Hydraulic Charts for the Selection of Highway Culverts

HEC 5
December 1965

HEC-5 Hydraulic Charts for the Selection of Highway Culverts

Table of Contents

U.S. Department of Transportation
Federal Highway Administration

Prepared by Lester A. Herr
Chief, Hydraulics Branch, Bridge Division

In Collaboration with Herbert G. Bossy
Highway Research Engineer, Hydraulic Research Division

DISCLAIMER: During the editing of this manual for conversion to an electronic format, the intent has been to keep the document text as close to the original as possible. In the process of scanning and converting, some changes may have been made inadvertently.
Table of Contents for HEC 5-Hydraulic Charts for the Selection of Highway Culverts

Cover Page : HEC 5-Hydraulic Charts for the Selection of Highway Culverts

Part I : HEC 5 Hydraulic Charts for the Selection of Highway Culverts
► Introduction
► Culvert Hydraulics
► Culverts Flowing with Inlet Control
► Culverts Flowing with Outlet Control
► Computing Depth of Tailwater
► Velocity of Culvert Flow
► Performance Curves
► Inlets and Culvert Capacity

Part II : HEC 5 Hydraulic Charts for the Selection of Highway Culverts
► Procedure for Selection of Culvert Size
► Inlet-Control Nomographs (Charts 1 through 7) Instructions for Use

Part III : HEC 5 Hydraulic Charts for the Selection of Highway Culverts
► Outlet-Control Nomographs (Charts 8 through 14) Instructions for Use

Appendix A : HEC 5 Performance Curves
Appendix B : HEC 5 Hydraulic Charts for the Selection of Highway Culverts
Appendix C : HEC 5 Illustrative Problems
References
List of Figures for HEC 5-Hydraulic Charts for the Selection of Highway Culverts

- Figure 1. Inlet Control
- Figure 2. Outlet Control
- Figure 3
- Figure 4
- Figure 5
- Figure 6
- Figure 7
- Figure 8. Hydraulic Performance Curves, 48-Inch C.M. Pipe Culvert with Projecting Inlet
Introduction

Designing highway culverts involves many factors including estimating flood peaks, hydraulic performance, structural adequacy, and overall construction and maintenance costs. This circular contains a brief discussion of the hydraulics of conventional culverts and charts for selecting a culvert size for a given set of conditions. Instructions for using the charts are provided. No attempt is made to cover all phases of culvert design. Subsequent circulars will cover culverts with modified inlets and outlets designed to increase performance or to apply to a particular location. Some approximations are made in the hydraulic design procedure for simplicity. These approximations are discussed at appropriate points throughout the circular.

For this discussion, conventional culverts include those commonly installed, such as circular, arch and oval pipes, both metal and concrete, and concrete box culverts. All such conventional culverts have a uniform barrel cross section throughout. The culvert inlet may consist of the culvert barrel projected from the roadway fill or mitered to the embankment slope. Sometimes inlets have headwalls, wingwalls, and apron slabs, or standard end sections of concrete or metal. The more common types of conventional culverts are considered in this circular.

Culvert Hydraulics

Laboratory tests and field observations show two major types of culvert flow: (1) flow with inlet control and (2) flow with outlet control. For each type of control, different factors and formulas are used to compute the hydraulic capacity of a culvert. Under inlet control, the cross-sectional area of the culvert barrel, the inlet geometry and the amount of headwater or ponding at the entrance are of primary importance. Outlet control involves the additional consideration of the elevation of the tailwater in the outlet channel and the slope, roughness and length of the culvert barrel.

It is possible by involved hydraulic computations to determine the probable type of flow under which a culvert will operate for a given set of conditions. The need for making these computations may be avoided, however, by computing headwater depths from the charts in this circular for both inlet control and outlet control and then using the higher value to indicate the type of control and to determine the headwater depth. This method of determining the type of control is accurate except for a few cases where the headwater is approximately the same for both types of control.

Both inlet control and outlet control types of flow are discussed briefly in the following paragraphs and procedures for the use of the charts are given.
Inlet control means that the discharge capacity of a culvert is controlled at the culvert entrance by the depth of headwater (HW) and the entrance geometry, including the barrel shape and cross-sectional area, and the type of inlet edge. Sketches of inlet-control flow for both unsubmerged and submerged projecting entrances are shown in Figure 1A and Figure 1B. Figure 1C shows a mitered entrance flowing under a submerged condition with inlet control.

