.064	**0.079**	**0.109**	**0.138**	**0.168**
53 × 41	48	24		12			
60 × 46	54	24		20			
66 × 51	60	24		20			
73 × 55	66	24		20			
81 × 59	72	24		17	17	②	
87 × 63	78	24		16	16		
95 × 67	84	24		16	16		
103 × 71	90	24			16	16	
112 × 75	96	24			16	16	
117 × 79	102	24			16	16	
128 × 83	108	24				16	16

* *Minimum fill height is measured from the top of the pipe to the top of the rigid pavement or to the bottom of the flexible (plant mix) pavement. Maximum fill height is measured from the top of the pipe to the point of maximum cover, including the total surfacing thickness.*

For all pipe arches smaller than 95″x 67″, locate the top of the pipe a minimum of 0.3 ft below the surfacing subgrade. For all pipe arches 95″x 67″ and larger, locate the top of the pipe a minimum of 1.0 ft below the surfacing subgrade.

** *Nominal dimensions per manufacturers'/suppliers' product information.*

Fill heights are based on the AASHTO LRFD Specifications.

Notes:

① *Based upon load modification factor of 1, a soil density of 120 pcf, and 4000 psf corner bearing pressure.*

② *Unshaded cells are fill heights for 3" x 1" corrugations, and shaded cells are fill heights for 5″× 1″ corrugations.*

Figure 11.A-10 — STRUCTURAL REQUIREMENTS FOR SSPP (6″ × 2″ Corrugations)

6″ × 2″ Corrugations ***Structural Steel Plate Pipe***										
Pipe Diameter**	**Minimum Fill Height* (in.)**	**Maximum Fill Height* (ft)①**								
		Gage (Metal Thickness in Inches)								
		12 (0.111)	**10 (0.140)**	**8 (0.170)**	**7 (0.188)**	**5 (0.218)**	**3 (0.249)**	**1 (0.280)**	**5/16 (0.318)**	**3/8 (0.380)**
5′-0″	18	47	67	87	100	121	143	156	250	301
6′-0″	18	38	55	73	83	101	119	130	208	250
7′-0″	18	32	47	62	71	86	102	111	178	214
8′-0″	18	28	41	54	62	75	89	97	156	187
9′-0″	18	25	37	48	55	67	79	86	138	166
10′-0″	18	22	33	43	50	60	71	77	124	150
11′-0″	18	20	30	39	45	54	64	70	113	136
12′-0″	18	18	27	36	41	50	59	64	104	125
13′-0″	20	17	25	33	38	46	54	59	95	115
14′-0″	24	16	23	31	35	43	50	55	89	107
15′-0″	24	14	21	28	33	40	47	51	83	99
16′-0″	24		20	27	31	37	44	48	77	93
17′-0″	28		19	25	29	35	41	45	73	88
18′-0″	28			23	27	33	39	43	69	83
19′-0″	32			22	26	31	37	40	65	78
20′-0″	32				24	29	35	38	62	74
21′-0″	32				24	28	33	36	59	71

* *Minimum fill height is measured from the top of the pipe to the top of the rigid pavement or to the bottom of the flexible (plant mix) pavement. Maximum fill height is measured from the top of the pipe to the point of maximum cover, including the total surfacing thickness.*

For all pipes less than 7′-0″, locate the top of the pipe a minimum of 0.3 ft below the bottom of the surfacing subgrade. For all pipes 7′-0″ and larger, locate the top of the pipe a minimum of 1.0 ft below the surfacing subgrade.

** *Nominal diameters per manufacturers'/suppliers' product information.*

Fill heights are based on the AASHTO LRFD Specifications.

Notes:

① *Fill heights are based on suitable backfill (granular material) and foundation conditions. Consult the Geotechnical Section for special backfill/foundation requirements when wet and/or unsuitable in-place soil conditions exist.*

Figure 11.A-11 — STRUCTURAL REQUIREMENTS FOR SSPPA (6″ x 2″ Corrugations, 18″ Corner Radius)

