



7.3 Culvert Design

A *culvert* is a short, closed (covered) conduit that conveys stormwater runoff under an embankment, usually a roadway. The primary purpose of a culvert is to convey surface water, but properly designed it may also be used to restrict flow and reduce downstream peak flows. In addition to the hydraulic function, a culvert must also support the embankment and/or roadway, and protect traffic and adjacent property owners from flood hazards to the extent practicable.

Most culvert design is empirical and relies on nomographs and standard procedures. The purpose of this section is to provide an overview of culvert design standards and procedures.

7.3.1 Symbols and Definitions

To provide consistency within this section the symbols listed in Table 7-1 will be used. These symbols were selected because of their wide use.

Table 7-1. Culvert Design Symbols and Definitions

| Symbol | Definition | Units |
|----------------|--|-------------------|
| A | Area of cross section of flow | ft ² |
| B | Barrel width | ft |
| C _d | Overtopping discharge coefficient | - |
| D | Culvert diameter or barrel width | in or ft |
| d | Depth of flow | ft |
| d _c | Critical depth of flow | ft |
| d _u | Uniform depth of flow | ft |
| g | Acceleration due to gravity | ft/s ² |
| H _f | Depth of pool or head, above the face section of invert | ft |
| h _o | Height of hydraulic grade line above outlet invert | ft |
| HW | Headwater depth above invert of culvert (depth from inlet to upstream total energy grade line) | ft |
| K _e | Inlet loss coefficient | - |
| L | Length of culvert | ft |
| N | Number of barrels | - |
| Q | Rate of discharge | cfs |
| S | Slope of culvert | ft/ft |
| TW | Tailwater depth above invert of culvert | ft |
| V | Mean velocity of flow | ft/s |
| V _c | Critical velocity | ft/s |

7.3.2 Design Standards and Considerations

The design of a culvert should take into account many different engineering and technical aspects at the culvert site and adjacent areas. The list below presents the key considerations for the design of culverts.

- Culverts can serve double duty as flow retarding structures in grass channel design. Care should be taken to design them as storage control structures if flow depths exceed several feet, and to ensure public safety.
- Improved inlet designs can absorb considerable energy for steeper sloped and skewed inlet condition designs, thus helping to protect channels.

All culverts designed and installed in Knox County shall conform to the design standards listed in the following sections.



7.3.2.1 Frequency Flood

The 25-year frequency storm shall be routed through all culverts and the 100-year storm shall be used as a check, to verify structures (e.g., houses, commercial buildings) are not flooded or increased damage does not occur to the highway or adjacent property for this design event.

7.3.2.2 Velocity Limitations

Both minimum and maximum velocities shall be considered when designing a culvert. The maximum velocity shall be consistent with channel stability requirements at the culvert outlet. The maximum allowable velocity is 15 feet per second. Outlet protection shall be provided where discharge velocities will cause erosion problems. To ensure self-cleaning during partial depth flow, culverts shall have a minimum velocity of 2.5 feet per second at design flow or lower, with a minimum slope of 0.5%.

7.3.2.3 Buoyancy Protection

Buoyancy protection shall be provided for all flexible culverts. This can be provided through the use of headwalls, endwalls, slope paving or other means of anchoring.

7.3.2.4 Length and Slope

The culvert length and slope shall be chosen to approximate existing topography. To the degree practicable, the culvert invert should be aligned with the channel bottom and the skew angle of the stream, and the culvert entrance should match the geometry of the roadway embankment.

7.3.2.5 Debris Control

Debris control shall be performed in a manner consistent with *Hydraulic Engineering Circular No. 9* entitled Debris Control Structures (FHWA, 1971), which contains criteria pertaining to the design of debris control structures.

7.3.2.6 Headwater Limitations

Headwater is water above the culvert invert at the entrance end of the culvert. The allowable headwater elevation is that elevation above which damage may be caused to adjacent property and/or the roadway. The headwater elevation is determined from an evaluation of land use upstream of the culvert and the proposed or existing roadway elevation. It is this allowable headwater depth that is the primary basis for sizing a culvert.

The following criteria related to headwater should be considered when designing a culvert for the 25-year design storm event.

- The *allowable headwater* is the depth of water that can be ponded at the upstream end of the culvert during the 100 yr event with clogged conditions, which will be limited by one or more of the following constraints or conditions.
 - (1) The allowable headwater must not damage upstream property.
 - (2) The ponding depth is to be no greater than the low point in the road grade.
 - (3) The ponding depth is to be no greater than the elevation where flow diverts around the culvert.
 - (4) Headwater elevations shall be established to delineate potential flood zones.
- In general, the constraint that gives the lowest allowable headwater elevation (HW) establishes the criteria for the hydraulic calculations.



- For drainage facilities with cross-sectional area equal to or less than 30 ft², HW/D should be equal to or less than 1.5.
- For drainage facilities with cross-sectional area greater than 30 ft², HW/D should be equal to or less than 1.2.
- The headwater should be checked using the peak discharge for the 100-year frequency event (Q_{p100}) to ensure compliance with storm system design criteria. As well, the culvert should be sized to maintain flood-free conditions on classified roadways.
- The maximum acceptable outlet velocity shall be identified (see Section 7.4.3) in drainage calculations included with the Stormwater Management Plan.
- Acceptable flow velocities shall be achieved by one of two ways: the headwater shall be set to an appropriate elevation; or, stabilization or energy dissipation shall be provided where acceptable velocities are exceeded.
- Other site-specific design considerations shall be addressed as required by the Director.