Inlet control the roughness and length of the culvert barrel and outlet conditions (including depth of tailwater) are not factors in determining culvert capacity. An increase in barrel slope reduces headwater to a small degree and any correction for slope can be neglected for
conventional or commonly used culverts flowing with inlet control.

In all culvert design, headwater or depth of ponding at the entrance to a culvert is an important factor in culvert capacity. The headwater depth (or headwater HW) is the vertical distance from the culvert invert at the entrance to the energy line of the headwater pool (depth + velocity head). Because of the low velocities in most entrance pools and the difficulty in determining the velocity head for all flows, the water surface and the energy line at the entrance are assumed to be coincident, thus the headwater depths given by the inlet control charts in this circular can be higher than will occur in some installations. For the purposes of measuring headwater, the culvert invert at the entrance is the low point in the culvert opening at the beginning of the full cross-section of the culvert barrel.

Headwater-discharge relationships for the various types of circular and pipe-arch culverts flowing with inlet control are based on laboratory research with models and verified in some instances by prototype tests. This research is reported in National Bureau of Standards Report No. 4444 entitled "Hydraulic Characteristics of Commonly Used Pipe Entrances", by John L. French and "Hydraulics of Conventional Highway Culverts", by H. G. Bossy (Presented at the Tenth National Conference, Hydraulics Division, ASCE, August 1961.) Experimental data for box culverts with headwalls and wingwalls were obtained from an unpublished report of the U. S. Geological Survey.

These research data were analyzed and nomographs for determining culvert capacity for inlet control were developed by the Division of Hydraulic Research, Bureau of Public Roads. These nomographs, Charts 1 through 6, give headwater-discharge relationships for most conventional culverts flowing with inlet control through a range of headwater depths and discharges. Chart 7, discussed in Part I, is included in this revised edition to stress the importance of improving the inlets of culverts flowing with inlet control.
Culverts flowing with outlet control can flow with the culvert barrel full or part full for part of the barrel length or for all of it, (see Figure 2). If the entire cross section of the barrel is filled with water for the total length of the barrel, the culvert is said to be in full flow or flowing full, Figure 2A and Figure 2B. Two other common types of outlet-control flow are shown in Figure 2C and Figure 2D. The procedures given in this circular provide methods for the accurate determination of headwater depth for the flow conditions shown in Figure 2A, Figure 2B and Figure 2C. The
The method given for the part full flow condition, Figure 2D, gives a solution for headwater depth that decreases in accuracy as the headwater decreases.

The head $H$ (Figure 2A) or energy required to pass a given quantity of water through a culvert flowing in outlet control with the barrel flowing full throughout its length is made up of three major parts. These three parts are usually expressed in feet of water and include a velocity head $H_v$, an entrance loss $H_e$, and a friction loss $H_f$. This energy is obtained from ponding of water at the entrance and expressed in equation form

$$H = H_v + H_e + H_f$$

(1)

The velocity head $H_v$ equals

$$\frac{V^2}{2g}$$

where $V$ is the mean or average velocity in the culvert barrel.

(The mean velocity is the discharge $Q$, in cfs, divided by the cross-sectional area $A$, in sq. ft., of the barrel.)

The entrance loss $H_e$ depends upon the geometry of the inlet edge. This loss is expressed as a coefficient $k_e$ times the barrel velocity head or

$$H_e = k_e \frac{V^2}{2g}$$

The entrance loss coefficients $k_e$ for various types of entrances when the flow is in outlet control are given in Appendix B, Table 1.