Structural Steel Plate Pipe Arch, 6″ x 2″ Corrugations *18″ Corner Radius* ①		
Pipe Dimensions② Span × Rise	Minimum Fill Height* (in.)	Maximum Fill Height* (ft) ③ Minimum Metal Thickness (in.) 0.111 (12 gage)
6′-1″ × 4′-7″	24	14
6′-4″ × 4′-9″	24	13
7′-0″ × 5′-1″	24	12
7′-3″ × 5′-3″	24	11
7′-8″ × 5′-5″	24	10
8′-2″ × 5′-9″	30	10
8′-10″ × 6′-1″	30	9
9′-9″ × 6′-7″	30	8
10′-8″ × 6’-11″	30	6
10′-11″ × 7′-1″	30	6
11′-10″ × 7′-7″	36	5
12′-8″ × 8′-1″	36	5
12′-10″ × 8′-4″	48	5

* *Minimum fill height is measured from the top of the pipe to the top of the rigid pavement or to the bottom of the flexible (plant mix) pavement. Maximum fill height is measured from the top of the pipe to the point of maximum cover, including the total surfacing thickness.*

For all SSPPA pipes, locate the top of the pipe a minimum of 1.0 ft below the surfacing subgrade.

Fill heights are based on the AASHTO LRFD Specifications.

Notes:

① *Do not specify these sizes unless site conditions preclude the use of CSPA or SSPPA with 31-in. corner radii.*

② *Intermediate sizes not listed have the same maximum and minimum fill heights and metal thicknesses as the next larger size listed in this table.*

③ *Based upon a 2-ton corner bearing pressure. Special foundation investigation required when higher corner bearing pressures need to be developed.*

Figure 11.A-12 — STRUCTURAL REQUIREMENTS FOR SSPPA (6″ × 2″ Corrugations, 31″ Corner Radius)

Structural Steel Plate Pipe Arch, 6″ × 2″ Corrugations *31″ Corner Radius*							
Pipe Dimensions① Span × Rise (in.)	**Minimum Fill Height* (in.)**	**Maximum Fill Height* (ft)② Minimum Metal Thickness (in.)**					
		0.140	**0.170**	**0.188**	**0.218**	**0.249**	**0.280**
13′-6″ × 9′-6″	30	11	11	11	11	11	11
14′-2″ × 9′-10″	30	10	10	10	10	10	10
15′-7″ × 10′-6″	30	9	9	9	9	9	9
15′-10″ × 10′-8″	30		9	9	9	9	9
17′-2″ × 11′-4″	30		8	8	8	8	8
17′-11″ × 11′-8″	30			7	7	7	7
18′-1″ × 11′-10″	30			7	7	7	7
18′-9″ × 12′-2″	36			7	7	7	7
19′-11″ × 12′-10″	36				6	6	6
20′-7″ v 13′-2″	36				6	6	6

* *Minimum fill height is measured from the top of the pipe to the top of the rigid pavement or to the bottom of the flexible (plant mix) pavement. Maximum fill height is measured from the top of the pipe to the point of maximum cover, including the total surfacing thickness.*

For all SSPPA pipes, locate the top of the pipe a minimum of 1.0 ft below the surfacing subgrade.

Fill heights are based on the AASHTO LRFD Specifications.

Notes:

① *Intermediate sizes not listed have the same maximum and minimum fill heights and metal thicknesses as the next larger size listed in this table.*

② *Based upon a 2-ton corner bearing pressure. Special foundation investigation required when higher corner bearing pressures need to be developed.*

Figure 11.A-13 — STRUCTURAL REQUIREMENTS FOR CAP (Lock Seam Aluminum) (2 ⅔″ × ½″ Corrugations)

Corrugated Aluminum Pipe, 2 ⅔″ × ½″ Corrugations ①, ②, ③ *Lock Seam Aluminum Pipe*						
Pipe Diameter (in.)	**Minimum Fill Height* (in.)**	**Maximum Fill Height* (ft) Metal Thickness (in.)**				
		0.060	**0.075**	**0.105**	**0.135**	**0.164**
12	18	125	157			
18	18	83	104			
24	18	62	78	109		
30	18		62	87		
36	18		51	73	94	
42	18			62	80	
48	18			54	70	85
54	18			48	62	76
60	18				52	64
66	18					52
72	18					43

* *Minimum fill height is measured from the top of the pipe to the top of the rigid pavement or to the bottom of the flexible (plant mix) pavement. Maximum fill height is measured from the top of the pipe to the point of maximum cover, including the total surfacing thickness.*

For all aluminum pipes, locate the top of the pipe a minimum of 0.3 ft below the surfacing subgrade.

Fill heights are based on the AASHTO LRFD Specifications.

