**CHAPTER 4**
**DESIGN OF CULVERTS**
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**Chapter Four - Design of Culverts**

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## 4.1 Overview

### 4.1.1 Introduction

The design of a culvert is influenced by cost, hydraulic efficiency, purpose, and the topography at the proposed culvert site. Thus physical data must be integrated with engineering and economic considerations. The information contained in this chapter should give the design engineer the ability to design culverts taking into account the factors that influence their design and selection.

### 4.1.2 Definition

Culverts are structures used to convey surface runoff through embankments. Culverts are usually covered with embankment and composed of structural material around the entire perimeter, although some are supported on spread footings with the streambed serving as the bottom of the culvert. For economy and hydraulic efficiency, culverts should be designed to operate with the inlet submerged during flood flows, if conditions permit. Cross-drains are those culverts and pipes that are used to convey runoff from one side of a roadway to another.

### 4.1.3 Purpose

The primary purpose of a culvert is to convey surface water across or from the roadway right-of-way. In addition to the hydraulic function, a culvert must also support the embankment and roadway for traffic conveyance, and protect the traveling public and adjacent property owners from flood hazards to the extent practicable and in a reasonable and prudent manner.

### 4.1.4 Consideration

Primary considerations for the final selection of any drainage structure are that its design be based upon appropriate hydraulic principles, economy, and minimized effects on adjacent property by the resultant headwater depth and outlet velocity. In addition to sound hydraulic design, sound structural design, site design, and construction practices are necessary for a culvert to function properly. The allowable headwater elevation is that elevation above which damage may be caused to adjacent property and/or the roadway. It is this allowable headwater depth that is the primary basis for sizing a culvert.

To ensure safety during major flood events, access and egress routes to developed areas shall be checked for the100-year flood to determine if these streets will provide safe access for emergency vehicles and local residents.

### 4.1.5 Bridge or Culvert Selection

At many sites, either a bridge or a culvert will fulfill the structural and hydraulic requirements. The structural choice should be based on:

- risk of property damage,
- construction and maintenance costs,
- traffic safety,
- environmental considerations,
- risk of failure, and
- aesthetic considerations.

## 4.2 Symbols and Definitions

To provide consistency within this chapter, as well as throughout this manual, the following symbols will be used. These symbols were selected because of their wide use in many culvert design publications.

**Table 4-1 Symbols, Definitions And Units**

| Symbol | Definition | Units |
|---|---|---|
| A | Area of cross section of flow | sq. ft |
| B | Barrel width | ft |
| $C_d$ | Overtopping discharge coefficient | – |
| D | Culvert diameter or barrel depth | in. or ft |
| d | Depth of flow | ft |
| $d_c$ | Critical depth of flow | ft |
| $d_u$ | Uniform depth of flow | ft |
| g | Acceleration of gravity | ft/s |
| H | Total energy loss | ft |
| $H_e$ | Entrance head loss | ft |
| $H_f$ | Friction head loss ft | |
| $h_o$ | Height of hydraulic grade line above outlet invert | ft |
| HW | Headwater depth above invert of culvert (depth from inlet invert to upstream total energy grade line) | ft |
| $K_e$ | Inlet loss coefficient | – |
| L | Length of culvert | ft |
| P | Empirical approximation of equivalent hydraulic grade line | ft |
| Q | Rate of discharge | cfs |
| S | Slope of culvert | ft/f |
| TW | Tailwater depth above invert of culvert | ft |
| V | Mean velocity of flow | ft/s |
| $V_c$ | Critical velocity ft/s | |

**{Put into Glossary, Appendix 4.1}**

## 4.3 Concept Definitions

Critical Depth

Critical depth can best be illustrated as the depth at which water flows over a weir, this depth being attained automatically where no other backwater forces are involved. For a given discharge and cross-section geometry there is only one critical depth. Appendix B at the end of this chapter gives a series of critical depth charts for the different culvert shapes.

Uniform Flow

Uniform flow is flow in a prismatic channel of constant cross section having a constant discharge, velocity and depth of flow throughout the reach. This type of flow will exist in a culvert operating on a steep slope provided the culvert is sufficiently long.

Free Outlets

Free outlets are outlets whose tailwater is equal to or lower than critical depth. For culverts having free outlets, lowering of the tailwater has no effect on the discharge or the backwater profile upstream of the tailwater.

Submerged Outlets

Partially submerged outlets are outlets whose tailwater is higher than critical depth and lower than the height of the culvert. Submerged outlets are outlets having a tailwater elevation higher than the soffit of the culvert.

Submerged Inlets

Submerged inlets are those inlets having a headwater greater than about one and one-half times the diameter of the culvert.

Improved Inlets

Flared, improved, or tapered inlets indicate a special entrance condition which decreases the amount of energy needed to pass the flow through the inlet and thus increases the capacity of culverts at the inlet.

Soffit

Soffit refers to the inside top of the culvert. The soffit is also referred to as the crown of the culvert.

Invert

Invert refers to the flowline of the culvert (inside bottom).

Steep and Mild Slope

A steep slope culvert operation is where the computed critical depth is greater than the computed uniform depth. A mild slope culvert operation is where critical depth is less than uniform depth.

## 4.4 Culvert Design Steps

Following are the recommended steps in the design of a culvert in order to ensure that all design aspects are taken into account.

Step 1 Determine And Analyze Site Characteristics - Site characteristics include the generalized shape of the roadway embankment, bottom elevations and cross sections along the stream bed, the approximate length of the culvert, and the allowable headwater elevation. In determining the allowable headwater elevation, roadway elevations and the elevation of upstream property should be considered. The consequences of exceeding the allowable headwater elevation should be evaluated and kept in mind throughout the design process.

Culvert design is actually a trial-and-error procedure because the length of the barrel cannot be accurately determined until the size is known, and the size cannot be precisely determined until the length is known. In most cases, however, a reasonable estimate of length will be accurate enough to determine the culvert size.

Step 2 Perform Hydrologic Analysis - Delineate the drainage area above the culvert site. Develop flow estimates for the design frequencies. Design frequencies are discussed in Section 4.5.2. The probable accuracy of the estimate should be kept in mind as the design proceeds.