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7.3.2.7 Tailwater Considerations

The hydraulic conditions downstream of the culvert site must be evaluated to determine a tailwater depth for a range of discharge. At times, there may be a need for calculating backwater curves to establish the tailwater conditions. The following conditions must be considered when establishing tailwater conditions.

- If the culvert outlet is operating with a free outfall, the critical depth and equivalent hydraulic grade line should be determined.
- For culverts that discharge to an open channel, the stage-discharge curve for the channel must be determined (see Section 7.4).
- If an upstream culvert outlet is located near a downstream culvert inlet, the headwater elevation of the downstream culvert may establish the design tailwater depth for the upstream culvert.
- If the culvert discharges to a lake, pond, or other major water body, the expected high water elevation of the particular water body can be used to establish the culvert tailwater.

7.3.2.8 Storage

If storage is being assumed or will occur upstream of the culvert, storage routing must be performed in accordance with the information provided in Section 7.3.4.6.

7.3.2.9 Culvert Inlets

Hydraulic efficiency and cost can be significantly affected by inlet conditions. The inlet coefficient K_e, is a measure of the hydraulic efficiency of the inlet, with lower values indicating greater efficiency. Recommended inlet coefficients are given in Table 7-2.

Table 7-2. Inlet Coefficients

(Source: USDOT, 1985)

| Type of Structure & Design of Entrance | Coefficient K _e |
|---|----------------------------|
| Pipe Concrete | |
| Projecting from fill, socket end (groove-end) | 0.2 |
| Projecting from fill, square cut end | 0.5 |
| Headwall or headwall and wingwalls | |
| Socket end of pipe (groove-end) | 0.2 |



| | |
|---|-----|
| Square-edge | 0.5 |
| Rounded [radius = 1/12(D)] | 0.2 |
| Mitered to conform to fill slope | 0.7 |
| End-Section conforming to fill slope* | 0.5 |
| Beveled edges, 33.7° or 45° bevels | 0.2 |
| Side- or slope-tapered inlet | 0.2 |
| Pipe, or Pipe-Arch, Corrugated Metal¹ | |
| Projecting from fill (no headwall) | 0.9 |
| Headwall or headwall and wingwalls square-edge | 0.5 |
| Mitered to fill slope, paved or unpaved slope | 0.7 |
| End-Section conforming to fill slope* | 0.5 |
| Beveled edges, 33.7° or 45° bevels | 0.2 |
| Side- or slope-tapered inlet | 0.2 |
| Box, Reinforced Concrete | |
| Headwall parallel to embankment (no wingwalls) | |
| Square-edged on 3 edges | 0.5 |
| Rounded on 3 edges to radius of [1/12(D)] or beveled edges on 3 sides | 0.2 |
| Wingwalls at 30° to 75° to barrel | |
| Square-edged at crown | 0.4 |
| Crown edge rounded to radius of [1/12(D)] or beveled top edge | 0.2 |
| Wingwalls at 10° or 25° to barrel | |
| Square-edged at crown | 0.5 |
| Side- or slope-tapered inlet | 0.2 |
| ¹ Although laboratory tests have not been completed on K_e values for High-Density Polyethylene (HDPE) pipes, the K_e values for corrugated metal pipes are recommended for HDPE pipes. * Note: End Section conforming to fill slope, made of either metal or concrete, are the sections commonly available from manufacturers. From limited hydraulic tests they are equivalent in operation to a headwall in both inlet and outlet control. | |

7.3.2.10 Inlets with Headwalls

Headwalls may be used for a variety of reasons, including increasing the efficiency of the inlet, providing embankment stability, providing embankment protection against erosion, providing protection from buoyancy, and shortening the length of the required structure. Headwalls are required for all metal culverts and where buoyancy protection is necessary. If high headwater depths are to be encountered, or the approach velocity in the channel will cause scour, a short channel apron shall be provided at the toe of the headwall.

This apron should extend at least one pipe diameter upstream from the entrance, and the top of the apron should not protrude above the normal streambed elevation.

7.3.2.11 Wingwalls

Wingwalls must be used where the side slopes of the channel adjacent to the entrance are unstable or where the culvert is skewed to the normal channel flow.

7.3.2.12 Improved Inlets

Where inlet conditions control the amount of flow that can pass through the culvert, improved inlets can greatly increase the hydraulic performance of the culvert.

7.3.2.13 Material Selection

Reinforced concrete pipe (RCP) is recommended for use (1) under a roadway, (2) when pipe slopes are less than 1%, or (3) for all flowing streams. RCP must be used for culverts designed for a 100-year storm, if the culverts lie in public lands or easements.



RCP and fully coated corrugated metal pipe can be used in all other cases. High-density polyethylene (HDPE) pipe may also be used where permitted by the Director. Table 7-3 gives recommended Manning's "n" values for different materials.