Notes:

① *Fill heights are based on suitable backfill (granular material) and foundation conditions. Consult the Geotechnical Section for special backfill/foundation requirements when wet and/or unsuitable in-place soil conditions exist.*

② *For a given fill height, compare the wall thicknesses for both the 2 ⅔″ × ½″ and 3″ × 1″ corrugations and specify the corrugations that allow the use of the thinner wall.*

③ *Fill heights taken from manufacturers'/suppliers' product information.*

Figure 11.A-14 — STRUCTURAL REQUIREMENTS FOR CAP (Lock Seam Aluminum) (3″ × 1″ Corrugations)

Corrugated Aluminum Pipe, 3″ × 1″ Corrugations ①, ②, ③ *Lock Seam Aluminum Pipe*						
Pipe Diameter (in.)	**Minimum Fill Height* (in.)**	**Maximum Fill Height* (ft) Metal Thickness (in.)**				
		0.060	**0.075**	**0.105**	**0.135**	**0.164**
30	18	57	72	101		
36	18	47	60	84	112	
42	18	40	51	72	96	
48	18	35	44	62	84	99
54	18	31	39	55	74	88
60	18		35	50	67	79
66	18		32	45	61	72
72	18		29	41	56	66

* *Minimum fill height is measured from the top of the pipe to the top of the rigid pavement or to the bottom of the flexible (plant mix) pavement. Maximum fill height is measured from the top of the pipe to the point of maximum cover, including the total surfacing thickness.*

For all aluminum pipes, locate the top of the pipe a minimum of 0.3 ft below the surfacing subgrade.

Fill heights are based on the AASHTO LRFD Specifications.

Notes:

① *Fill heights are based on suitable backfill (granular material) and foundation conditions. Consult the Geotechnical Section for special backfill/foundation requirements when wet and/or unsuitable in-place soil conditions exist.*

② *For a given fill height, compare the wall thicknesses for both the 2⅔″ × ½″ and 3″ × 1″ corrugations and specify the corrugations that allow the use of the thinner wall.*

③ *Fill heights taken from manufacturers'/suppliers' product information.*

Figure 11.A-15 — MINIMUM THICKNESSES FOR SCP

Steel Casing Pipes (SCP)	
Pipe Diameter (in.)	**Minimum Pipe Thickness (in.)**
18	0.250
24	0.312
30	0.375
36	0.500
42	0.500
48	0.625
54	0.625
60	0.625
66	0.625
72	0.750

Table is from the following document: DEPARTMENT OF THE ARMY EM 1110-2-2902 U.S. Army Corps of Engineers Change 1 CECW-ED Washington, DC 20314-1000 Manual No. 1110-2-2902 31 March 1998 Engineering and Design CONDUITS, CULVERTS, AND PIPES Table 8-1.

Figure 11.A-16 — STRUCTURAL REQUIREMENTS FOR PLASTIC PIPES

Plastic Pipes					
		Maximum Fill Height* (ft)			
				Solid Wall PVC ③	
				Pipe Stiffness (psi)	
Pipe Diameter (in.)	Minimum Fill Height* (in.)	HDPE①	Profile Wall PVC ②	46	115
12	24	18	24	24④	30④
18	24	17	24	24	30
24	24	15	24	24	30
30	24**	14	23	24	30
36	24**	12	22	24	30
42	24**	12	-	24	30
48	24**	11	-	24	30

* *Minimum fill height is measured from the top of the pipe to the top of the rigid pavement or to the bottom of the flexible (plant mix) pavement. Maximum fill height is measured from the top of the pipe to the point of maximum cover, including the total surfacing thickness.*

** *Due to pipe buoyancy, if plastic pipe is installed in locations where groundwater is present, the minimum cover for the pipe is the pipe diameter.*

For all plastic pipes, locate the top of the pipe a minimum of 0.3 ft below the surfacing subgrade.