Step 3 Perform Outlet Control Calculations And Select Culvert - These calculations are performed before inlet control calculations in order to select the smallest feasible barrel which can be used without the required headwater elevation in outlet control exceeding the allowable headwater elevation. The full flow outlet control performance curve for a given culvert (size, inlet edge, shape, material) defines its maximum performance. Therefore, the inlet improvements beyond the beveled edge or changes in inlet invert elevation will not reduce the required outlet control headwater elevation. This makes the outlet control performance curve an ideal limit for improved inlet design. The results of these calculations should be the outlet control performance curve. In addition to considering the allowable headwater elevation, the velocity of flow at the exit to the culvert should be checked to determine if downstream erosion problems will be created.

Step 4 Perform Inlet Control Calculations For Conventional And Beveled Edge Culvert Inlets - Perform the inlet control calculations to develop the inlet control performance curve to determine if the culvert design selected will be on inlet or outlet control for the design and check flood frequencies. A drop may be incorporated upstream of the culvert to increase the flow through the culvert.

Step 5 Perform Throat Control Calculations For Side- And Slope-Tapered Inlets - The same concepts are involved here as with conventional or beveled edge culvert design.

Step 6 Analyze The Effect of a Drop On Inlet Control Section Performance -The purpose of this step is to determine if having a drop before the inlet of the culvert would increase the capacity of the culvert and if a drop can be justified from a cost perspective and site characteristics.

Step 7 Design Side- And/Or Slope-Tapered Inlet - Side- and slope-tapered inlets can be used to significantly increase the capacity of many culvert designs. Develop performance curves based on side- and/or slope- tapered inlets and determine from a cost perspective and site characteristics if such a design would be justified.

Step 8 Complete File Documentation - Complete a documentation file for the final design selected.

## 4.5 Engineering Design Criteria

### 4.5.1 Criteria

The design of a culvert should take into account many different engineering and technical aspects at the culvert site and adjacent areas. The following design criteria should be considered for all culvert designs as applicable.

<u>Engineering aspects</u>

- Flood frequency
- Velocity limitation
- Buoyancy protection

<u>Site criteria</u>

- Length and slope
- Debris control

<u>Design limitations</u>

- Headwater
- Tailwater conditions
- Storage

<u>Design options</u>

- Culvert inlets
- Inlets with headwalls
- Wingwalls and aprons
- Improved inlets
- Material selection
- Culvert skews
- Culvert sizes

<u>Related designs</u>

- Weep holes
- Outlet protection
- Erosion and sediment control
- Environmental considerations
- Safety considerations
- Loading requirements

Some culvert designs are relatively simple, involving a straight-forward determination of culvert size and length. Other designs are more complex where structural, hydraulic, environmental, or other considerations must be evaluated and provided for in the final design. The design engineer must incorporate personal experience and judgment to determine which criteria must be evaluated and how to design the final culvert installation.

Following is a discussion of each of the above criteria as it relates to culvert siting and design.

### 4.5.2 Flood Frequency

Culverts shall be designed to convey (at a minimum) the 50-year runoff event without overtopping the roadway. The flow rate shall be based on upstream full-buildout land-use conditions from the City of Lincoln/Lancaster County comprehensive plan. Where roadside ditches convey the minor storm drainage in lieu of storm sewers, appurtenant culverts shall be designed to convey the 10-year storm event, but in no case shall be less than the minimum sizes specified in Section 4.5.16 of this chapter.

In addition, the 100-year frequency storm shall be routed through all culverts to be sure structures are not flooded or increased damage does not occur to the roadway or adjacent property for this design event.

An economic analysis may justify a design to pass floods greater than those noted above where potential damage to adjacent property, to human life, or heavy financial loss due to flooding is significant.

Also, in compliance with the National Flood Insurance Program, it is necessary to consider the 100-year frequency flood at locations identified as being special flood hazard areas. This does not necessitate that the culvert be sized to pass the 100-year flood, provided the capacity of the culvert plus flow by-passing the culvert, is sufficient to accommodate the 100-year flood without raising the associated water surface elevation more than floodplain regulations or adjacent property elevations allow for that location. In addition, stormwater management facilities cannot be installed which would result in a major lowering of the associated water surface elevation without a downstream evaluation. The design engineer should review the City floodway regulations for more information related to floodplain regulations.

### 4.5.3 Velocity Limitations

Both minimum and maximum velocities should be considered when designing a culvert. The maximum velocity should not exceed culvert manufacturer recommendations. The maximum velocity should be consistent with channel stability requirements at the culvert outlet. As outlet velocities increase, the need for channel stabilization at the culvert outlet increases. If velocities exceed permissible velocities for the various types of nonstructural outlet lining material available, the installation of structural energy dissipators is appropriate.
A minimum velocity of 3.0 ft/s when the culvert is flowing partially full is recommended to ensure a self-cleaning condition during partial depth flow. Energy dissipation may be required at the outlet of the culvert (see Chapter 7).

### 4.5.4 Buoyancy Protection

Headwalls, endwalls, slope paving or other means of anchoring to provide buoyancy protection should be considered for all flexible culverts. Buoyancy is more serious with steepness of the culvert slope, depth of the potential headwater (debris blockage may increase), flatness of the upstream fill slope, height of the fill, large culvert skews, or mitered ends.

### 4.5.5 Length and Slope

Since the capacity of culverts on outlet control will be affected by the length of the culvert, their length should be kept to a minimum and existing facilities shall not be extended without determining the decrease in capacity that will occur. In addition, the culvert length and slope should 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.

### 4.5.6 Debris Control

The need for bar grates should be considered for each culvert site, but in general, bar grates shall not be used on end sections for culverts (either inlets or outlets) unless approved by the Director of Public Works and Utilities.

### 4.5.7 Headwater Limitations

The allowable headwater elevation is determined from an evaluation of land use upstream of the culvert and the proposed roadway elevation. Headwater is the depth of water above the culvert invert measured at the entrance end of the culvert.