Table 7-3. Manning's "n" Values

(Source: USDOT, 1985)

| Type of Conduit | Wall & Joint Description | Manning's "n" |
|---|--|---------------|
| Concrete Pipe | Good joints, smooth walls | 0.012 |
| | Good joints, rough walls | 0.016 |
| | Poor joints, rough walls | 0.017 |
| Concrete Box | Good joints, smooth finished walls | 0.012 |
| | Poor joints, rough, unfinished walls | 0.018 |
| Corrugated Metal Pipes and Boxes Annular Corregations | 2-2/3- by 1/2-inch corrugations | 0.024 |
| | 6- by 1-inch corrugations | 0.025 |
| | 5- by 1-inch corrugations | 0.026 |
| | 3- by 1-inch corrugations | 0.028 |
| | 6-by 2-inch structural plate | 0.035 |
| | 9-by 2-1/2 inch structural plate | 0.035 |
| Corrugated Metal Pipes, Helical Corrugations, Full Circular Flow | 2-2/3-by 1/2-inch corrugated 24-inch plate width | 0.012 |
| Spiral Rib Metal Pipe | 3/4 by 3/4 in recesses at 12 inch spacing, good joints | 0.013 |
| High Density Polyethylene (HDPE) | Corrugated Smooth Liner | 0.015 |
| | Corrugated | 0.020 |
| Polyvinyl Chloride (PVC) | | 0.011 |
| Note: For further information concerning Manning "n" values for selected conduits consult Hydraulic Design of Highway Culverts, Federal Highway Administration, HDS No. 5, page 163 | | |

7.3.2.14 Culvert Skews

Culvert skews shall not exceed 45 degrees as measured from a line perpendicular to the roadway centerline without approval.

7.3.2.15 Culvert Sizes

The minimum allowable pipe diameter shall be 15 inches.

7.3.2.16 Weep Holes

Weep holes are sometimes used to relieve uplift pressure. Filter materials shall be used in conjunction with the weep holes in order to intercept the flow and prevent the formation of piping channels. The filter materials shall be designed as an underdrain filter so as not to become clogged and so that piping cannot occur through the pervious material and the weep hole.

7.3.2.17 Outlet Protection

Water shall not discharge from a culvert in an erosive manner. Outlet protection shall be provided for all design storms. See Section 7.5 for information on the design of outlet protection.

7.3.2.18 Environmental Considerations

Where compatible with good hydraulic engineering, a site should be selected that will permit the culvert to be constructed to cause the least impact on the stream, wetlands and other environmentally sensitive features that may be located on the site. This selection must consider the entire site, including any necessary lead channels.

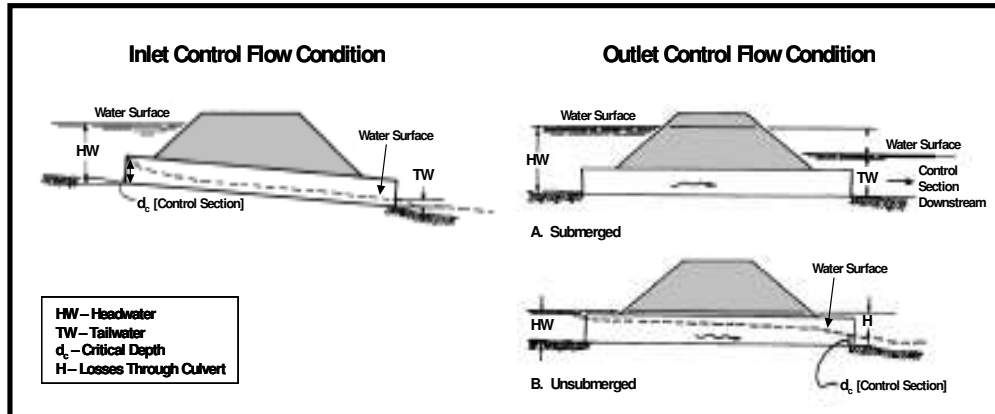
7.3.3 Design Procedures

7.3.3.1 Types of Flow Control

There are two types of flow conditions for culverts that are based upon the location of the control section and the critical flow depth. These flow conditions are presented in Figure 7-7 and are described briefly below.

Figure 7-7. Culvert Flow Conditions

(Adapted from: USDOT, 1985)



Inlet Control – Inlet control occurs when the culvert barrel is capable of conveying more flow than the inlet will accept. This typically happens when a culvert is operating on a steep slope. The control section of a culvert is located just inside the entrance. Critical depth occurs at or near this location, and the flow regime immediately downstream is supercritical.

Outlet Control – Outlet control flow occurs when the culvert barrel is not capable of conveying as much flow as the inlet opening will accept. The control section for outlet control flow in a culvert is located at the barrel exit or further downstream. Either subcritical or pressure flow exists in the culvert barrel under these conditions.

Proper culvert design and analysis requires checking for both inlet and outlet control to determine which will govern particular culvert designs. For more information on inlet and outlet control, see [Hydraulic Design of Highway Culverts](#) (USDOT, 1985).

7.3.3.2 Procedures

There are two procedures for designing culverts: manual use of inlet and outlet control nomographs; and the use computer programs such as HY8 or Haestad Methods programs such as CulvertMaster or FlowMaster. It is recommended that a computer model be used for culvert design. The computer software packages available use the theoretical basis from the nomographs to size culverts. In addition, these software packages can evaluate improved inlets, route hydrographs, consider road overtopping, and evaluate outlet streambed scour. By using water surface profiles, this procedure is more accurate in predicting backwater effects and outlet scour.



7.3.3.3 Nomographs

The use of culvert design nomographs requires a trial and error solution. Nomograph solutions provide reliable designs for many applications. It should be remembered that velocity, hydrograph routing, roadway overtopping, and outlet scour require additional, separate computations beyond what can be obtained from the nomographs. Figures 7-8(a) and (b) show examples of an inlet control and outlet control nomograph for the design of concrete pipe culverts. For other culvert designs, refer to the complete set of nomographs in Appendix A.