Notes:

① *HDPE smooth lined or corrugated, Corrugated Polyethylene Drainage Pipe Standard Specification 708.07.*

② *Profile Wall PVC, Standard Specification 708.05.4.*

③ *Large Diameter Solid Wall PVC Gravity Pipe, Standard Specification 708.05.3.*

④ *PSM PVC Solid Wall Gravity Pipe, Standard Specification 708.05.2.*

Figure 11.A-17 — STRUCTURAL REQUIREMENTS FOR PRIVATE APPROACH PIPES

Private Approach Pipes			
Pipe Size & Type	**Class of Pipe**	**Minimum Fill Height* (ft)**	**Maximum Fill Height* (ft)**
18″ RCP	2	①	①
	3	1.5	15
	4	0.5	22
	5	0.5	33
18″ CSP	—	1	142
18″ CAP	—	1.5	75
18″ HDPE	—	2	17

* *Minimum fill height is measured from the top of the pipe to the top of the rigid pavement or to the bottom of the flexible (plant mix) pavement. Maximum fill height is measured from the top of the pipe to the point of maximum cover, including the total surfacing thickness.*

Notes:

① *Class 2 reinforced concrete pipe does not exist for 18-in. diameter pipe.*

Appendix 11B — PIPE REPLACEMENT AND REHABILITATION OPTIONS

Pipe Replacement and Rehabilitation Options

Option 1: Keep Existing Pipe in Place

- Determine remaining service life of the existing pipe:
  - The remaining service life of the culvert must meet the requirements in Section 11.3.2.
  - In addition to water and soil samples, coupon samples of the existing steel pipe can be taken to determine remaining thickness and remaining pipe life due to corrosion and abrasion. Another option is to use a D-Meter to take ultrasonic measurements of metal culvert walls to determine the remaining wall thickness.
  - Assume concrete life is 100 years.
  - Evaluate existing performance to ensure that there are no existing flooding or erosion problems.
  - Analyze structural capacity of the pipe for current and proposed fill height conditions.
- Considerations for extending the existing pipe:
  - Evaluate the condition of the existing pipe with either visual inspection or remote control video.
  - If the pipe is going to be extended more than 50% of the in-place pipe length, the minimum remaining pipe service life is 50 years.
  - Verify that the extension will align properly with the channel. Channel changes or possibly a vertical or horizontal bend in the pipe may be required.
  - Structural plate pipe can be difficult to attach to, and these connection points have caused structural problems in the past.
  - Consult with the Geotechnical Section on the potential for differential settlement between the existing and new pipe.
  - If the grade is being raised, verify that the class of RCP pipe is adequate.
- Environmental permitting may require retrofitting the existing pipe for AOP sites (e.g., fish passage).
- Include channel change, end section(s), environmental requirements, etc., in cost analysis.

Option 2: Install New Pipe(s)

- Consider the condition and age of the existing pipe when determining applicable pipe material options:
  - What condition is causing the pipe to be replaced (e.g., corrosion, abrasion, shape)?
  - Does the corrosion (soil and water) and metal coupon testing or D-Meter measurements match the condition of the pipe?
  - Use the modified service life calculation that includes the actual life of the existing culvert to determine service life of the proposed pipe.
  - Do not specify thinner steel than the existing pipe.

- When specifying pipe size in fill heights greater than 15 ft, enlarge replacement concrete culverts by 18” and corrugated metal culverts by 24” to allow room for future rehabilitation.
- The design service life must be meet the requirements in Section 11.3.2.
- Consider detour, excavation, large pipe removal, edge protections, and bedding costs in the cost estimate.

Option 3: Jack & Bore New Pipes

- Determine if there are any site constraints that will affect the jacking & boring contractor from accessing the sites:
    - Require a 12-ft x 36-ft boring pit to set up and operate boring equipment.
    - Maintain a minimum distance of 20 ft from edge of pavement of the PTW.
    - Maximum boring slope of 0.2 ft/ft (20%).
    - Must be a minimum of 5 ft between new pipe and old pipe (measure outside edge to outside edge).
    - Identify areas that will require extra ROW, railroad involvement, or construction permits.
    - Identify which end to be jacked and bored from; i.e., inlet or outlet (typically the outlet is preferred).
- Existing pipes will be abandoned or plugged and abandoned. See the MDT *Road Design Manual,* Section 11.2.14.
- Check for conflicts with utilities or irrigation systems.
- Obtain as much information as possible about the existing fill material where pipes will be jacked & bored. Bedrock, groundwater, rocks in the fill, and the ground/fill interface can be significant problems. A geotechnical investigation is required.
- Currently, MDT has had good experience with specifying steel casing pipe up to 72 in. in diameter. The use of other pipe materials will be investigated in the future.
- If possible with available jacking pipe sizes, increase the diameter of the jacking pipe by 12” from the hydraulically designed pipe size to allow for future rehabilitation.
- As the jack and bore length increases, the accuracy, risk, and cost of this method will also increase, which may preclude it as a viable option. Evaluate costs with other alternatives.