The following criteria related to headwater should be considered:

- The allowable headwater for design frequency conditions should allow for the following upstream controls:
  - 12 inch freeboard.
  - Avoidance of upstream property damage.
  - Elevations established to delineate floodplain zoning.
  - Low point in the road grade either adjacent to or away from the culvert location.
  - Ditch elevation of the terrain that would permit flow to divert around culvert.
- The headwater shall be checked for the 100-year flood to ensure compliance with floodplain management criteria and to avoid flooding of building sites. For most facilities, the culvert should be sized to maintain flood-free conditions on major thoroughfares for one-half lane of two-lane facilities and one lane of multi-lane facilities.
- The maximum acceptable outlet velocity shall be identified. Either the headwater shall be set to produce acceptable velocities or stabilization measures shall be provided where these velocities are exceeded.
- Site-specific design considerations shall be addressed.
- In general the constraint which gives the lowest allowable headwater elevation establishes the criteria for the hydraulic calculations.

Invert elevations will be established after determining the allowable headwater elevation, tailwater elevation, and approximate length. Scour can be minimized if the culvert has the same slope as the channel. Thus, to reduce the chance of failure due to scour, invert elevations should correspond to the natural grade where feasible. In addition, the flow conditions and velocity in the channel upstream from the culvert should be investigated to determine if scour will occur.

If there is insufficient headwater elevation to convey the required discharge, it will be necessary to either use a larger culvert, lower the inlet invert, use an irregular cross section, use an improved inlet if in inlet control, use multiple barrels or a bridge, or use a combination of these measures. If the inlet invert is lowered, special consideration must be given to scour.

### 4.5.8 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. If the culvert outlet is operating with a free outfall, the critical depth and equivalent hydraulic grade line should be determined.

For culverts which discharge to an open channel, the stage-discharge curve for the channel must be determined. (See Chapter 5.)

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 may establish the culvert tailwater.

### 4.5.9 Freeboard

In the design of cross drainage culverts, there shall be a minimum of a one-foot freeboard between the flood elevation and the roadway surface for all floods that are equal to or less than the design flood event. In addition, there shall be a minimum of one-foot freeboard between the headwater elevation for a culvert under 100-year storm event flow or by-pass conditions and the low opening of upstream or adjacent building sites.

### 4.5.10 Culvert Inlets

Selection of the type of inlet is an important part of culvert design, particularly with inlet control. 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. All methods described in this chapter, directly or indirectly, use inlet coefficients. Recommended inlet coefficients are given in Table 4-2.

**Table 4-2 Inlet Coefficients**

| Type of Structure and Design of Entrance | Coefficient $K_e$ |
|---|---|
| **Pipe, Concrete** | |
| Projecting from fill, socket end (grove-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, 33.7º or 45º bevels | 0.2 |
| Side- or slope-tapered inlet | 0.2 |
| **Pipe, or Pipe-Arch, Corrugated Metal** | |
| 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, 33.7º or 45º 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 30o to 75o 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 10º or 25º to barrel | |
| Square-edged at crown | 0.5 |
| Wingwalls parallel (extension of sides) | |
| Square-edged at crown | 0.7 |
| Side- or slope-tapered inlet | 0.2 |

* Note: End Sections 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. Some end sections incorporating a closed taper in their design have a superior hydraulic performance.

~~Source: HDS:5~~

### 4.5.11 Inlets with Headwalls

Headwalls may be used for a variety of reasons:

(1) increasing the efficiency of the inlet
(2) providing embankment stability
(3) providing embankment protection against erosion
(4) providing protection from buoyancy or
(5) to shorten the length of the required structure.

The primary reasons for using headwalls are for embankment protection, buoyancy control, and ease of maintenance. Figure 4-1 shows typical headwall and wingwall configurations. Culvert or storm sewer headwalls constructed in or adjacent to public right-of-way shall be designed to protect pedestrians. This protection shall include a pipe railing fence on the headwall and any wingwalls, unless the grading and size of the pipe precludes the need for the fence, as approved by the Director of Public Works and Utilities.

### 4.5.12 Wingwalls and Aprons

Wingwalls are 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.

Little increase in hydraulic efficiency is realized with the use of wingwalls, regardless of the pipe material used and, therefore, the use should be justified for other reasons. Wingwalls can be used to increase hydraulic efficiency if designed as a side-tapered inlet (See Section 4.9.6.2 for more information on the design of side-tapered inlets.)

If high headwater depths are to be encountered, or the approach velocity in the channel will cause scour, a short channel apron should 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.

### 4.5.13 Improved Inlets

Where inlet conditions control the amount of flow that can pass through the culvert, improved inlets can greatly increase the hydraulic performance at the culvert. For these designs refer to the section 4.9 which describes the design of improved inlets.

### 4.5.14 Manning's n Values

For culvert selection, only reinforced concrete pipe is allowed within City street right-of-way except for driveway culverts. For culverts equal to or greater than 60 inches in diameter, corrugated metal pipe is allowed if it is bituminous coated with a concrete-poured invert. Table 4-3 gives recommended Manning's n values.

**Table 4-3 Manning's n Values**

| Type of Conduit | Wall & Joint Description | Manning's n |
|---|---|---|
| Concrete Pipe | Good joints, smooth walls | 0.011-0.013 |
| | Good joints, rough walls | 0.014-0.016 |
| | Poor joints, rough walls | 0.016-0.017 |
| Concrete Box | Good joints, smooth finished walls | 0.014-0.018 |
| | Poor joints, rough, unfinished walls | 0.014-0.018 |
| Corrugated Metal Pipes and Boxes, Annular Corrugations | 2 2/3 by 1/2-inch corrugations | 0.027-0.022 |
| | 6 by 1-inch corrugations | 0.025-0.022 |
| | 5 by 1-inch corrugations | 0.026-0.025 |
| | 3 by 1-inch corrugations | 0.028-0.027 |
| | 6 by 2-inch structural plate | 0.035-0.033 |
| | 9 by 2 1/2-inch structural plate | 0.037-0.033 |
| Corrugated Metal Pipes, Helical Corrugations, Full Circular Flow | 2 2/3 by 1/2-inch corrugated 24-inch plate width | 0.024-0.012 |
| Spiral Rib Metal Pipe | 3/4 by 3/4-inch recesses at 12-inch spacing, good joints | 0.012-0.013 |

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.