The friction loss $H_f$ is the energy required to overcome the roughness of the culvert barrel. $H_f$ can be expressed in several ways. Since most highway engineers are familiar with Manning’s $n$ the following expression is used:

$$H_f = \left[\frac{2g n^2 L}{R^{1.33}}\right] \frac{V^2}{2g}$$

where

- $n$ = Manning’s friction factor (see nomographs and Part II for values)
- $L$ = length of culvert barrel (ft)
- $V$ = mean velocity of flow in culvert barrel (ft/sec)
- $g$ = acceleration of gravity, 32.2 (ft/sec$^2$)
- $R$ = hydraulic radius or \( \frac{A}{WP} \) (ft)

where

- $A$ = area of flow for full cross-section (sq. ft)
- $WP$ = wetted perimeter (ft)
Substituting in Equation 1 and simplifying, we get for full flow:

\[ H = \left[ 1 + k_e + \frac{2n^2L}{R^{1.33}} \right] \frac{V^2}{2g} \]  

(2)

**Figure 3**

Figure 3 shows the terms of Equation 2, the energy line, the hydraulic grade line and the headwater depth, HW. The energy line represents the total energy at any point along the culvert barrel. The hydraulic grade line, sometimes called the pressure line, is defined by the elevations to which water would rise in small vertical pipes attached to the culvert wall along its length. The energy line and the pressure line are parallel over the length of the barrel except in the immediate vicinity of the inlet where the flow contracts and re-expands. The difference in elevation between these two lines is the velocity head, \( \frac{V^2}{2g} \).

The expression for H is derived by equating the total energy upstream from the culvert entrance to the energy just inside the culvert outlet with consideration of all the major losses in energy. By referring to Figure 3 and using the culvert invert at the outlet as a datum, we get:

\[ d_1 + \frac{V_1^2}{2g} + LS_o = d_2 + Hv + He + Hf \]

where

\( d_1 \) and \( d_2 \)= depths of flow as shown in Figure 3

\( \frac{V_1^2}{2g} \) = velocity head in entrance pool

\( LS_o \) = length of culvert times barrel slope

then
\[
d_1 + \frac{V_1^2}{2g} + Ls_0 - d_2 = H_v + H_e + H_f
\]

and

\[
H = d_1 + \frac{V_1^2}{2g} + Ls_0 - d_2 = H_v + H_e + H_f
\]

From the development of this energy equation and Figure 3, head \( H \) is the difference between the elevations of the hydraulic grade line at the outlet and the energy line at the inlet. Since the velocity head in the entrance pool is usually small under ponded conditions, the water surface or headwater pool elevation can be assumed to equal the elevation of the energy line. Thus headwater elevations and headwater depths, as computed by the methods given in this circular, for outlet control, can be higher than might occur in some installations. Headwater depth is the vertical distance from the culvert invert at the entrance to the water surface, assuming the water surface (hydraulic grade line) and the energy line to be coincident, \( d_1 + \frac{V_1^2}{2g} \) in Figure 3.

Equation 2 can be solved for \( H \) readily by the use of the full-flow nomographs, Charts 8 through 14. Each nomograph is drawn for a particular barrel shape and material and a single value of \( n \) as noted on the respective charts. These nomographs can be used for other values of \( n \) by modifying the culvert length as directed in the instructions (Part III) for the use of the full-flow nomographs.

In culvert design the depth of headwater \( HW \) or the elevation of the ponded water surface is usually desired. Finding the value of \( H \) from the nomographs or by Equation 2 is only part of the solution for this headwater depth or elevation. In the case of Figure 2A or Figure 3, where the outlet is totally submerged, the headwater pool elevation (assumed to be the same elevation as the energy line) is found by adding \( H \) to the elevation of the tailwater. The headwater depth is the difference in elevations of the pool surface and the culvert invert at the entrance.

When the tailwater is below the crown of the culvert, the submerged condition discussed above no longer exists and the determination of headwater is somewhat more difficult. In discussing outlet-control flow for this condition, tailwater will be assumed to be so low that it has no effect on the culvert flow. (The effect of tailwater will be discussed later.) The common types of flow for the low tailwater condition are shown in Figure 2B, Figure 2C and Figure 2D. Each of these flow conditions are dependent on the amount of discharge and the shape of the culvert cross section. Each condition will be discussed separately.

Full flow at the outlet, Figure 2B, will occur only with the higher rates of discharge. Charts 15 through 20 are provided to aid in determining this full flow condition. The curves shown on
these charts give the depth of flow at the outlet for a given discharge when a culvert is flowing with outlet control. This depth is called critical depth \( d_c \). When the discharge is sufficient to give a critical depth equal to the crown of the culvert barrel, full flow exists at the outlet as in Figure 2B. The hydraulic grade line will pass through the crown of the culvert at the outlet for all discharges greater than the discharge causing critical depth to reach the crown of the culvert. Head \( H \) can be measured from the crown of the culvert in computing the water surface elevation of the headwater pool.

