Chapter 11
Culverts and Bridges

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1.0 Introduction

This chapter addresses design criteria for culverts and bridges as they relate to drainageways. Generally, a culvert is a conduit for the passage of surface drainage water under a roadway, railroad, canal, or other embankment; a bridge is a structure carrying a pathway, roadway, or railway over a waterway.

2.0 General Design

2.1 Design Criteria

The procedures and basic data to be used for the design and hydraulic evaluation of culverts shall be consistent with the Culverts Chapter of the UDFCD Manual, except as modified herein. The designer is also referred to the many texts covering the subject for additional information, including *Hydraulic Design of Highway Culverts, Hydraulic Design Series No. 5* (FHWA 2012).

Bridges are typically designed to cross the waterway with minimal disturbance to the flow. However, for practical and economic reasons, abutment encroachments and piers are often located within the waterway. Consequently, the bridge structure can cause adverse hydraulic effects and scour potential that must be evaluated and addressed as part of each design. The design of a bridge is very specific to site conditions and numerous factors must be considered.

There are many acceptable manuals that are available and should be used in bridge hydraulic studies and river stability analysis. The Major Drainage and Hydraulic Structures Chapters of the UDFCD Manual shall be consulted for basic criteria and information regarding other publications and resources. Additional references include the *CDOT Drainage Design Manual (CDOT 2004)* and FHWA publications including *Highways in the River Environment (FHWA 1990)*, *Evaluating Scour at Bridges (FHWA 2001)*, *Design of Encroachments on Flood Plains Using Risk Analysis (FHWA 1981)*, and *FHWA Stream Stability at Highway Structures (FHWA 2001)*.

2.2 Design Flows

Culverts and bridges shall be designed for future fully developed basin conditions consistent with approved drainage plans as outlined in the Hydrology Chapter. Specific requirements for culverts and bridges are contained in their respective sections and may vary depending on the classification of the roadway being crossed.

2.3 Permitting and Regulations

Designers of stream crossings must be cognizant of relevant local, state, and federal laws and permit requirements. Permits for construction activities in navigable waters are under the jurisdiction of the U.S. Army Corps of Engineers (USACE). For example, a USACE Section 404 permit is required for the discharge of dredged or fill material in waters of the U.S. Applications for federal permits may require environmental impact assessments under the National Environmental Policy Act of 1969. In Colorado, provisions of Senate Bill 40, which requires a Wildlife Certification, must be addressed on any stream crossing. Additionally, a Floodplain Development Permit is required for any stream crossing constructed in a regulatory floodplain, and FEMA CLOMR/LOMR requirements may apply, especially if work in the regulatory floodway is necessary. Refer to Chapter 5, Floodplain Management, for information regarding construction of improvements in floodplains.

2.4 Aesthetics and Safety

The appearance and safety of structures, including headwalls and wingwalls, are important considerations for acceptance of the design. The safety of the public, especially in areas of recreational use, shall also be considered when selecting the appropriate structure and handrail treatment for a given area. Structure geometry, materials, and the texture, patterning, and color of structure surfaces shall be selected to blend with the adjacent landscape and provide an attractive appearance.

2.5 Easement, Ownership and Maintenance Requirements

Culverts and bridges must be constructed within the public right-of-way for the roadway or within a combination of easements, tracts, and public right-of-way. Additional easement or right-of-way beyond the normal roadway right-of-way, tracts, or easement width may be required to facilitate the construction, operation and/or maintenance of the structure. Design plans for the structure shall include the proposed easement and/or right-of-way limits. Maintenance issues and access shall be considered in the structure design, and appropriate measures must be included to facilitate proper maintenance (e.g., access road if necessary).