7.3.3.4 Design Procedure

The following design procedure requires the use of inlet and outlet nomographs.

(Step 1) List design data:

- | | |
|---|---|
| Q = discharge (cfs) | L = culvert length (ft) |
| S = culvert slope (ft/ft) | TW= tailwater depth (ft) |
| V = velocity for trial diameter (ft/s) | K _e = inlet loss coefficient |
| HW= allowable headwater depth for the design storm (ft) | D = pipe diameter (in) |

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(Step 2) Determine trial culvert size by assuming a trial velocity 5 to 8 ft/s and computing the culvert area, $A = Q/V$. Determine the culvert diameter.

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(Step 3) Find the actual HW for the trial size culvert for both inlet and outlet control.

- For inlet control, enter inlet control nomograph with D and Q and find HW/D for the proper entrance type.
- Compute HW and, if too large or too small, try another culvert size before computing HW for outlet control.
- For outlet control enter the outlet control nomograph with the culvert length, entrance loss coefficient, and trial culvert diameter.
- To compute HW, connect the length scale for the type of entrance condition and culvert diameter scale with a straight line, pivot on the turning line, and draw a straight line from the design discharge through the turning point to the head loss scale H. Compute the headwater elevation HW from Equation 7-10.

Equation 7-10

$$HW = H + h_o - LS$$

- where:
- H = head loss, ft
 - h_o = ½(critical depth + D) or tailwater depth, whichever is greater (maximum = D)
 - L = culvert length
 - S = culvert slope



Figure 7-8(a). Headwater Depth for Concrete Pipe Culvert with Inlet Control
 (Source: USDOT, 1985)