When critical depth falls below the crown of the culvert at the outlet, the water surface drops as shown in either Figure 2C or Figure 2D, depending again on the discharge. To accurately determine headwater for these conditions, computations for locating a backwater curve are usually required. These backwater computations are tedious and time consuming and they should be avoided if possible. Fortunately, headwater for the flow condition shown in Figure 2C can be solved by using the nomographs and the instructions given in this circular.

For the condition shown in Figure 2C, the culvert must flow full for part of its length. The hydraulic grade line for the portion of the length in full flow will pass through a point where the water breaks with the top of the culvert as represented by point A in Figure 2C. Backwater computations show that the hydraulic grade line if extended as a straight line will cut the plane of the outlet cross section at a point above critical depth (water surface). This point is at a height approximately equal to one half the distance between critical depth and the crown of the culvert. The elevation of this point can be used as an equivalent hydraulic grade line and \( H \), as determined by Equation 2 or the nomographs, can be added to this elevation to find the water surface elevation of the headwater pool.

The full flow condition for part of the barrel length, Figure 2C, will exist when the headwater depth \( HW \), as computed from the above headwater pool elevation, is equal to or greater than the quantity

\[
D + \left(1 + k_e \right) \frac{V^2}{2g}
\]

where \( V \) is the mean velocity for the full cross section of the barrel; \( k_e \), the entrance loss coefficient; and \( D \), the inside height of the culvert. If the headwater is less than the above value, a free water surface, Figure 2D, will extend through the culvert barrel.

The part full flow condition of Figure 2D must be solved by a backwater computation if accurate headwater depths are desired. Details for making this computation are not given in this circular. Instead the solution used is the same as that given for the flow condition of Figure 2C, with the reservation that headwater depths become less accurate as the discharge for a particular culvert decreases. Generally, for design purposes, this method is satisfactory for headwater depths above 0.75D, where D is the height of the culvert barrel. Culvert capacity charts found in Hydraulic Engineering Circular No. 10 give a more accurate and easy solution for this free surface flow condition.
Headwater depth HW can be expressed by a common equation for all outlet-control conditions, including all depths of tailwater. This is accomplished by designating the vertical dimension from the culvert invert at the outlet to the elevation from which H is measured as $h_o$. The headwater depth HW equation is

$$HW = H + h_o - LS_o$$

(3)

All the terms in this equation are in feet. H is computed by Equation 2 or found from the full-flow nomographs. L is the length of culvert in feet and $S_o$ the barrel slope in ft. per ft. The distance $h_o$ is discussed in the following paragraphs for the various conditions of outlet-control flow. Headwater HW is the distance in feet from the invert of the culvert at the inlet to the water surface of the headwater pool.

When the elevation of the water surface in the outlet channel is equal to or above the elevation of the top of the culvert opening at the outlet, Figure 2A, $h_o$ is equal to the tailwater depth. Tailwater depth TW is the distance in feet from the culvert invert at the outlet to the water surface in the outlet channel. The relationship of HW to the other terms in Equation 3 is illustrated in Figure 4.

Figure 4

If the tailwater elevation is below the top of the culvert opening at the outlet, Figure 2B, Figure 2C, and Figure 2D, $h_o$ is more difficult to determine. The discharge, size and shape of culvert, and the TW must be considered. In these cases, $h_o$ is the greater of two values (1) TW depth as defined above or (2) $\frac{d_c + D}{2}$. The latter dimension is the distance to the equivalent hydraulic grade line discussed previously. In this fraction $d_c$ is the critical depth, as read from Charts 15 through 20 and D is the culvert height. The value of $d_c$ can never exceed D, making the upper limit of this fraction equal to D. Where TW is the greater of these two values, critical depth is submerged sufficiently to make TW effective in increasing the headwater. The sketch in Figure 5 shows the terms of Equation 3 for this low tailwater condition. Figure 5 is drawn similar to Figure 2C, but a change in discharge can change the water surface profile to that of Figure 2B or Figure 2D.
Computing Depth of Tailwater

In culverts flowing with outlet control, tailwater can be an important factor in computing both the headwater depth and the hydraulic capacity of a culvert. Thus, in many culvert designs, it becomes necessary to determine tailwater depth in the outlet channel.