### 4.5.15 Culvert Skews

Culvert skews shall not exceed 45 degrees as measured from a line perpendicular to the roadway centerline without approval of the Director of Public Works and Utilities.

### 4.5.16 Minimum

The minimum culvert size shall be 18 inches for roadways and 15 inches for driveways.

### 4.5.17 Outlet Protection

See Chapter 7 for information on the design of outlet protection. In general, scour holes at culvert outlets provide efficient energy dissipation. As such, outlet protection for the culvert should be provided where the outlet scour hole depth computations indicate:

- the scour hole will undermine the culvert outlet,
- the expected scour hole may cause costly property damage,
- the scour hole will cause a nuisance effect (most common in urban areas), or
- the scour hole will conflict with land use.

### 4.5.18 Permitting Considerations

There may be federal or state permitting implications that affect the culvert design. These could include wetlands, regulatory floodplains and preparation of a stormwater pollution prevention plan for construction activity.

### 4.5.19 Safety Considerations

Traffic should be protected from culvert ends as follows.

- Small culverts should use an end section or a sloped headwall.
- Large culverts should receive one of the following treatments:
  a. Be extended to the appropriate "clear zone" distance per AASHTO Roadside Design Guide.
  b. Shielded with a traffic barrier if the culvert is very large, cannot be extended, or has a channel which cannot be safely traversed by a vehicle.
- Routinely inspect each site to determine if safety problems exist for traffic or for the structural safety of the culvert and embankment.

### 4.5.20 Loading Requirements

Reinforced concrete box culverts, reinforced concrete pipe culverts, and corrugated metal pipe culverts shall all be designed for HS20 live load, with the appropriate impact factor, and dead load. Dead load (fill) shall be based on the depth of earth cover, plus pavement, above the top of the culvert.

## 4.6 Culvert Flow Controls and Equations

### 4.6.1 Introduction

Generally, the hydraulic control in a culvert will be at the culvert outlet if the culvert is operating on a mild slope. Entrance control usually occurs if the culvert is operating on a steep slope.

For outlet control, the head losses due to tailwater and barrel friction are predominant in controlling the headwater of the culvert. The entrance will allow the water to enter the culvert faster than the backwater effects of the tailwater and barrel friction will allow it to flow through the culvert.

For inlet control, the entrance characteristics of the culvert are such that the entrance head losses are predominant in determining the headwater of the culvert. The barrel will carry water through the culvert more efficiently than the water can enter the culvert.

The design procedures contained in this chapter are for the design of culverts for a constant discharge, considering inlet and outlet control.

### 4.6.2 Inlet And Outlet Control

Inlet Control - If the culvert is operating on a steep slope it is likely that the entrance geometry will control the headwater and the culvert will be on inlet control.

Outlet Control - If the culvert is operating on a mild slope, the outlet characteristics will probably control the flow and the culvert will be on outlet control.

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 the Federal Highway Administration publication entitled Hydraulic Design Of Highway Culverts, HDS-5, 1985.

### ~~4.6.3 Equations~~

~~There are many combinations of conditions which classify a particular culvert's hydraulic operation. By consideration of a succession of parameters; the engineer may arrive at the appropriate calculation procedure. The most common types of culvert operations for any barrel type are classified as follows.~~

#### 4.6.3.1 Mild Slope

Critical Depth – Outlet Control - The entrance is unsubmerged (HW ≤ 1.5D), the critical depth is less than uniform depth at the design discharge ($d_c < d_u$) and the tailwater is less than or equal to critical depth (TW ≤ $d_c$). This condition is a common occurrence where the natural channels are on flat grades and have wide, flat floodplains. The control is critical depth at the outlet.

$$HW = d_c + V^2/(2g) + H_e + H_f - SL \qquad (4.1)$$

Where: HW = headwater depth (ft)
$d_c$ = critical depth (ft)
$V_c$ = critical velocity g = 32.2 (ft/sec$^2$)
$H_e$ = entrance headloss (ft)
$H_f$ = friction headloss (ft)
S = slope of culvert (ft/ft)
L = length of culvert (ft)

Tailwater Depth – Outlet Control - The entrance is unsubmerged (HW ≤ 1.5D), the critical depth is less than uniform depth at design discharge ($d_c < d_u$) and TW is greater than critical depth (TW > $d_c$) and TW is less than D (TW < D). This condition is a common occurrence where the channel is deep, narrow, and well defined. The control is tailwater at the culvert outlet. The outlet velocity is the discharge divided by the area of flow in the culvert at tailwater depth.

$$HW = TW + V^2/(2g) + H_e + H_f - SL \qquad (4.2)$$

Where: HW = headwater depth (ft)
TW = tailwater at the outlet (ft)
V = velocity based on tailwater depth (ft)
g = 32.2 (ft/sec$^2$)
$H_e$ = entrance headloss (ft)
$H_f$ = friction headloss (ft)
S = slope of culvert (ft/ft)
L = length of culvert (ft)

Tailwater Depth > Barrel Depth - Outlet Control - This condition will exist if the critical depth is less than uniform depth at the design discharge ($d_c < d_u$) and TW depth is greater than D (TW > D), or; the critical depth is greater than the uniform depth at the design discharge ($d_c > d_u$) and TW is greater than (SL + D), [TW > (SL + D)]. The HW may or may not be greater than 1.5D, though often it is greater. If the critical depth of flow is determined to be greater than the barrel depth (only possible for rectangular culvert barrels), then this operation will govern. Outlet velocity is based on full flow at the outlet.

$$HW = H + TW - SL \qquad (4.3)$$

Where: HW = headwater depth (ft)
H = total head loss of discharge through culvert (ft)
TW = tailwater depth (ft)
SL = culvert slope times length of culvert (ft)

Tailwater Depth < Barrel Depth - Outlet Control - The entrance is submerged (HW > 1.5D) and the tailwater depth is less than D (TW < D). Normally, the engineer should arrive at this type of operation only after previous consideration of the operations depth covered when the critical depth, tailwater depth, or "slug" flow controls the flow in outlet control conditions. On occasion, it may be found that (HW ≥ 1.5D) for the three previously outlined conditions but (HW < 1.5D) for equation 4.4. If so, the higher HW should be used. Outlet velocity is based on critical depth if TW depth is less than critical depth. If TW depth is greater than critical depth, outlet velocity is based on TW depth.