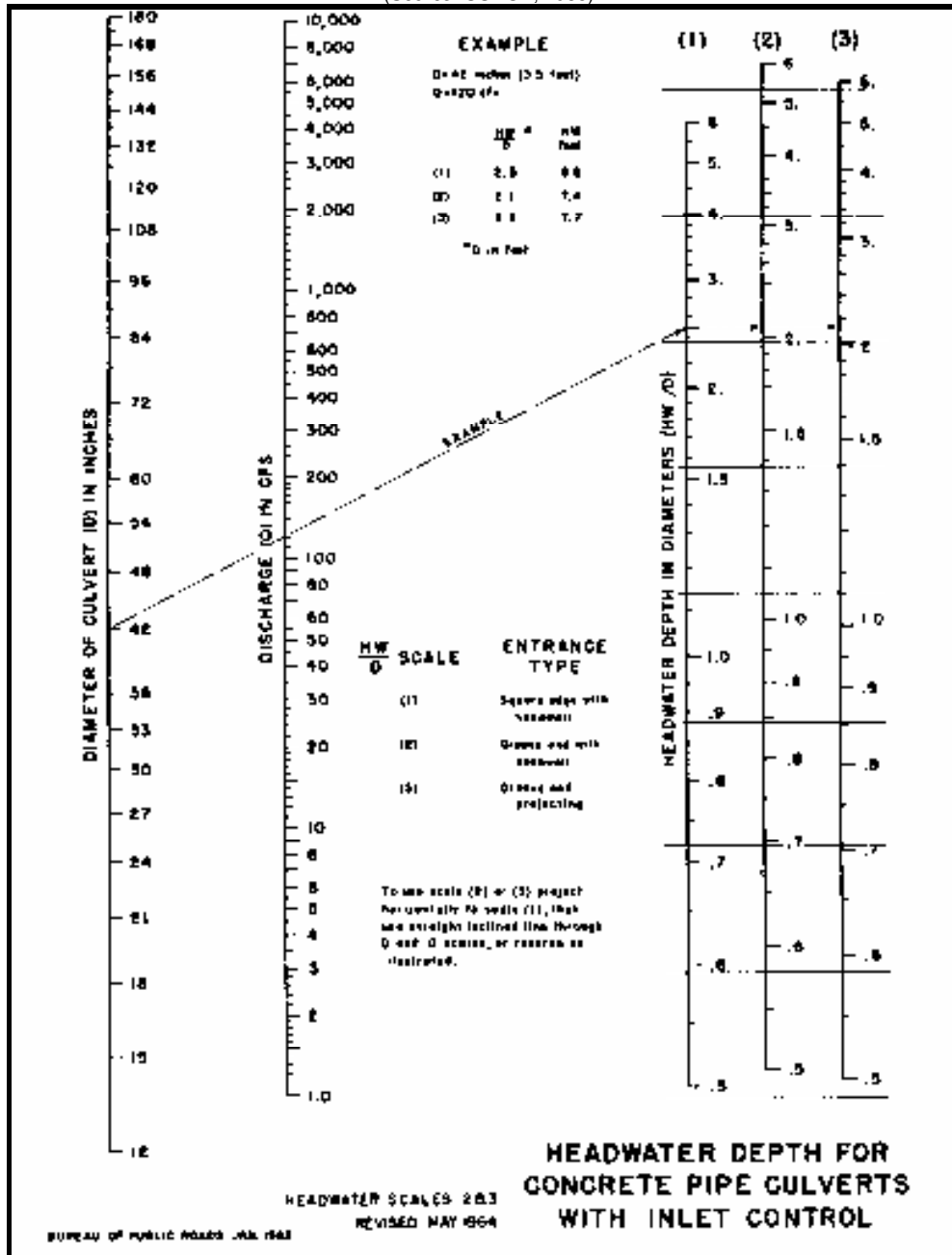
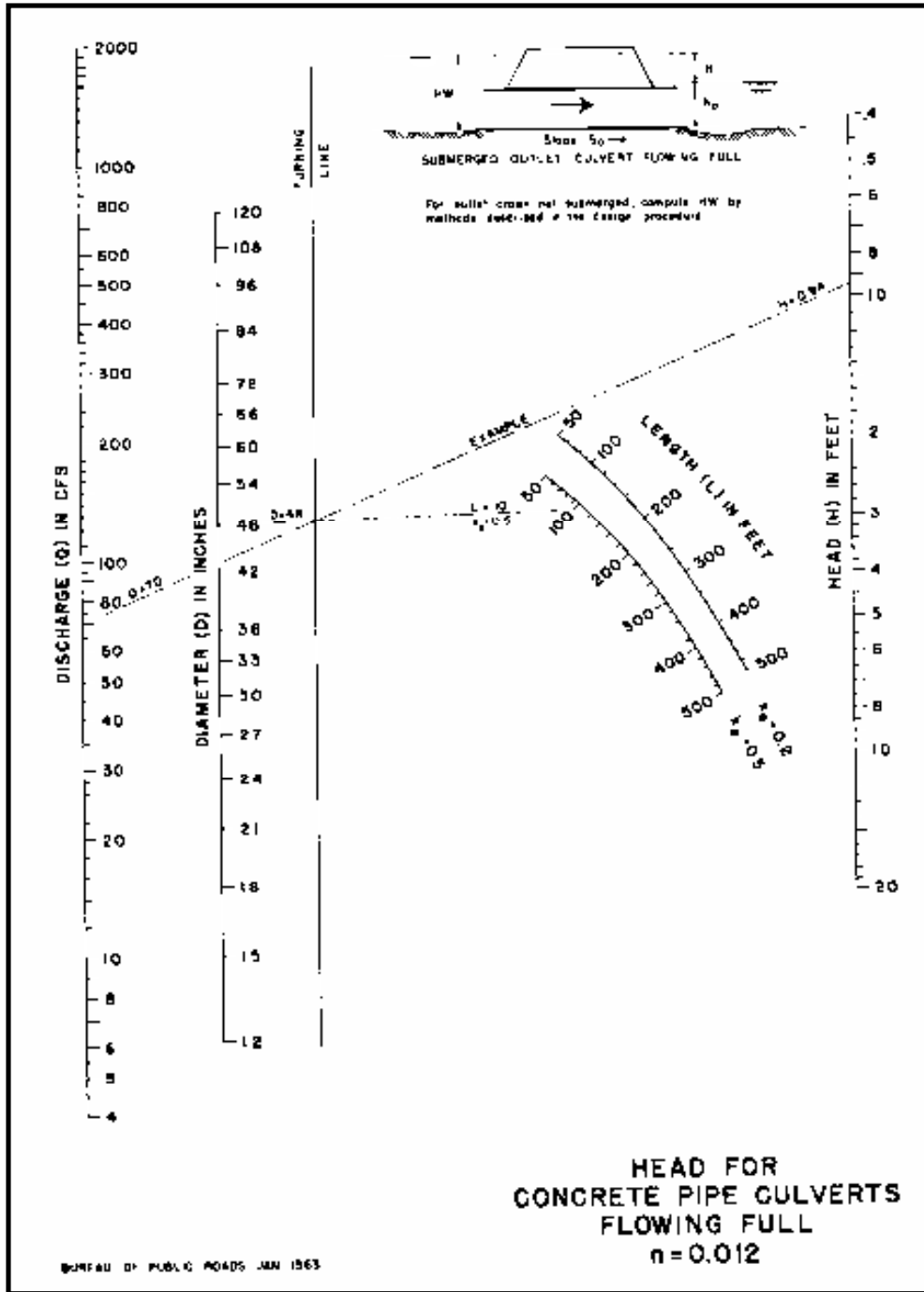




Figure 7-8(b). Head for Concrete Pipe Culverts Flowing Full

(Source: USDOT, 1985)





- (Step 4) Compare the computed headwaters and use the higher HW nomograph to determine if the culvert is under inlet or outlet control.
- If inlet control governs, then the design is complete and no further analysis is required.
 - If outlet control governs and the HW is unacceptable, select a larger trial size and find another HW with the outlet control nomographs. Since the smaller size of culvert had been selected for allowable HW by the inlet control nomographs, the inlet control for the larger pipe need not be checked.
- (Step 5) Calculate exit velocity and if erosion problems might be expected, refer to Section 7.5 for appropriate energy dissipation designs.

7.3.3.5 Performance Curves - Roadway Overtopping

A performance curve for any culvert can be obtained from the nomographs by repeating the steps outlined above for a range of discharges that are of interest for that particular culvert design. A graph is then plotted of headwater versus discharge with sufficient points so that a curve can be drawn through the range of interest. These curves are applicable through a range of headwater depths and velocities versus discharges for specific lengths and types of culvert. Such computations are made much easier by the use of computer programs.

To complete the culvert design, roadway overtopping must be analyzed. A performance curve showing the culvert flow as well as the flow across the roadway is a useful analysis tool. Rather than using a trial and error procedure to determine the flow division between the overtopping flow and the culvert flow, an overall performance curve can be developed.

The overall performance curve can be determined using the following general procedure.