Much engineering judgment and experience is needed to evaluate possible tailwater conditions during floods. A field inspection should be made to check on downstream controls and to determine water stages. Oftentimes tailwater is controlled by a downstream obstruction or by water stages in another stream. Fortunately, most natural channels are wide compared to the culvert and the depth of water in the natural channel is considerably less than critical depth, thus the tailwater is ineffective and channel depth computations are not always warranted.

An approximation of the depth of flow in a natural stream (outlet channel) can be made by using Manning's equation if the channel is reasonably uniform in cross section, slope and roughness. Values of $n$ for natural streams for use in Manning's equation may be found in Table 2, in Appendix B. If the water surface in the outlet channel is established by downstream controls, other means must be found to determine the tailwater elevation. Sometimes this necessitates a study of the stage-discharge relationship of another stream into which the stream in question flows or the securing of data on reservoir elevations if a storage dam is involved.

Velocity of Culvert Flow

A culvert, because of its hydraulic characteristics, increases the velocity of flow over that in the natural channel. High velocities are most damaging just downstream from the culvert outlet and the erosion potential at this point is a feature to be considered in culvert design.

Energy dissipators for channel flow have been investigated in the laboratory and many have been constructed, especially in irrigation channels. Designs for highway use have been developed and constructed at culvert outlets. All energy dissipators add to the cost of a culvert,
therefore, they should be used only to prevent or to correct a serious erosion problem. (See references 4 and 5.)

The judgment of engineers working in a particular area is required to determine the need for energy dissipators at culvert outlets. As an aid in evaluating this need, culvert outlet velocities should be computed. These computed velocities can be compared with outlet velocities of alternate culvert designs, existing culverts in the area, or the natural stream velocities. In many streams the maximum velocity in the main channel is considerably higher than the mean velocity for the whole channel cross-section. Culvert outlet velocities should be compared with maximum stream velocities in determining the need for channel protection. A change in size of culvert does not change outlet velocities appreciably in most cases.

Outlet velocities for culverts flowing with inlet control may be approximated by computing the mean velocity for the culvert cross section using Manning’s equation

\[
V = \frac{1.49}{n} R^{2/3} S_0^{1/2}
\]

Since the depth of flow is not known the use of tables or charts is recommended in solving this equation (see references). The outlet velocity as computed by this method will usually be high because the normal depth, assumed in using Manning’s equation, is seldom reached in the relatively short length of the average culvert. Also, the shape of the outlet channel, including aprons and wingwalls, have much to do with changing the velocity occurring at the end of the culvert barrel. Tailwater is not considered effective in reducing outlet velocities for most inlet control conditions.

In outlet control, the average outlet velocity will be the discharge divided by the cross-sectional area of flow at the outlet. This flow area can be either that corresponding to critical depth, tailwater depth (if below the crown of the culvert) or the full cross section of the culvert barrel.

---

**Performance Curves**

Although the procedure given in this circular is primarily for use in selecting a size of culvert to pass a given discharge at a given headwater, a better understanding of culvert operation can be gained by plotting performance curves through some range of discharges and barrel slopes. Such curves can also be used to compare the performance of different sizes and types of culverts. The construction of such curves is described in Appendix A.

---

**Inlets and Culvert Capacity**

Inlet shape, edge geometry and skew of the entrance affects culvert capacity. Both the shape and edge geometry have been investigated by recent research but the effect of skew for various flow conditions has not been examined. Results show that the inlet edge geometry is
particularly important to culvert performance in inlet-control flow. A comparison of several types of commonly used inlets can be made by referring to Chart 2 and Chart 5. The type of inlet has some effect on capacity in outlet control but generally the edge geometry is less important than in inlet control. (See reference 6.)

As shown by the inlet control nomograph on Chart 5, the capacity of a thin edge projecting metal pipe can be increased by incorporating the thin edge in a headwall. The capacity of the same thin edged pipe can be further increased if the entrance is rounded, beveled or tapered by the addition of an attachment or the building of these shapes into a headwall. Although research on improving culvert entrances is not complete, sufficient data are available to permit the construction of Chart 7, an inlet control nomograph for the performance of a beveled inlet on a circular culvert. A sketch on the nomograph shows the dimensions of two possible bevels. Although nomographs have not been prepared for other barrel shapes, the capacity of box culverts can be increased at little cost by incorporating a bevel into the headwall. In computing headwater depths for outlet control, when the above bevel is used, $k_e$ equals 0.25 for corrugated metal barrels and 0.2 for concrete barrels.