Option 4: Insert New Pipe into Existing Pipe

- Verify hydraulic capacity of lined culvert:
    - If the level of service cannot be met without overtopping the roadway, lining is not a valid option.
    - Evaluate the risk of upstream flooding.
    - Evaluate the inlet and outlet edge and channel protection for increased velocity and higher water surface elevations.
- The host pipe may require cleaning, which can be sufficiently difficult to be cost prohibitive.
- Obtain a detailed survey of the profile and interior geometry of the pipe to determine if the recommended size pipe can be inserted.

- Allow adequate space for grouting. Base the decision on minimum survey dimensions versus the reported pipe diameter.
- Determine if there are any site constraints that will inhibit the contractor from accessing the sites:
  - Require a staging area to set up and insert the liner.
  - Identify areas that will require extra ROW, railroad involvement, or construction permits.
  - Identify which end the liner pipe will be inserted from; i.e., inlet or outlet (typically the outlet is preferred).
  - Proximity to the railroad property could affect insert capability.
- If using CMP, determine service life of lining pipe material:
  - Specify coating as required.
  - Assume grout in the annular space will mitigate soil side corrosion.
  - Do not use steel lining if the service life cannot be obtained based on the water samples.
- Plastic options up to 36 in. include:
  - HDPE solid wall pipe with welded or snap tight joints.
  - Corrugated PVC liner pipe.

Option 5: Cured in Place Pipe (CIPP)

- If the pipe is severely corroded or significantly deformed, do not use this method.
- The pipe will require cleaning thoroughly, which can be costly.
- Curing methods may include hot water, steam, and ultraviolet lights.
- If hot water curing method is used, the discharge of heated water can environmentally damage downstream waters. Discharge water may have to be trucked offsite to a predetermined disposal area.
- Check costs closely. Contact suppliers with site data and photos to obtain a unit cost estimate.
- Determine if there are any site constraints that will affect the contractor from accessing the sites:
  - Require a staging area to set up and insert the liner.
  - Identify areas that will require extra ROW or construction permits.

Option 6: Spray-On Liner

- Concrete and epoxy spray liners may be used to rehabilitate pipes.

Option 7: Invert Paving

- If all pipe except the invert is in good condition, the invert can be paved with concrete. A structural analysis may be necessary to determine if additional reinforcement is required to restore culvert hoop strength.
- Fill voids and hollow areas beneath the pipe with grout.
- Extend concrete sufficiently up the sides and utilize wire mesh for concrete reinforcement.

- Analyze culvert hydraulics and improve cutoff walls and edge protection as necessary to account for increased velocities.
- Details may be available from MDT Hydraulics.

Figure 11B-1 summarizes and compares the replacement and rehabilitation options described above.

Figure 11.B-1 — PIPE REPLACEMENT AND REHABILITATION SUMMARY

Option	Cost	Size Range[1]	Advantages	Limitations
Option 1: Keep Existing Pipe in Place	Low	—	• Low construction cost • Detour not required • Minimal permitting required	• Difficult to estimate remaining life • May not meet current hydraulic standards • Extensions may require channel changes
Option 2: Install New Pipe	High	—	• Full-service life is restored • Meets current hydraulic and environmental standards	• Detour or road closure may be required • Could be a high cost in a deep fill or high traffic volume road
Option 3: Jack and Bore New Pipe	High	72 in. or less	• Full-service life is restored • Detour not required • Avoids excavation of large fills	• Need a large staging area • Limited to smaller diameters • Uniform embankment fill required. Large rocks within the fill make a jack and bore significantly more difficult • Geotechnical investigation is required
Option 4: Insert New Pipe into Existing Pipe	Med	—	• Full-service life is restored • Detour not required • Applies to a large range of diameters	• Need a large staging area • May reduce capacity of culvert • May reduce the culvert capacity Host pipe shape must be uniform
Option 5: Line Existing Pipe with CIPP	High	72 in. or less	• Detour not required • No grouting required • Smooth interior	• Specialized equipment and personnel required • Discharge of water may be an environmental problem if the CIPP is water or steam cured • May reduce the culvert capacity • May increase velocity
Option 6: Spray-On Liner	High	60 in. to 144 in.	• Full-service life is restored • Detour not required • Avoids excavation of large fills	• Specialized equipment and personnel required • Depending on liner thickness, may reduce the culvert capacity • May increase velocity
Option 7: Invert Paving	Med	60 in. or Greater	• Work limited to bottom ⅓ of pipe • Can be retrofitted for AOP	• Applies to culverts with invert damage only • May require structural analysis • May increase velocity • May reduce the culvert capacity