- (Step 1) Select a range of flow rates and determine the corresponding headwater elevations for the culvert flow alone. The flow rates should fall above and below the design discharge and cover the entire flow range of interest. Both inlet and outlet control headwaters should be calculated.
- (Step 2) Combine the inlet and outlet control performance curves to define a single performance curve for the culvert.
- (Step 3) When the culvert headwater elevations exceed the roadway crest elevation, overtopping will begin. Calculate the equivalent upstream water surface depth above the roadway (crest of weir) for each selected flow rate. Use these water surface depths and equation 7-11 to calculate flow rates across the roadway.

Equation 7-11
$$Q = C_d L(HW)^{1.5}$$

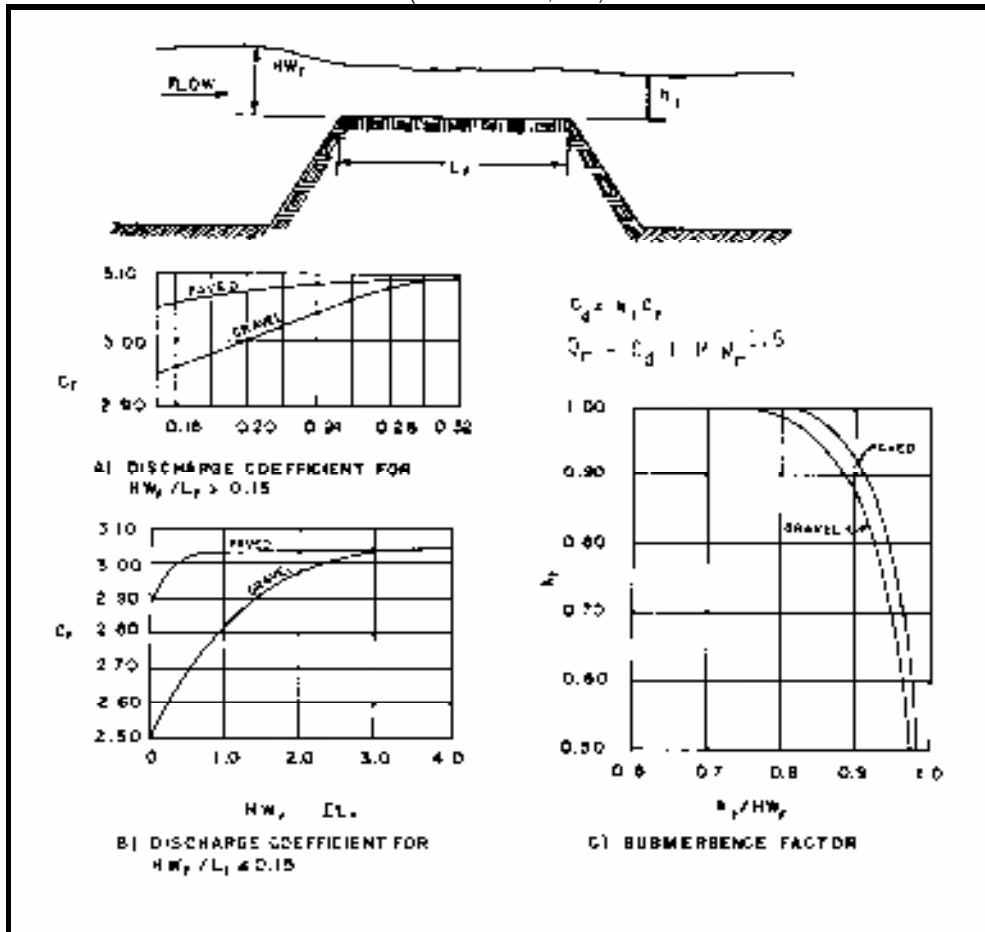
where: Q = overtopping flow rate (cfs)
 C_d = overtopping discharge coefficient
 L = length of roadway (ft)
 HW = upstream depth, measured from the roadway crest to the water surface up-stream of the weir drawdown (ft)

Note: See Figure 7-9 for guidance in determining a value for C_d . For more information on calculating overtopping flow rates see pages 38 - 40 in the Hydraulic Design of Highway Culverts (USDOT, 1985).

- (Step 4) Add the culvert flow and the roadway overtopping flow at the corresponding headwater elevations to obtain the overall culvert performance curve.

Figure 7-9. Discharge Coefficients for Roadway Overtopping

(Source: USDOT, 1985)



7.3.3.6 Storage Routing

A significant storage capacity behind a highway embankment attenuates a flood hydrograph. Because of the reduction of the peak discharge associated with this attenuation, the required capacity of the culvert, and its size, may be reduced considerably. If significant storage is anticipated behind a culvert, the design should be checked by routing the design hydrographs through the culvert to determine the discharge and stage behind the culvert. See Section 7.3.7 and Volume 2, Chapter 3, Section 3.2 for more information on routing. Additional routing procedures are outlined in Hydraulic Design of Highway Culverts (USDOT, 1985).

Note: Storage should be taken into consideration only if the storage area will remain available for the life of the culvert as a result of purchase of ownership or right-of-way or an easement has been acquired.



7.3.4 Culvert Design Example

The following example problem illustrates the procedures to be used in designing culverts using the nomographs.

Example 7-1. Culvert Sizing Example

Size a concrete pipe culvert given the following example data, which were determined by physical limitations at the culvert site and hydraulic procedures described elsewhere in this manual.