Figure 6 shows a photograph of a bevel constructed in the headwall of a corrugated metal pipe.
Procedure for Selection of Culvert Size

Step 1: List design data. (See suggested tabulation form, Figure 7.)

- Design discharge \( Q \), in cfs., with average return period. (i.e. \( Q_{25} \) or \( Q_{50} \) etc.)
- Approximate length \( L \) of culvert, in feet.
- Slope of culvert. (If grade is given in percent, convert to slope in ft. per ft.)
- Allowable headwater depth, in feet, which is the vertical distance from the culvert invert (flow line) at the entrance to the water surface elevation permissible in the headwater pool or approach channel upstream from the culvert.
- Mean and maximum flood velocities in natural stream.
- Type of culvert for first trial selection, including barrel material, barrel cross-sectional shape and entrance type.

Step 2: Determine the first trial size culvert.

Since the procedure given is one of trial and error, the initial trial size can be determined in several ways:

- By arbitrary selection.
- By using an approximating equation such as \( Q/10 = A \) from which the trial culvert dimensions are determined.
- By using inlet control nomographs (Charts 1-7) for the culvert type selected. If this method is used an \( \text{HW} \) must be assumed, say \( \text{HW} = 1.5 \), and using the given \( Q \) a trial size is determined.

If any trial size is too large in dimension because of limited height of embankment or availability of size, multiple culverts may be used by dividing the discharge equally between the number of barrels used. Raising the embankment height or the use of pipe arch and box culverts with width greater than height should be considered. Final selection should be based on an economic analysis.

Step 3: Find headwater depth for trial size culvert.

Assuming INLET CONTROL

1. Using the trial size from step 2, find the headwater depth \( HW \) by use of the appropriate inlet control nomograph (Charts 1-7). Tailwater TW conditions are to be neglected in this determination. \( HW \) in this case is found by multiplying \( \frac{HW}{D} \) obtained from the nomographs by the height of culvert \( D \).

2. If \( HW \) is greater or less than allowable, try another trial size until \( HW \) is acceptable for inlet control before computing \( HW \) for outlet control.

Assuming OUTLET CONTROL

1. Approximate the depth of tailwater \( TW \), in feet, above the invert at the outlet for the design flood condition in the outlet channel. (See general discussion on tailwater, Part I.)
2. For tailwater TW elevation equal to or greater than the top of the culvert at the outlet set \( h_o \) equal to TW and find HW by the following equation (Equation 3)

\[
HW = H + h_o - LS_o
\]

where

- \( HW \) = vertical distance in feet from culvert invert (flow line) at entrance to the pool surface.
- \( H \) = head loss in feet as determined from the appropriate nomograph (Charts 8-14)
- \( h_o \) = vertical distance in feet from culvert invert at outlet to the hydraulic grade line (In this case \( h_o \) equals TW, measured in feet above the culvert invert.)
- \( S_o \) = slope of barrel in ft./ft.
- \( L \) = culvert length in ft.

3. For tailwater TW elevations less than the top of the culvert at the outlet, find headwater HW by Equation 3 as in b(2) above except that

\[
h_o = \frac{d_c + D}{2} \quad \text{or} \quad TW, \text{ whichever is the greater.}
\]

where

- \( d_c \) = critical depth in ft. (Charts 15 through 20) Note: \( d_c \) cannot exceed D
- \( D \) = height of culvert opening in ft.

Note: Headwater depth determined in b(3) becomes increasingly less accurate as
the headwater computed by this method falls below the value \( D + \left(1 + k_2\right) \frac{v^2}{2g} \).

(See discussion under "Culvert Flowing Full with Outlet Control", Part II.)

c. Compare the headwaters found in Step 3(a) and Step 3(b) (Inlet Control and Outlet Control). The higher headwater governs and indicates the flow control existing under the given conditions for the trial size selected.

d. If outlet control governs and the HW is higher than is acceptable, select a larger trial size and find HW as instructed under Step 3b. (Inlet control need not be checked, since the smaller size was satisfactory for this control as determined under Step 3a.)