[1] *Sizes are typical and may be adjusted based on available materials and technology.*

Appendix 11C — ENERGY DISSIPATORS

The dissipator type selected for a site must be appropriate to the location. All dissipator types in Figure 11.C-1 can be designed by using either HEC 14 (4) or HY-8 software (see Chapter 8, "Hydraulics Software)."

In this Appendix, the terms "internal" and "external" are used to indicate the location of the dissipator in relationship to the culvert. An external dissipator is located outside of the culvert and an internal dissipator is located within the culvert barrel. Internal dissipators and broken back culverts are not commonly used for box culverts. Internal dissipators may be used in combination with external dissipators.

The following general guidelines, with a reference to the applicable chapter in HEC 14, can be used to limit the number of alternative types of dissipators to consider:

1. Internal Dissipators (HEC 14, Chapter 7). Consider broken back culverts, manhole drop structures, rings for tumbling flow, or increased resistance internal dissipators where:
   - The existing or estimated outlet scour hole is not acceptable,
   - The right-of-way is limited,
   - Debris is not a problem, and/or
   - Moderate velocity reduction is needed.
2. Existing/Estimated Scour Holes (HEC 14, Chapter 5). Existing/estimated scour holes are used with riprap, and a cutoff wall is used to prevent undermining of the culvert outlet. Ensure that the existing or estimated scour hole:
   - Will not cause costly property damage, or
   - Create a public nuisance.
3. External Dissipators. Consider riprap basins and aprons (HEC 14, Chapter 10) or other external dissipators (HEC 14, Chapter 9) where:
   - The existing or estimated outlet scour hole with riprap is not acceptable,
   - A moderate amount of debris is present, and
   - The culvert outlet velocity (V_o) is moderate ($Fr \leq 3$).
4. Stilling Basins (HEC 14, Chapter 8). Stilling basins are used where:
   - The estimated outlet scour hole is not acceptable,
   - Debris is present, and
   - The culvert outlet velocity (V_o) is high ($Fr > 3$).
5. Drop Structures (HEC 14, Chapter 11). Drop structures are used where:
   - The downstream channel is degrading, or
   - Channel headcutting is present.

Figure 11.C-1 provides guidelines for each dissipator type and can be used to help determine the alternative types to consider.

Figure 11.C-1— ENERGY DISSIPATORS AND LIMITATIONS

HEC 14 Chapter	Dissipator Type	Froude Number[1] (Fr)	Allowable Debris[2]			Tailwater (TW)
			Silt/ Sand	Boulders	Floating	
4	Flow transitions	N/A	H	H	H	Desirable
5	Scour hole	N/A	H	H	H	Desirable
6	Hydraulic jump	> 1	H	H	H	Required
7	Tumbling flow[3]	> 1	M	L	L	Not needed
7	Increased resistance[4]	N/A	M	L	L	Not needed
7	USBR Type IX baffled apron	< 1	M	L	L	Not needed
7	Broken-back culvert[4]	> 1	M	L	L	Desirable
7	Outlet weir	2 – 7	M	L	M	Not needed
7	Outlet drop/weir	3.5 – 6	M	L	M	Not needed
8	USBR Type III stilling basin	4.5 – 17	M	L	M	Required
8	USBR Type IV stilling basin	2.5 – 4.5	M	L	M	Required
8	SAF stilling basin	1.7 – 17	M	L	M	Required
9	CSU rigid boundary basin	< 3	M	L	M	Not needed
9	Contra Costa basin	< 3	H	M	M	< 0.5D
9	Hook basin	1.8 – 3	H	M	M	Not needed
9	USBR Type VI impact basin[5]	N/A	M	L	L	Desirable
10	Riprap basin	< 3	H	H	H	Not needed
10	Riprap apron	N/A	H	H	H	Not needed
11	Straight drop structure[6]	< 1	H	L	M	Required
11	Box inlet drop structure[7]	< 1	H	L	M	Required
12	USACE stilling well	N/A	M	L	N	Desirable