2.6 Trail Coordination

Culverts and bridges often provide an opportunity for trails to cross roadways with a grade separation, avoiding conflicts between pedestrians and vehicles. Advance coordination with parks and trails personnel is necessary to determine if the proposed culvert or bridge location has been identified as a potential location for a separated grade trail crossing. If the location is determined to be compatible with a grade-separated trail from a planning standpoint and the crossing is physically possible, final design requirements for trail width, vertical clearance, surfacing, and lighting and safety improvements shall be coordinated with the parks and trails personnel. The low-flow channel adjacent to the trail bench shall pass the minor storm event or as much flow as practicable without inundating the trail, considering the duration of the flooding, inconvenience to the public, and available alternate routes. The low-flow channel adjacent to the trail shall convey flow at least equal to the capacity of the upstream low-flow channel when one is present. Connections of the trail to the roadway grade must be considered.

2.7 Utility Coordination

Utilities often run parallel to roadways and cross culverts or are located near culvert inlets and outlets. Advance coordination with the appropriate utility representatives is critical to avoid conflicts, provide adequate access, and protect them from damage.

2.8 Channel Stability

Drainage channels crossed by culverts and bridges must be stable for these structures to function as intended and remain structurally sound. The stability of the adjacent channel must be evaluated and addressed so that culverts and bridges are not threatened by channel degradation, sedimentation or migration. Guidance for stable channel design is provided in Chapter 12, Open Channels.

3.0 Culvert and Bridge Sizing

3.1 Culvert and Bridge Sizing Factors

The sizing of a culvert or bridge depends on several factors including whether the drainageway is major or minor, the street designation (i.e., residential, industrial, collector, arterial, or highway), the allowable street overtopping, and the allowable headwater depth. Overtopping is not allowed for any street designation at major drainageway crossings. Additionally, all new bridge structures must be designed to safely handle the major storm flows with the required freeboard.

For minor drainageways with culvert crossings, the allowable street overtopping for the various street designations is identified in Table 11-1.

Table 11-1. Allowable Culvert Overtopping for Minor Drainageways

Roadway Designation	Minor Storm	Major Storm
Residential, Industrial and Collector	No overtopping allowed	Must not exceed 12 inches at gutter flowline or 4 inches at crown[1]
Arterial	No overtopping allowed	No overtopping allowed
Freeway/Expressway	No overtopping allowed	No overtopping allowed

Note: No overtopping allowed for major drainageways.

[1] See Street Drainage Chapter, for further discussion regarding allowable flow depth in the street based on roadway designation.

When overtopping flows are allowed, adequate roadway embankment erosion protections measures should be provided to protect the roadway from erosion and potential embankment failure problems. Potential for overtopping and piping failures should be considered.

The criteria in this Manual are considered the minimum design standards and may need to be modified where other factors are considered more important. For example, the designer shall consider flooding of adjacent structures or private property, excessive channel velocities, availability of alternate routes, and other factors pertinent to a specific site. Lesser design criteria for rural areas or low-volume roadways may be approved on a case-by-case basis. Any variance from the design criteria outlined in this chapter will require prior approval.

3.2 Sizing Procedure for Streets When Overtopping is Allowed

When overtopping is allowed for residential, industrial, and collector streets, the following sizing procedure shall be followed:

1. Using the future developed condition major storm flow, the allowable flow over the street shall be determined based on the allowable overtopping depth and the roadway profile, treating the street crossing as a broad-crested weir.

2. The culvert is then sized for the difference between the major storm flow and the allowable flow over the street, using the allowable overtopping elevation as the maximum headwater elevation.

3. The culvert is then sized for the fully developed condition minor storm flow based on applicable design criteria.

4. The design culvert size shall be the larger of the two sizes.

3.3 Allowable Headwater

For all residential, industrial, and collector roadways, the maximum headwater to depth ratio for the major storm design flows will be 1.5 times the culvert opening height. For culverts through arterial roads and highways, the maximum headwater to depth ratio for the major storm design flows will be 1.2 times the culvert opening height. Headwater depth is typically measured from the centerline of the culvert rather than the invert.

3.4 Freeboard Requirements

No overtopping of roadways and bridges shall be allowed at major drainageway crossings for the major storm event. For culvert crossing structures, the minimum freeboard shall be 2 feet, measured from the major stormwater surface elevation to the lowest point of the roadway profile. The minimum required clearance for bridges shall be 2 feet, measured from the major stormwater surface elevation to the lowest elevation of the bridge low chord. However, the design engineer shall consider the profile grade of the bridge and roadway, potential for debris accumulation, predicted sedimentation, maintenance requirements, and other site-specific conditions to determine whether additional freeboard should be provided for the crossing structures.