$$HW = H + P - SL \quad (4.4)$$

Where: HW = headwater depth (ft)
H = total head loss of discharge through culvert (ft)
P = empirical approximation of equivalent hydraulic grade line (ft)
P = $(d_c + D)/2$ if TW depth is less than critical depth at design discharge. If TW is greater than critical depth, then P = TW. (ft)
SL = culvert slope times length of culvert (ft)

#### 4.6.3.2 Steep Slope

Tailwater Insignificant - Inlet Control - The entrance may be submerged or unsubmerged, the critical depth is greater than uniform depth at the design discharge ($d_c > d_u$), TW depth is less than SL (tailwater elevation is lower than the upstream flowline). Tailwater depth with respect to the diameter of the culvert is inconsequential as long as the above conditions are met. This condition is a common occurrence for culverts in rolling or hilly country. The control is critical depth at the entrance for HW values up to about 1.5D. Control is the entrance geometry for HW values over about 1.5D. HW is determined from empirical curves in the form of nomographs that are discussed later in this chapter. If TW is greater than D, outlet velocity is based on full flow at the outlet. If TW is less than D, outlet velocity is based on uniform depth for the culvert.

#### 4.6.3.3 Slug Flow

Inlet or Outlet Control - For "slug" flow operation the entrance may be submerged or unsubmerged, critical depth is greater than uniform depth at the design discharge ($d_c > d_u$), TW depth is greater than (SL + $d_c$) (TW elevation is above the critical depth at the entrance), and TW depth is less than SL + D (TW elevation is below the upstream soffit). TW depth with respect to D alone is inconsequential as long as the above conditions are met. This condition is a common occurrence for culverts in rolling or hilly country. The control for this type of operation may be at the entrance or the outlet, or control may transfer itself back and forth between the two (commonly called "slug" flow). For this reason, it is recommended that HW be determined for both entrance control and outlet control and the higher of the two determinations be used. Entrance control HW is determined from the inlet control nomographs and outlet control HW is determined by equations 4.3, 4.4, or the outlet control nomographs.

If TW depth is less than D, outlet velocity should be based on TW depth. If TW depth is greater than D, outlet velocity should be based on full flow at the outlet.

## 4.7 Design Procedures

### 4.7.1 Procedures

There are two procedures for designing culverts described in this chapter: (1) the manual use of inlet and outlet control nomographs and (2) the use of a personal computer system HYDRAIN that follows standard culvert calculating procedures and processes.

It is recommended that the HYDRAIN computer systems model be used for culvert design since it will allow the engineer to easily develop performance curves to examine more than one design situation. The personal computer system HYDRAIN uses the theoretical basis for the nomographs to size a culvert. In addition, computer this systems 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.

The following will outline the design procedures for use of the nomograph. The use of the computer model will follow the discussion on flood routing and culvert design. Other computer programs can be used if approved by the City.

### 4.7.2 Tallwater Elevations

In some cases, culverts fail to perform as intended because of tailwater elevations high enough to create backwater. The problem is more severe in areas where gradients are very flat, and in some cases in areas with moderate slopes. Thus, as part of the design process, the normal depth of flow in the downstream channel at discharges equal to those being considered should be computed.

If the tailwater computation leads to water surface elevations below the invert of the culvert exit, there are obviously no problems; if elevations above the culvert invert are computed, the culvert capacity will be somewhat less than assumed. The tailwater computation can be simple, and on steep slopes requires little more than the determination of a cross section downstream where normal flow can be assumed, and a Manning equation calculation. (See Chapter 5 for more information on open channel analysis.) Conversely, with sensitive flood hazard sites, if the slopes are flat, or natural and man-made obstructions exist downstream, a water surface profile analysis reaching beyond these obstructions may be required.

### 4.7.3 Culvert Design Nomographs

The use of culvert design nomographs requires a trial and error solution. The solution provides 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 4-2 and 4-3 show examples of an inlet control and outlet control nomograph that can be used to design concrete pipe culverts. ~~For culvert designs not covered by these nomographs, refer to the complete set of nomographs given in Appendix D at the end of this chapter.~~

### 4.7.4 Steps in The Design Procedure

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

Step Action

(1) List design data:

Q = discharge (cfs)
L = culvert length (ft)
S = culvert slope (ft/ft)
HW = allowable headwater depth for the design storm (ft)
V = velocity for trial diameter (ft/s)
$K_e$ = inlet loss coefficient
TW = tailwater depth (ft)

(2) Determine trial culvert size by assuming a trial velocity 3 to 5 ft/s and computing the culvert area, A = Q/V. Determine the culvert diameter (inches).

(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 the equation:

$$\mathbf{HW = H + h_o - LS} \qquad \textbf{(4.5)}$$

Where: $h_o$ = 1/2 (critical depth + D), or tailwater depth, whichever is greater.

(4) Compare the computed headwaters and use the higher HW to determine if the culvert is under inlet or outlet control.

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.

(5) Calculate exit velocity and expected streambed scour to determine if an energy dissipator is needed.

### 4.7.5 Performance Curves

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 vs. 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, velocities, and scour depths versus discharges for a length and type of culvert. Usually charts with length intervals of 25 to 50 feet are satisfactory for design purposes. Such computations are made much easier by the computer programs discussed in section 4.11 of this manual.

### 4.7.6 Roadway Overtopping

To complete the culvert design, roadway overtopping should 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 as follows:

| Step | Action |
|---|---|
| (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. |
| (2) | Combine the inlet and outlet control performance curves to define a single performance curve for the culvert. |
| (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 4.6 to calculate flow rates across the roadway. |

$$\mathbf{Q = C_d L (HW)^{1.5}} \qquad \textbf{(4.6)}$$

Where: Q = overtopping flow rate ($ft^3/s$)
$C_d$ = overtopping discharge coefficient
L = length of roadway (ft)
HW = upstream depth, measured from the roadway crest to the water surface upstream of the weir drawdown (ft)

Note: See Figure 4-4 for guidance in determining a value for $C_d$. For more information on calculating overtopping flow rates see pages 39 - 42 in HDS No. 5.