Source: HEC 14 (4)

(1) *At release point from culvert or channel*
(2) *Debris notes: N = None, L = Low, M = Moderate, H = Heavy*
(3) *Internal: Bed slope must be in the range of 4% < S < 25%*
(4) *Internal: Check headwater for outlet control*
(5) *Discharge, Q < 400 ft^3/s and Velocity, V < 50 ft/s*
(6) *Drop < 15 ft*
(7) *Drop < 12 ft*

Appendix 11D — DRAINAGE AND CULVERT RECOMMENDATION MEMO AND REPORT TEMPLATE

MONTANA
Department of Transportation

Malcolm “Mack” Long, Director

2701 Prospect ▪ PO Box 201001
Helena MT 59620-1001

Memorandum

To: "Click here and type name" , P.E. (Design Project Manager)
"Click here and type title"

From: Name, P.E. (Sign Electronically)
"Click here and type title"

Thru: Name, P.E. (Sign Electronically)
"Click here and type title"

Date: 12/8/2023

Subject: [Project Number]
[Project Name]
UPN [UPN]
Drainage and Culvert Recommendation Memo

This memo describes the drainage and culvert recommendations for the above project.

(At the beginning of the memo, list any global or general recommendations. However, if necessary, include culvert skew and coating steel culverts with the recommendation for each site.)

General

The following special provisions are attached:

- (Example) Existing CSP Drainage Pipe Verification
- *Hydraulic special provisions can be found at: \\state\mdt\prd\Helena\Hydraulics\HYDR\41_ENGINEERING\SPECIAL PROVISIONS Common special provisions include:*
  - *701-X Riprap Acceptance (WipFrag)*
  - *Streambank Revegetation*
  - *Streambed Material*
  - *Existing CSP Drainage Pipe Verification*
  - *Existing Pipe Connection*
  - *Salvage Streambed Material*

Add the following standard special provisions to the plan set:

- (Example) Precast Reinforced Box Culverts
- *Standard Special Provisions may be found at: https://www.mdt.mt.gov/business/contracting/standard-specials.shtml, and include:*
  - *107-24 Montana Floodplain and Floodway Management Act*

- *602-1 Fill and Abandon Pipe*
- *602-2 Plug Ends and Abandon Pipe*
- *603-1 Special Installation of Pipe*
- *603-2 Corrugated Polyethylene Approach Pipe*
- *603-3 Precast Reinforced Box Culverts*
- *603-4 Basic Bid Pipe – Concrete*
- *603-7 Reinforced Concrete Pipes, Boxes, Inlets and Manholes*

MONTANA
Department of Transportation

Malcolm "Mack" Long, Director

2701 Prospect ▪ PO Box 201001
Helena MT 59620-1001

Hydraulic Design Recommendations

(Then, starting at the beginning of the project, describe station by station the proposed hydraulic design. The information in this memo will be used by the road designer as a checklist to enter the hydraulic design into the plan set. In addition, at the end of the project the checker will use this memo or a revised version to ensure the hydraulic design is accurately presented in the plan set.)

Table 1. Existing drainage features

STATION	MATERIAL	SIZE	LENGTH	ACTION
				Remove and replace
				Plug and abandon
				Remove
				Extend

TABLE 2. PROPOSED DRAINAGE FEATURES

STATION	CULVERT PIPE[1] - IN	LENGTH OF PIPE [2] - FT	PIPE OPTIONS (in)		COATING #	END SECTIONS		SLOPE	INVERT IN ELEVATION - FT	INVERT OUT ELEVATION [3] – FT	SKEW ANGLE - DEGREES	MAX/MIN FILL HEIGHT -FT
			STEEL CONCRETE ALUM.	CLASS OR THK.		LEFT	RIGHT					

[1] The size references Material Option 1 in Table 1; other material options and sizes are summarized in Table 3.

[2] Pipe length is assumed – the road designer determines the final pipe length based on the final grading.

[3] The invert out elevation may change if adjustments to the pipe length are made. Maintain the invert in elevation and slope.