4.0 Culvert Design

4.1 Construction Material

Culverts shall be made of reinforced concrete in round or elliptical cross-sections (minimum Class 3) or reinforced concrete box shapes that are either cast-in-place or supplied in precast sections. Other materials may be allowed if design criteria and service life requirements can be satisfied. Special design considerations, such as bedding requirements, shall also be considered if an alternate material is used. When the culvert is expected to carry a large, persistent load of abrasive material (e.g., gravel or cobble bedload), a special design is required to protect the full invert area (lower 90 degrees).

4.2 Minimum Size

The minimum pipe size for a cross culvert within a public right-of-way shall be 18 inches in diameter for round culverts, or shall have an equivalent cross-sectional area for arch or elliptical shapes. Box culverts shall be as tall as practical, but shall not have less than a 3-foot-high inside dimension.

4.3 Culvert Sizing and Design

Culvert design involves an iterative approach. Two references are particularly helpful in the design of culverts. The Culverts Chapter of the UDFCD Manual provides design aids and guidance taken from *Hydraulic Design Series No. 5, Hydraulic Design of Highway Culverts* (FHWA 2012). The FHWA circular explains inlet and outlet control and the procedure for designing culverts.

4.4 Capacity Curves

There are many charts, tables, and curves in the literature for the computation of culvert hydraulic capacity. To assist in the review of the culvert design computations and to obtain uniformity of analysis, the Capacity Charts and Nomographs provided in the Culverts Chapter of the UDFCD Manual shall be used for determining culvert capacity.

Selection of the appropriate entrance coefficients shall be based on the information presented in the Culverts Chapter of the UDFCD Manual or in *Hydraulic Design of Highway Culverts* (FHWA 2012). When non-standard design elements are utilized, the designer should refer to *Hydraulic Design of Highway Culverts* (FHWA 2012) for information on treating special cases.

4.5 Design Forms

Standard Form CU-8 in the Culverts Chapter of the UDFCD Manual or other versions of this form shall be used to present and document the culvert design process when spreadsheets or computer programs are not used for culvert sizing and design. Form CU-8 or the equivalent must be included in the drainage report when used to document the culvert design.

4.6 Design Software

UDFCD has prepared a spreadsheet to aid with the calculations for the more common culvert designs. The spreadsheet applications utilize the FHWA nomographs. FHWA's HY-8 Culvert Analysis program is another computer application used to design culverts (FHWA 2011). Other computer programs or software, which are based on the methodologies presented in *Hydraulic Design of Highway Culverts* (FHWA 2012) may also be used for culvert design. The UD-Culvert Spreadsheet and the FHWA's HY-8 Culvert Analysis programs are available on the UDFCD website www.udfcd.org.

4.7 Velocity Considerations

In the design of culverts, both the minimum and maximum velocities must be considered. A minimum flow velocity of 3 feet per second (ft/sec) is required when the culvert conveys runoff from frequently occurring storm events to reduce the potential for sediment accumulation and reduce maintenance requirements. A flow equal to 25 percent of the minor storm event flow shall be used to check the minimum velocity. The culvert slope must be equal to or greater than the slope required to achieve the minimum velocity. The slope should be checked for each design, and if the proper minimum velocity is not achieved, the pipe diameter may be decreased, the slope steepened, a smoother pipe used, or a combination of these may be used.

When a large culvert size is required to pass the major storm event, it may be necessary to route the minor storm event in a separate structure or in a portion of the larger culvert to maintain minimum velocities. Also, when the channel conveying flows to the culvert has a low-flow channel within its cross section, the design flow of the low-flow channel shall be passed through the culvert while maintaining the minimum velocity.

The velocity in a culvert during the major storm event shall not exceed 15 ft/sec.