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

### 4.7.7 Storage Routing

A significant storage capacity behind a roadway 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. If significant storage is anticipated behind a culvert, the design may be checked by routing the design hydrographs through the culvert to determine the discharge and stage behind the culvert. Routing procedures are outlined in Hydraulic Design of Highway Culverts, Section V - Storage Routing, HDS No. 5, Federal Highway

Administration. If storage routing is performed for a culvert, the facility should be designed as a detention pond and the area inundated by floodwater should not be encroached upon.

## 4.8 Culvert Design Example Using Nomographs

The following example problem illustrates the procedures to be used in designing culverts using the nomographs. Size a culvert given the following design conditions which were determined by physical limitations at the culvert site and hydraulic procedures described elsewhere in this handbook.

Input Data

Discharge for 50-yr flood = 70 cfs
Discharge for 100-yr flood = 176 cfs
Allowable HW for 10-yr discharge = 4.5 ft
Allowable HW for 100-yr discharge = 7.0 ft
Length of culvert = 100 ft
Natural channel invert elevations - inlet = 15.50 ft
outlet = 15.35 ft
Culvert slope = 0.0015 ft/ft
Tailwater depth for 50-yr discharge = 3.0 ft
Tailwater depth for 100-yr discharge = 4.0 ft
Tailwater depth is the normal depth in downstream channel
Entrance type = Groove end with headwall
Culvert type = Reinforced concrete

Computations

1. Assume a culvert velocity of 5 ft/s.

   Required flow area = 70 cfs/5 ft/s = 14 sq ft (for the 50-yr recurrence flood).

2. The corresponding culvert diameter is about 48 in.

   This can be calculated by using the formula for area of a circle:

   Area = $(3.14D^2)/4$ or D = $(\text{Area} \times 4/3.14)^{0.5}$

   Therefore: D = $((14 \text{ sq ft} \times 4)/3.14)^{0.5} \times 12$ in./ft

   D = 50.7 in.

2. A grooved end culvert with a headwall is selected for the design. Using the inlet control nomograph (Figure 4-2), with a pipe diameter of 48 in. and a discharge of 70 cfs; read a HW/D value of 0.93.

2. The depth of headwater (HW) is (0.93) x (4) = 3.72 ft which is less than the allowable headwater of 4.5 ft.

2. The culvert is checked for outlet control by using Figure 4-3.

   With an entrance loss coefficient $K_e$ of 0.20 (see Table 4-2), a culvert length of 100 ft, and a pipe diameter of 48 in., an H value of 0.77 ft is determined. The headwater for outlet control is computed by the equation:

   $HW = H + h_o - LS$

   For the tailwater depth lower than the top of culvert,

   $h_o$ = TW or 1/2 (critical depth in culvert + D) whichever is greater. $h_o$ = 3.0 ft or $h_o$ = 1/2 (2.55 + 4.0) = 3.28 ft

The headwater depth for outlet control is:

$HW = H + h_o - LS = 0.77 + 3.28 - (100) \times (0.0015) = 3.90$ ft

2. Since HW for outlet control (3.90 ft) is greater than the HW for inlet control (3.72 ft), outlet control governs the culvert design.

   Thus, the maximum headwater expected for a 50-yr recurrence flood is 3.90 ft, which is less than the allowable headwater of 4.5 ft.

2. The performance of the culvert is checked for the 100-yr discharge.

   The allowable headwater for a 100-yr discharge is 7 ft; critical depth in the 48 in. diameter culvert for the 100-yr discharge is 3.96 ft.

   For outlet control, an H of 4.6 is read from the outlet control nomograph. The maximum headwater is:

   $HW = H + h_o - LS = 4.6 + 4.0 - (100) \times (0.0015) = 8.45$ ft

   This depth is greater than the allowable depth of 7 ft, thus a larger size culvert must be selected.

2. A 54 in. diameter culvert is tried and found to have a maximum headwater depth of 3.74 ft for the 10-yr discharge and a maximum headwater depth of 6.97 ft for the 100-yr discharge. These values are acceptable for the design conditions.

2. Estimate outlet exit velocity. Since this culvert is on outlet control and discharges into an open channel downstream, the culvert will be flowing full at the flow depth in the channel. Using the 100-year design peak discharge of 176 cfs and the area of a 54 in. or 4.5 ft diameter culvert, the exit velocity will be:

   $V = Q/A = 176 / (3.14 \ (4.5)^2)/4 = 11.1$ ft/s

   With this high velocity, some energy dissipator is needed downstream from this culvert for stream-bank protection. It will first be necessary to compute a scour hole depth and then decide what protection is needed. See Chapter 7, Energy Dissipators for design procedures related to energy dissipators.

2. Design engineers should check minimum velocities for low frequency flows if the larger storm event (100-year) controls culvert design.

   Figure 4-5 provides a convenient form to organize culvert design calculations.

   For an example of a design which incorporates roadway overtopping, see Appendix 4A -- example application of the HY8 Culvert Analysis Microcomputer Program.

## 4.9 Design of Improved Inlets

### 4.9.1 Introduction

A culvert operates in either inlet or outlet control. As previously discussed under outlet control, headwater depth, tailwater depth, entrance configuration, and barrel characteristics all influence a culvert's capacity.

The entrance configuration is defined by the barrel cross sectional area, shape, and edge condition, while the barrel characteristics are area, shape, slope, length, and roughness.

### 4.9.2 Outlet Control

The flow condition for outlet control may be full or partly full for all or part of the culvert length. The design discharge usually results in full flow. Inlet improvements in these culverts reduce the entrance losses, which are onlya small portion of the total headwater requirements. Therefore, only minor modifications of the inlet geometry which result in little additional cost are justified.

### 4.9.3 Inlet Control

In inlet control, only entrance configuration and headwater depth determine the culvert's hydraulic capacity. Barrel characteristics and tailwater depth are of no consequence. These culverts usually lie on relatively steep slopes and flow only partly full. Entrance improvements can result in full, or nearly full flow, thereby increasing culvert capacity significantly.