Input Data

Discharge for 2-yr flood = 35 cfs
 Discharge for 25-yr flood = 70 cfs
 Allowable headwater (HW) for 25-yr discharge = 5.25 ft
 Length of culvert = 100 ft
 Natural channel invert elevations - inlet = 15.50 ft, outlet = 14.30 ft
 Culvert slope = 0.012 ft/ft
 Tailwater depth for 25-yr discharge = 3.5 ft
 Tailwater depth is the normal depth in downstream channel
 Entrance type = Groove end with headwall

Computations

Step 1. Assume a culvert velocity of 5 ft/s. Required flow area = $70 \text{ cfs}/(5 \text{ ft/s}) = 14 \text{ ft}^2$ (for the 25-yr recurrence flood).

Step 2. The corresponding culvert diameter is about 48 in (4 ft). This can be calculated by using the formula for area of a circle: $\text{Area} = (3.14D^2)/4$ or $D = (\text{Area times } 4/3.14)^{0.5}$. Therefore,

$$D = ((14)(4)/3.14)^{0.5}(12\text{in}/1\text{ft})$$

$$D = 50.7 \text{ in}$$

Step 3. A grooved end culvert with a headwall is selected for the design. Using the inlet control nomograph (Figure 7-8(a)), with a pipe diameter of 48 inches and a discharge of 70 cfs; read a HW/D value of 0.93.

Step 4. The depth of headwater (HW) is $(0.93) \times (4) = 3.72 \text{ ft}$, which is less than the allowable headwater of 5.25 ft. Since 3.72 ft is considerably less than 5.25, try a smaller culvert.

Step 5. Using the same procedures outlined in Steps 3 and 4 the following results were obtained.

42-inch culvert – HW = 4.13 ft
 36-inch culvert – HW = 4.98 ft
 Select a 36-inch culvert to check for outlet control.

Step 6. The culvert is checked for outlet control by using Figure 7-8(b).

With an entrance loss coefficient K_e of 0.20, a culvert length of 100 ft, and a pipe diameter of 36 in., an H value of 2.8 ft is determined. The headwater for outlet control is computed by the equation: $\text{HW} = H + h_o - LS$

Compute h_o
 $h_o = TW$ or $\frac{1}{2}$ (critical depth in culvert + D), whichever is greater.



$$h_o = 3.5 \text{ ft or } h_o = 0.5(2.7+3.0) = 2.85 \text{ ft}$$

Note: critical depth is obtained from Chart 4, located in Appendix A.

Therefore: $h_o = 3.5 \text{ ft}$

The headwater depth for outlet control is:

$$HW = H + h_o - LS = 2.8 + 3.5 - (100)(0.012) = 5.10 \text{ ft}$$

Step 7. Since HW for outlet (5.10 ft) is greater than the HW for inlet control (4.98 ft), outlet control governs the culvert design. Thus, the maximum headwater expected for a 25-year recurrence flood is 5.10 ft, which is less than the allowable headwater of 5.25 ft.

Step 8. Estimate outlet exit velocity. Since this culvert is on outlet control and discharges into an open channel downstream with tailwater above culvert, the culvert will be flowing full at the flow depth in the channel. Using the design peak discharge of 70 cfs and the area of a 36-inch or 3.0-foot diameter culvert the exit velocity will be:

$$Q = VA$$

Therefore:

$$V = 70 / ((3.14)(3.0)^2 / 4) = 9.9 \text{ ft/s}$$

With this high velocity, consideration should be given to provide an energy dissipator at the culvert outlet. See Section 7.5 (Energy Dissipation Design).

Step 9. Check for minimum velocity using the 2-year flow of 35 cfs.

Therefore:

$$V = 35 / ((3.14)(3.0)^2 / 4) = 5.0 \text{ ft/s} > \text{minimum of 2.5 therefore, OK}$$

Step 10. The 100-year flow should be routed through the culvert to determine if any flooding problems will be associated with this event.

7.3.5 Design Procedures for Beveled-Edged Inlets

Improved inlets include inlet geometry refinements beyond those normally used in conventional culvert design practice. Several degrees of improvements are possible, including bevel-edged, side-tapered, and slope-tapered inlets. Those designers interested in using side- and slope-tapered inlets should consult the detailed design criteria and example designs outlined in the [Hydraulic Design of Highway Culverts](#) (USDOT, 1985).

7.3.5.1 Design Figures

Four inlet control figures for culverts with beveled edges are included in Appendix A.

| Chart | Use for : |
|-------|---|
| 3 | circular pipe culverts with beveled rings |
| 9 | wingwalls with flare angles of 18 to 45 degrees |
| 10 | 90° headwalls (same for 90° wingwalls) |
| 11 | skewed headwalls |

The following symbols are used in Figure 7-10:

- B - width of culvert barrel or diameter of pipe culvert;
- D - height of box culvert or diameter of pipe culvert;
- H - depth of pool or head, above the face section of invert;
- N - number of barrels; and,
- Q - design discharge.