Step 4: Try a culvert of another type or shape and determine size and HW by the above procedure.

Step 5: Compute outlet velocities for size and types to be considered in selection and determine need for channel protection.

   a. If outlet control governs in Step 3c above, outlet velocity equals \( \frac{Q}{A_o} \), where \( A_o \) is the cross-sectional area of flow in the culvert barrel at the outlet. If \( d_c \) or TW is less than the height of the culvert barrel use \( A_o \) corresponding to \( d_c \) or TW depth, whichever gives the greater area of flow. \( A_o \) should not exceed the total cross-sectional area \( A \) of the culvert barrel.

   b. If inlet control governs in Step 3c, outlet velocity can be assumed to equal mean velocity in open-channel flow in the barrel as computed by Manning's equation for the rate of flow, barrel size, roughness and slope of culvert selected.
Note: Charts and tables are helpful in computing outlet velocities. (See references.)

Step 6: Record final selection of culvert with size, type, required headwater, outlet velocity, and economic justification.

![Figure 7](image)

Inlet-Control Nomographs (Charts 1 through 7)

Instructions for Use

1. To determine headwater (HW), given Q. and size and type of culvert.

   Connect with a straightedge the given culvert diameter or height (D) and the discharge Q, or \( \frac{Q}{B} \) for box culverts; mark intersection of straightedge on \( \frac{H/W}{D} \) scale marked (1).

2. If \( \frac{H/W}{D} \) scale marked (1) represents entrance type used, read \( \frac{H/W}{D} \) on scale (1). If another of the three entrance types listed on the nomograph is used, extend the point of intersection in (a) horizontally to scale (2) or (3) and read \( \frac{H/W}{D} \).

3. Compute HW by multiplying \( \frac{H/W}{D} \) by D.
2. To determine discharge (Q) per barrel, given HW, and size and type of culvert.
   a. Compute $\frac{HW}{D}$ for given conditions.
   b. Locate $\frac{HW}{D}$ on scale for appropriate entrance type. If scale (2) or (3) is used, extend $\frac{HW}{D}$ point horizontally to scale (1).
   c. Connect point on $\frac{HW}{D}$ scale (1) as found in (b) above and the size of culvert on the left scale. Read $Q$ or $\frac{Q}{B}$ on the discharge scale.
   d. If $\frac{Q}{B}$ is read in (c) multiply by B (span of box culvert) to find Q.

3. To determine culvert size, given Q, allowable HW and type of culvert.
   a. Using a trial size, compute $\frac{HW}{D}$.
   b. Locate $\frac{HW}{D}$ on scale for appropriate entrance type. If scale (2) or (3) is used, extend $\frac{HW}{D}$ point horizontally to scale (1).
   c. Connect point on $\frac{HW}{D}$ scale (1) as found in (b) above to given discharge and read diameter, height or size of culvert required for $\frac{HW}{D}$ value.
   d. If D is not that originally assumed, repeat procedure with a new D.

Chart 1. Headwater Depth for Box Culverts with Inlet Control
Chart 2. Headwater Depth for Concrete Pipe Culverts with Inlet Control
Chart 3. Headwater Depth for Oval Concrete Pipe Culverts Long Axis Horizontal with Inlet Control
Chart 4. Headwater Depth for Oval Concrete Pipe Culverts Long Axis Vertical with Inlet Control
Chart 5. Headwater Depth for C.M. Pipe Culverts with Inlet Control.
Chart 6. Headwater Depth for C.M. Pipe-Arch Culverts with Inlet Control.
Chart 7. Headwater Depth for Circular Pipe Culverts with Beveled Ring Inlet Control.

Go to Part III
Outlet-Control Nomographs (Charts 8 through 14)

Instructions for Use

Outlet control nomographs solve Equation 2, for head H when the culvert barrel flows full for its entire length. They are also used to determine head H for some part-full flow conditions with outlet control. These nomographs do not give a complete solution for finding headwater HW, since they only give H in Equation 3, \( HW = H + h_0 - LS_0 \). (See discussion for "Culverts Flowing with Outlet Control", Part I.)