4.8 Structural Design

As a minimum, all culverts shall be designed to withstand an HS-20 loading in accordance with the design procedures in *Standard Specifications for Highway Bridges, 17th Edition* (AASHTO 2002, updated

2005) and with the pipe manufacturer's recommendation and anticipated static and dynamic loadings. It is the engineer’s responsibility to determine if a culvert installation needs to be designed to withstand a loading other than HS-20.

4.9 Alignment

The alignment of the culvert with respect to the natural channel is very important for proper hydraulic performance. Culverts may pass beneath the roadway normal to the centerline, or they may pass at an angle (skewed). Culverts shall be aligned with the natural channel to the extent practical. This reduces inlet and outlet transition problems.

Where the natural channel alignment would result in an exceptionally long culvert, modification of the natural channel alignment may be necessary. Modifications to the channel alignment or profile affect the natural stability of the channel, and proposed modifications shall be thoroughly investigated. In many cases where the channel alignment is modified, grade control or drop structures are needed to achieve stable channel slopes upstream or downstream of the culvert. Although economic factors are important, the hydraulic effectiveness of the culvert and channel stability must be given major consideration. Improper culvert alignment and poorly designed outlet protection may cause erosion of adjacent properties, increased instability of the natural channel and sedimentation in the culvert.

4.10 Stationing

Culvert stationing shall run from downstream to upstream and match channel stationing when designed as part of a channel improvement project. The location of the roadway centerline crossing with the culvert alignment shall be identified based on the culvert stationing.

4.11 Minimum Cover

The vertical alignment of roadways relative to the natural existing channel profile may define the maximum culvert diameter/height that can be used. Low vertical clearance may require the use of elliptical or arched culverts, or the use of a multiple-barrel culvert system. All culverts shall have a minimum of 1.5 feet of cover from the roadway subgrade elevation to the outside of the top of the pipe. A variance will be required for culverts with less than 1.5 feet of cover. When analyzing the minimum cover over a culvert, consideration should be given to potential treatment of the subgrade for mitigation of swelling soils, the placement of other utilities, live loading conditions, and other factors that may affect the pipe cover.

4.12 Multiple-Barrel Culverts

If the available fill height limits the size of the culvert necessary to convey the design flows, multiple culverts can be used. The number of separate culvert barrels shall be kept to a minimum to minimize clogging potential and maintenance costs. If each barrel of a multiple-barrel culvert is of the same type and size and constructed so that all hydraulic parameters are equal, the total flow shall be assumed to be equally divided among each of the barrels.

4.13 Trash Racks

Designs that include trash racks or grates on culvert inlets will be reviewed on a case-by-case basis when there is sufficient justification for considering the use of a trash rack or grate. Protecting public safety is of paramount importance when considering use of trash racks. Alternatives to limit access or catch debris upstream of the culvert inlet should be thoroughly investigated prior to considering improvements to the culvert inlet. See the Culverts Chapter of the UDFCD Manual for additional discussion and requirements regarding these structures, including public safety precautions.

4.14 Inlets and Outlets

Culvert inlets will require erosion protection where stable channel velocities are exceeded. If needed, riprap erosion protection shall be designed according to the procedures outlined in the Major Drainage Chapter in the UDFCD Manual. Additionally, culvert outlets are discussed further in Chapter 10, Conduit Outlet Structures.

4.15 Debris

When flows are likely to carry floating debris or other materials sufficient to obstruct the culvert entrance, the potential effects of the debris shall be considered. To address the effect of the debris, the culvert design may be altered to pass a higher flow or debris blockage devices may need to be installed upstream of the culvert entrance.

4.16 Service Life

The service life for culverts shall be 50 years. An extended service life of 100 years shall be required when:

- The depth of cover exceeds 15 feet.
- The culvert is located within the travel lanes of 4-lane or major and minor arterial roadways.
- The centerline of the culvert is located 15 feet or less horizontally from any building structure.

The approval of alternative pipe materials shall be based on the determination that their service life is estimated to be at least equal to durations stated herein.

5.0 Driveway Culverts

5.1 Applicable Criteria

The requirements in this section apply to new rural residential subdivisions where the roadside ditch has some depth (typically greater than 18 inches). Urban roadside grass buffers/swales, which are usually shallow and primarily used to minimize directly connected impervious area for a development, will be treated in a different manner (see Volume 3 of the UDFCD Manual).