Figure 7-10. Culvert Design Calculation Form
(Source: USDOT, 1985)

PROJECT NO. _____ COUNTY _____

SECTION NO. _____ DATE _____

DESIGNER _____

SCALE _____

PROJECT LOCATION _____

PROJECT DESCRIPTION _____

DESIGNER'S OFFICE _____

DATE OF DESIGN _____

DATE OF CONSTRUCTION _____

DESIGNER'S SIGNATURE _____

PROJECT ENGINEER'S SIGNATURE _____

PROJECT LOCATION MAP

SECTION 1: GENERAL INFORMATION

SECTION 2: DESIGN DATA

SECTION 3: DESIGN CALCULATIONS

SECTION 4: DESIGN RESULTS

SECTION 5: DESIGNER'S COMMENTS

SECTION 6: PROJECT ENGINEER'S COMMENTS

SECTION 7: DESIGNER'S SIGNATURE

SECTION 8: PROJECT ENGINEER'S SIGNATURE

SECTION 9: DESIGNER'S SIGNATURE

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SECTION 49: DESIGNER'S SIGNATURE

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7.3.5.2 Design Procedure

The figures (Appendix A) for bevel-edged inlets are used for design in the same manner as the conventional inlet design nomographs discussed earlier.

For box culverts the dimensions of the bevels to be used are based on the culvert dimensions. The top bevel dimension is determined by multiplying the height of the culvert by a factor. The side bevel dimensions are determined by multiplying the width of the culvert by a factor. For a 1:1 bevel, the factor is 0.5 inch/ft. For a 1.5:1 bevel the factor is 1 inch/ft. For example, the minimum bevel dimensions for an 8 ft x 6 ft box culvert with 1:1 bevels would be:

$$\begin{aligned} \text{Top Bevel} &= d = 6 \text{ ft} \times 0.5 \text{ inch/ft} = 3 \text{ inches; and,} \\ \text{Side Bevel} &= b = 8 \text{ ft} \times 0.5 \text{ inch/ft} = 4 \text{ inches.} \end{aligned}$$

For a 1.5:1 bevel, the dimension computations would result in $d = 6$ and $b = 8$ inches.

7.3.5.3 Design Figure Limits

The improved inlet design figures (Appendix A) are based on research results from culvert models with barrel width, B, to depth, D, ratios of 0.5:1 to 2:1. For box culverts with more than one barrel, the figures are used in the same manner as for a single barrel, except that the bevels must be sized on the basis of the total clear opening rather than on individual barrel size. For example, in a double 8 ft by 8 ft box culvert:

The top bevel is proportioned based on the height of 8 feet which results in a bevel of 4 in. for the 1:1 bevel and 8 in. for the 1.5:1 bevel.

The side bevel is proportioned based on the clear width of 16 feet, which results in a bevel of 8 in. for the 1:1 bevel and 16 in. for the 1.5:1 bevel.

7.3.5.4 Multi-barrel Installations

For multi-barrel culvert installations exceeding a 3:1 width to depth ratio, the side bevels become excessively large when proportioned on the basis of the total clear width. For these structures, it is recommended that the side bevel be sized in proportion to the total clear width, B, or three times the height, whichever is smaller.

The top bevel dimension should always be based on the culvert height.

The shape of the upstream edge of the intermediate walls of multi-barrel installations is not as important to the hydraulic performance of a culvert as the edge condition of the top and sides. Therefore, the edges of these walls may be square, rounded with a radius of one-half their thickness, chamfered, or beveled. The intermediate walls may also project from the face and slope downward to the channel bottom to help direct debris through the culvert.

Multi-barrel pipe culverts shall be designed as a series of single barrel installations since each pipe requires a separate bevel.

7.3.5.5 Skewed Inlets

It is recommended that Chart 11 for skewed inlets (Appendix A) not be used for multiple barrel installations, as the intermediate wall could cause an extreme contraction in the downstream barrels. This would result in under design due to a greatly reduced capacity. Skewed inlets (at an angle with the centerline of the stream) should be avoided whenever possible and should not be used with side- or slope-tapered inlets. It is important to align culverts with streams in order to avoid erosion problems associated with changing the direction of the natural stream flow.



7.3.6 Flood Routing and Culvert Design

Flood routing through a culvert is a practice that evaluates the effect of temporary upstream ponding caused by the culvert's backwater. If flood routing is not considered, it is possible that the findings from culvert analyses will be conservative. If the selected allowable headwater is accepted without flood routing, then costly over design of both the culvert and outlet protection may result, depending on the amount of temporary storage involved. However, if storage is used in the design of culverts, consideration should be given to:

- the total area of flooding,
- the average time that bankfull stage is exceeded for the design flood up to 48 hours in rural areas or 6 hours in urban areas, and
- ensuring that the storage area will remain available for the life of the culvert through the purchase of right-of-way or easement.

7.3.6.1 Design Procedure

The design procedure for flood routing through a culvert is the same as for reservoir routing. The site data and roadway geometry are obtained and the hydrology analysis completed to include estimating a hydrograph. Once this essential information is available, the culvert can be designed. Flood routing through a culvert can be time consuming. It is recommended that a computer program be used to perform routing calculations; however, an engineer should be familiar with the culvert flood routing design process.

A multiple trial and error procedure is required for culvert flood routing as presented in the general design steps listed below.

- (Step 1) A trial culvert(s) is selected.
- (Step 2) A trial discharge for a particular hydrograph time increment (selected time increment to estimate discharge from the design hydrograph) is selected.
- (Step 3) Flood routing computations are made with successive trial discharges until the flood routing equation is satisfied.
- (Step 4) The hydraulic findings are compared to the selected site criteria.
- (Step 5) If the selected site criteria are satisfied, then a trial discharge for the next time increment is selected and this procedure is repeated; if not, a new trial culvert is selected and the entire procedure is repeated.