Attachments: Hydraulic Report

e-copies: *List may be modified as needed.*

Highways Engineer
Hydraulic Engineer
Hydraulic Design Engineer
Hydraulics Operations Engineer
Road Design Engineer *(Headquarters Design)*
Road Design Designer
District Design Supervisor *(District Design)*
District Engineering Services Supervisor
District Project Design Engineer
District Geotechnical Engineer
District Biologist
District Development Engineer
Highways File

[Year]

Drainage and Culvert Report

ACTIVITY 364

NAME

Montana Department of Transportation
PO Box 201001
Helena, MT 59620-1001

Drainage & Culvert Report
Project Name:
Project Number:
UPN:
By:
Date:

Contents

Tables

Figures

1 Introduction

This report describes…

2 General Project Information

(Can copy and paste this section from the Hydrology Report.)

Provide a brief description of the project location, route, project limits, and scope of work.

Include a general description of the project area (terrain, land use, etc.).

3 Hydrology Summary

A complete description of the hydrologic analyses, flooding history, design event determination, and existing pipe capacities for this project is documented in hydrology report XXXXXXXHYCSP001.pdf that was completed X/XX/XXXX.

Below is a summary of the calculated discharges at each culvert crossing. The Design Event for this project is the XX-year.

Table 3. Hydrology Summary Table

Station	*Area (mi^2)*	*Q_2 (ft^3/s)*	*Q_{10} (ft^3/s)*	*Q_{25} (ft^3/s)*	*Q_{50} (ft^3/s)*	*Q_{100} (ft^3/s)*	*Q_{200} (ft^3/s)*

4 Fisheries

Describe any Fisheries present on the project or note if no fisheries are present*. Information on fisheries may be found in the PFR, BRR, or the SOW Report.*

5 Culvert Service Life

Describe when the existing culverts were installed and the current condition of the culverts.

6 Hydraulic Design

Start at the beginning of the project and describe all existing and proposed hydraulic features for each site, station by station, that are to be added to the plans. Include stockpasses, wildlife, crossings, and floodplain impacts (if applicable) within each crossing description. If increasing headwater over existing conditions at the design, 100-year, or 200-year events, complete a risk evaluation per Section 9.3.4 and document the risk evaluation and results.

Station XXX+XX

Write a description of the existing and proposed drainage patterns and hydraulic feature(s) at this site. Include existing photos if available and information pertinent to the design. Include descriptions from maintenance or local residents of historical performance.

If a culvert is at the site include the tables below with the existing culvert data and the proposed culvert sizes analyzed. Bold or highlight the recommended pipe in the tables. List elevations to the nearest tenth of a foot and discharges to the nearest ft³/s. If using pipe options, include the pipe options values in the second table.

Table 4. Station XXX+XX Site Conditions

Pipe	*Station*	*Drainage Area (mi²)*	*Qxx (ft3/s) (Design)*	*Q100 (ft³/s)*	*Pipe Slope (%)*	*Skew (XX° Lt or Rt)*	*OT Elev (ft)*	*OT Location*

Table 5. Station XXX+XX Culverts Analyzed

Pipe	*Inlet Elev (ft)*	*Inlet Ke*	*WSE Q_{xx} (ft) (Design)*	*HW Q_{xx} (ft) (Design)*	*Max Allow HW Qxx(ft) (Design)*	*WSE Q_{100} (ft)*	*HW Q_{100} (ft)*	*Max Allow HW Q_{100} (ft)*	*Q_{10} Outlet Vel (ft/s)*	*Q @ OT (ft³/s)*	*OT Freq. (~yr)*
(Existing)											
(Proposed)											
(Existing)											
(Proposed)											

Describe any additional proposed information that would be included in the recommendation memo for the site including allowable pipe materials, metal thickness, coating requirement, pipe class, culvert end treatments, ditch blocks, outlet protection. Also describe any ditch, inlet or outlet grading, and ditch lining. Include a discussion of the proposed hydraulic performance and why the recommended pipe size was selected, e.g., meets headwater requirements, maintains existing hydraulics, etc.

(May also include a plot of the proposed culvert cross section including the thalweg profile in and out of the culvert.)

7 Appendices

Appendix A — Drainage Basin Map

(Label roadway stations, basin names, drainage areas, flow arrows, existing crossings, channels, irrigation ditches, travel paths (optional), etc.)

Appendix B — Corrosive Soils Data

Appendix C — Proposed HY-8 Runs

At each pipe location, include 1-page summaries of the HY-8 input and results for the recommended pipe size and the options.

Appendix D — Proposed HEC-RAS Runs

Cross-section location plot, profile, cross-sections, Tables 1,2, six culvert cross section, and culvert output

Appendix E — Details