5.2 Construction Material

Driveway culverts shall be constructed from concrete (RCP), High Density Polyethylene (HDPE) or corrugated metal (CMP/CMPA).

5.3 Sizing

Driveway culverts for new developments shall be sized to pass the minor storm ditch flow so that the allowable street encroachments and depths defined in Chapter 7, Street Drainage, are not exceeded. The minimum size for driveway culverts shall be 18 inches in diameter for round pipe or shall have a minimum cross-sectional area of 1.77 square feet for arch or elliptical shapes.

5.4 Minimum Cover

Driveway culverts shall be provided with the minimum cover recommended by the pipe structural design requirements or 1 foot, whichever is greater.

5.5 Culvert End Treatments

All driveway culverts shall be provided with end treatments on the upstream and downstream ends of the culvert to protect and help maintain the integrity of the culvert opening. Headwalls, wingwalls, and flared end sections are acceptable end treatments. Erosion protection shall be provided as necessary according to the criteria for culvert inlets and outlets. Toe walls are not typically required for driveway culverts.

5.6 Design Velocity

The driveway culvert design shall achieve the minimum velocities outlined in Section 4.7 of this chapter, and the maximum velocity shall not exceed 10 ft/sec.

5.7 Drainage Report and Construction Drawings

Additional information must be included in the drainage report and on the construction drawings for new subdivisions where the use of roadside ditches and driveway culverts is proposed. The effect of driveway culverts on the capacity of the roadway to convey storm flows must be evaluated. The allowable flow depths and lane encroachments defined by the Chapter 7, Street Drainage, must be maintained, and flows must be contained within available right-of-way.

Driveway culverts shall be sized for each lot in the subdivision drainage report, based on the tributary area at the downstream lot line. The construction drawings shall include information regarding sizes, materials, locations, lengths, grades, and end treatments for all driveway culverts. Typical driveway crossing/culvert details shall be included in the construction drawings. In general, typical roadside ditch sections do not have adequate depth to accommodate driveway culvert installations, which meet the criteria outlined in this section. Construction drawings must address the roadside ditch section in detail to ensure that adequate depth is provided to accommodate the driveway culverts, including the minimum cover and considering overtopping of the driveway when the culvert capacity is exceeded. See Figure 11-1 for additional information.

6.0 Bridge Hydraulic Design

As described in Section 2.1, the hydraulic design of a bridge is very specific to site conditions and numerous factors must be considered. A partial list of these factors includes location and skew, structural type selection, water surface profiles and required freeboard, floodplain management and permitting, scour considerations, deck drainage, and environmental permitting. The consideration of these factors requires that every bridge project have a unique design. All new bridges shall be designed to safely handle the major design storm event flows with the required freeboard. Replacement bridge structures should also be designed to the same standards; however, depending on the site conditions, adjustments to the criteria may be necessary.

Hydraulic analysis of the channel passing under the bridge must be of sufficient extent upstream and downstream to identify any conditions that might affect the hydraulic performance of the channel and structure. The channel cross section, including the low-flow channel, should be maintained through the bridge to the extent practical to minimize changes to the hydraulics of the channel. Generally, a rise of no more than 1 foot in the water surface of the channel through the bridge structure should occur. Appropriate sediment transport and scour analyses shall also be completed to account for long-term changes in the channel bed or cross section. When debris flow is considered likely, the hydraulic capacity of the bridge crossing shall be appropriately adjusted to recognize the potential reduction due to accumulated debris or debris handling devices may need to be installed on the bridge or upstream.

7.0 Low-Water Crossings/Pedestrian Bridges

Crossings for pedestrian use can vary greatly from small, low-use crossings to regional trail crossings. The crossings can have impacts on the floodplain, wetlands, and wildlife habitat. For these reasons, pedestrian and low-water crossings will be treated on an individual basis, with criteria established following submittal of a request for the crossing. Consideration shall be given to floodplain impacts, debris accumulation and passage, sediment transport, structural design, tethering of the structure or potential blockage of other conveyance structures, clearances to water levels and structural members, maintenance responsibility and cost, and construction and replacement cost of the structure.