### 4.9.4 Common Entrances

The figure below illustrates the performance of a 30-in. circular culvert in inlet control with three commonly used entrances: thin-edged projecting, square-edged, and groove-edged.

### 4.9.5 Capacity Determinations

It is clear that inlet type and headwater depth determine the capacities of many culverts. For a given headwater, a groove-edged inlet has a greater capacity than a square-edged inlet, which in turn-out performs a thin-edged projecting inlet.

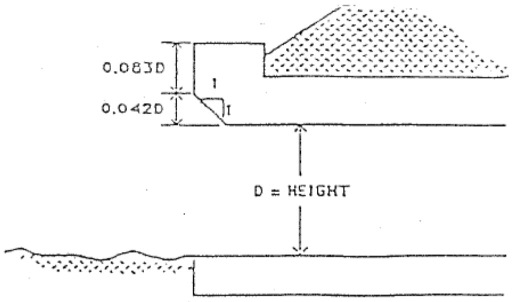
The performance of each inlet type is related to the degree of flow contraction. A high degree of contraction requires more energy, or headwater, to convey a given discharge than a low degree of contraction.

### 4.9.6 Improved 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.

#### 4.9.6.1 Bevel-Edged Inlet

The first degree of inlet improvement is a beveled edge. The bevel is proportioned based on the culvert barrel or face dimension and operates by decreasing the flow contraction at the inlet. A bevel is similar to a chamfer except that a chamfer is smaller and is generally used to prevent damage to sharp concrete edges during construction.




BEVELED EDGE

Adding bevels to a conventional culvert design with a square-edged inlet increases culvert capacity by 5 to 20 percent. The higher increase results from comparing a bevel-edged inlet with a square-edged inlet at high head-waters. The lower increase is the result of comparing inlets with bevels, with structures having wingwalls of 30 to 45 degrees. Although the bevels referred to in this publication are plane surfaces, rounded edges which approximate the bevels are also acceptable.

As a minimum, bevels should be used on all culverts which operate in inlet control, both conventional and improved inlet types. The exception to this is circular concrete culverts where the socket end performs much the same as a beveled edge.

Culverts flowing in outlet control cannot be improved as much as those in inlet control, but the entrance loss coefficient, $k_e$, is reduced from 0.5 for a square edge to 0.2 for beveled edges.

It is recommended that bevels be used on all culvert entrances if little additional cost is involved.

#### 4.9.6.2 Side-Tapered Inlet

The second degree of improvement is a side-tapered inlet. This inlet has an enlarged face area with the transition to the culvert barrel accomplished by tapering the sidewalls. The inlet face has the same height as the barrel, and its top and bottom are extensions of the top and bottom of the barrel. The intersection of the sidewall tapers and barrel is defined as the throat section. If a headwall and wingwalls are going to be used at the culvert entrance, side-tapered inlets should add little if any to the overall cost while significantly increasing hydraulic efficiency.

The side-tapered inlet provides an increase in flow capacity of 25 to 40 percent over that of a conventional culvert with a square-edged inlet.

Whenever increased inlet efficiency is needed or when a headwall and wing walls are planned to be used for a culvert installation, a side-tapered inlet should be considered.

#### 4.9.6.3 Slope-Tapered Inlet

A slope-tapered inlet is the third degree of improvement. Its advantage over the side-tapered inlet without a depression is that more head is available at the inlet. This is accomplished by incorporating a fall in the enclosed entrance section.

The slope-tapered inlet can have over a 100 percent greater capacity than a conventional culvert with square edges. The degree of increased capacity depends largely upon the amount of fall available. Since this fall may vary, a range of increased capacities is possible.

Side- and slope-tapered inlets should be used in culvert design when they can economically be used to increase the inlet efficiency over a conventional design.

For a complete discussion of tapered inlets, including figures and illustrations, see pages 65-93, Federal Highway Administration, HDS-5,1985.

### 4.9.6.4 Improved Inlet Performance

The two tables below compare the inlet control performance of the different inlet types. The first half of Table 4-4 shows the increase in discharge that is possible for a headwater depth of 8 feet. The bevel-edged inlet, side-tapered inlet and slope-tapered inlet show increases in discharge over the square-edged inlet of 16.7, 30.4 and 55.6 percent, respectively. It should be noted that the slope-tapered inlet incorporates only a minimum fall. Greater increases in capacity are often possible if a larger fall is used.

The second half of Table 4-4 depicts the reduction in headwater that is possible for a discharge of 500 cfs. The headwater varies from 12.5 ft for the square-edged inlet to 7.6 ft for the slope-tapered inlet. This is a 39.2 percent reduction in required headwater.

**Table 4-4 Comparison of Inlet Performance**

Comparison of Inlet Performance at Constant Headwater for 6 ft x 6 ft Concrete Box Culvert**

| Inlet Type | Headwater | Discharge | % Improvement |
|---|---|---|---|
| Square-edge | 8.0 feet | 336 cfs | 0 |
| Bevel-edge | 8.0 feet | 392 cfs | 16.7 |
| Side-tapered | 8.0 feet | 438 cfs | 30.4 |
| Slope-tapered* | 8.0 feet | 523 cfs | 55.6 |

* Minimum fall in inlet = D/4 = 6/4 = 1.5 ft

Comparison of Inlet Performance at Constant Discharge for 6 ft x 6 ft Concrete Box Culvert**

| Inlet Type | Discharge | Headwater | % Improvement |
|---|---|---|---|
| Square-edge | 500 cfs | 12.5 feet | 0 |
| Bevel-edge | 500 cfs | 10.1 feet | 19.2 |
| Side-tapered | 500 cfs | 8.8 feet | 29.6 |
| Slope-tapered* | 500 cfs | 7.6 feet | 39.2 |

* Minimum fall in inlet = D/4 = 6/4 = 1.5 ft

** Substantially less improvement in capacity can be accomplished if the culvert functions under outlet control.

## ~~4.10 Design Procedures For Beveled-Edged Inlets~~

### ~~4.10.1 Introduction~~

~~This section will outline the procedures and charts to use when incorporating bevel-edged inlets in the design of culverts. Those designers interested in using side- and slope-tapered inlets should consult the detailed design criteria and example designs outlined in the U. S. Department of Transportation publication Hydraulic Engineering Circular No. 5 entitled, "Hydraulic Design of Highway Culverts."~~