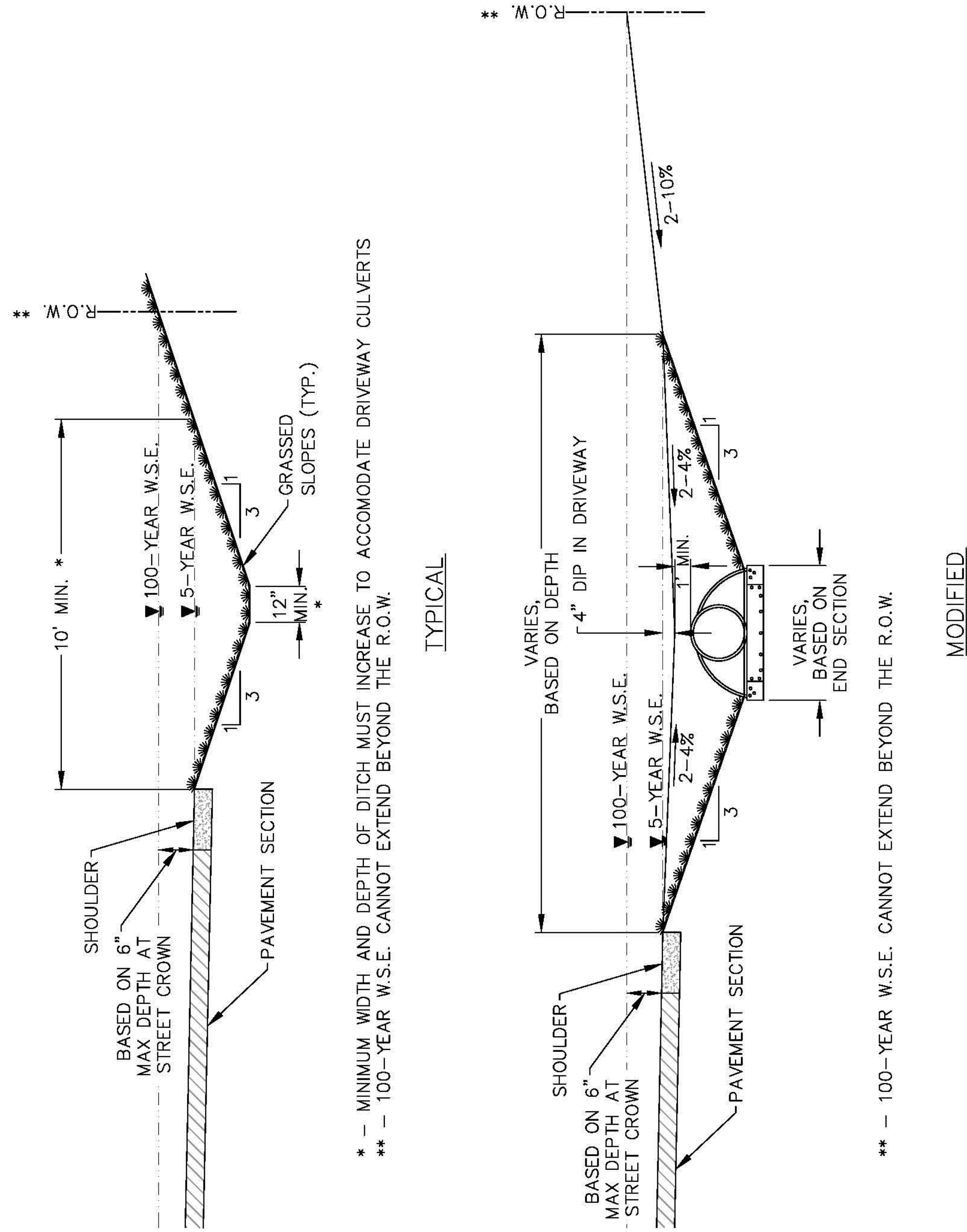

Figure 11-1. Roadside Ditch Modification for Driveway Culverts