### ~~4.10.2 Design Figures~~

~~Four inlet control figures for culverts with beveled edges are included in Appendix C at the end of this chapter.~~

| ~~Figure~~ | ~~Use for~~ |
|---|---|
| ~~0~~ | ~~circular pipe culverts with beveled rings~~ |
| ~~0~~ | ~~90$^{o}$ headwalls (same for 90$^{o}$ wingwalls)~~ |
| ~~0~~ | ~~skewed headwalls~~ |
| ~~0~~ | ~~wingwalls with flare angles of 18 to 45 degrees~~ |

### 4.10.3 Design Procedure

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

Note that Figures 2, 3, and 4 apply only to bevels having either a 33° angle (1.5:1) or a 45° angle (1:1).

For box culverts, the dimensions of the bevels to be used are based on the culvert's 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 1/2 in./ft. For a 1.5:1 bevel the factor is 1 in./ft.

For example the minimum bevel dimensions for a 8 ft x 6 ft box culvert with 1:1 bevels would be:

Top Bevel = d = 6 ft x 1/2 in./ft = 3
inches Side Bevel = b = 8 ft x 1/2 in./ft =
4 inches

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

### 4.10.4 Design Figure Limits

The improved inlet design figures are based on research results from culvert models with barrel width, B, to depth, D, ratios of from 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:

Top Bevel - is proportioned based on the height of 8 ft which results in a bevel of 4 in. for the 1:1 bevel and 8 in. for the 1.5:1 bevel.
Side Bevel - is proportioned based on the clear width of 16 ft which results in a bevel of 8 in. for the 1:1 bevel and 16 in. for the 1.5:1 bevel.

### 4.10.5 Area Ratios

The ratio of the inlet face area to the barrel area remains the same as for a single barrel culvert. Multibarrel pipe culverts should be designed as a series of single barrel installations since each pipe requires a separate bevel.

### 4.10.6 Multibarrel Installations

For multibarrel installations exceeding a 3:1 width to depth ratio, the side bevel becomes 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 multibarrel 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.

### 4.10.7 Skewed Inlets

Skewed inlets should be avoided whenever possible, and should not be used with side- or slope-tapered inlets.

## 4.11 ~~HYDRAIN~~ Culvert Computer Programs

### 4.11.1 Introduction

~~The HYDRAIN~~Many culvert analysis microcomputer programs are ~~is~~ available and if based on accepted culvert principles and practices are acceptable to use. ~~at nominal cost from McTrans Software or Dodson & Associates. It~~ They should be able to will perform the following calculations ~~for the following~~:

1. culvert analysis (including independent multiple barrel sizing)
2. hydrograph generation
3. hydrograph routing
4. roadway overtopping
5. outlet scour estimates

~~The example problems in Appendix A provide the user with analysis approaches to be used with the culvert analysis portion of the program. The examples provide instruction in data entry, file modification and culvert performance analysis. The three examples presented use the same site characteristics and discharge range, which are described in Example 1. The user should work through the problems on the computer while following the text so as to become familiar with the program. New users should consult the README file that accompanies the program for further help and directions.~~

### ~~4.11.2 User-Friendly Features~~

~~HYDRAIN's culvert analysis has several user-friendly features which permit easy data entry, editing and comparison of several design alternatives. Data are entered by selecting options on a menu or by entering numeric data at prompts. These data are periodically summarized in tables. Any incorrect entry can be changed, and design variations can be quickly analyzed. Another feature of HYDRAIN's culvert analysis is that plots of irregular cross sections, channel rating curves and culvert performance curves can be obtained if the terminal has graphics capabilities.~~

### ~~4.11.3 Examples~~

~~The following three examples are given in Appendix A:~~

- ~~Example 1 - Reinforced Concrete Box Culvert Design,~~
- ~~Example 2 - Irregular Culvert Cross Section,~~
- ~~Example 3 - Multiple Independent Barrels.~~

~~The culvert alternatives for these examples were chosen to illustrate the features of the software and do not necessarily represent cost effective designs. Since the program is still being developed, some of the screens shown in the examples may differ slightly from the version you obtain.~~

## 4.12 Construction, Safety and Maintenance Considerations

An important step in the design process involves identifying whether special provisions are warranted to properly construct or maintain proposed facilities. Culverts located on and aligned with the natural channel generally do not have a sedimentation problem. A stable channel is expected to balance erosion and sedimentation. A culvert resting on such a channel behaves in a similar manner. In a degrading channel, erosion, not sedimentation, is a potential problem. A culvert located in an agrading channel may encounter some sedimentation. Multi-barrel culverts and culverts with depressed inlets may encounter sedimentation problems. It is common for one or more barrels to accumulate sediment. Culverts built with an upstream depression have a barrel slope less than the stream slope and sediment accumulation is likely. Both usually are self-cleaning during periods of high discharge. Maintenance concerns of storm sewer system design center on adequate physical access for cleaning and repair.

Culverts must be kept free of obstructions. Sand or sediment deposits should be removed as soon as possible. During major storms, critical areas should be patrolled and the inlets kept free of debris. Inlet and outlet channels should be kept in alignment and vegetation should be controlled in order to prevent any significant restriction of flow. Provision for a smooth, well designed inlet and avoidance at multiple barrels and skewed inlets will help align and pass most floating debris. Preventative maintenance should be used to inspect for structural problems, replacement needs, and scheduling of needed repairs.

For multiple barrels, it may be warranted to do a conservation testing were one barrel is aligned with the natural channel and the remaining barrels are higher.  This will help to keep the barrels sediment free

Per section 4.5.6 no bar grates shall be used on either inlets or outlets unless approved in advance by the Director of Public Works and Utilities.  This does not include trash gates used for detention/retention ponds.

Per section 4.1.11 all headwalls and wingwalls will have fences (pipe railing), unless the grading and size of pipe precludes the need for a fence, as approved in advance by the Director of Public Works and Utilities.

## References

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