1. To determine head H for a given culvert and discharge Q.
   a. Locate appropriate nomograph for type of culvert selected. Find \( k_e \) for entrance type in Appendix B, Table 1.
   b. Begin nomograph solution by locating starting point on length scale. To locate the proper starting point on the length scales follow instructions below:
      1. If the n value of the nomograph corresponds to that of the culvert being used, select the length curve for the proper \( k_e \) and locate the starting point at the given culvert length. If a \( k_e \) curve is not shown for the selected \( k_e \), see (2) below. If the n value for the culvert selected differs from that of the nomograph, see (3) below.
      2. For the n of the nomograph and a \( k_e \) intermediate between the scales given, connect the given length on adjacent scales by a straight line and select a point on this line spaced between the two chart scales in proportion to the \( k_e \) values.
      3. For a different roughness coefficient \( n_1 \) than that of the chart n, use the length scales shown with an adjusted length \( L_1 \), calculated by the formula
         \[
         L_1 = L \left[ \frac{n_1}{n} \right]^2
         \]
   c. Using a straightedge, connect point on length scale to size of culvert barrel and mark the point of crossing on the "turning line". See instruction 3 below for size considerations for rectangular box culvert.
d. Pivot the straightedge on this point on the turning line and connect given discharge rate. Read head in feet on the head (H) scale. For values beyond the limit of the chart scales, find H by solving Equation 2.

2. Values of n for commonly used culvert materials.

<table>
<thead>
<tr>
<th>Material</th>
<th>Concrete Pipe</th>
<th>Concrete Boxes</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>n = 0.012</td>
<td>n = 0.012</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Material</th>
<th>Corrugated Metal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Small Corrugations (2 2/3” x 1/2”)</td>
</tr>
<tr>
<td>Unpaved</td>
<td>0.024</td>
</tr>
<tr>
<td>25% paved</td>
<td>0.021</td>
</tr>
<tr>
<td>Fully Paved</td>
<td>0.012</td>
</tr>
</tbody>
</table>

*Variation in n with diameter shown on charts. The various n values have been incorporated into the nomographs and no adjustments for culvert length is required as instructed in lb(3).

3. To use the box culvert nomograph, Chart 8, for full-flow for other than square boxes.
   a. Compute cross-sectional area of the rectangular box.
   b. Connect proper point (see instruction 1) on length scale to barrel area and mark point on turning line.
   c. Pivot the straightedge on this point on the turning line and connect given discharge rate. Read head in feet on the head (H) scale.

**Chart 8.** Head for Concrete Box Culverts Flowing Full, n=0.012  
**Chart 9.** Head for Concrete Pipe Culverts Flowing Full, n=0.012  
**Chart 10.** Head for Oval Concrete Pipe Culverts, Long Axis Horizontal or Vertical Flowing Full, n=0.012  
**Chart 11.** Head for Standard C.M. Pipe Culverts Flowing Full, n=0.024  
**Chart 12.** Head for Standard C.M. Pipe-Arch Culverts Flowing Full, n=0.024  
**Chart 13.** Head for Structural Plate, Corrugated Metal Pipe Culverts Flowing Full, n=0.0328 to 0.0302  
**Chart 14.** Head for Structural Plate, Corrugated Metal Pipe Arch Culverts, 18 in. Corner Radius, Flowing Full, n=0.0327 to 0.0306  
**Chart 15.** Critical Depth, Rectangular Section  
**Chart 16.** Critical Depth, Circular Pipe
NOTE:3 The area scale on the nomograph is calculated for barrel cross-sections with span B twice the height D; its close correspondence with area of square boxes assures it may be used for all sections intermediate between square and B = 2D or B = 1/2D For other box proportions use Equation 2 for more accurate results.

Go to Appendix A
The principal disadvantage in using nomographs for the selection of culvert sizes is that it requires the trial and error solution described in this circular. Some engineers who limit their selection to a relatively small number of types of culverts would find it advantageous to prepare performance curves such as shown in Figure 8. These curves are applicable through a range of headwaters and discharges for a length and type of culvert. Usually charts with length intervals of 25 to 50 feet are satisfactory for design purposes.

Figure 8 is plotted from the data shown in the following tabulations. These data were obtained from the nomographs contained in this circular. (Computer programs are available from Public Roads for making these computations.) The first tabulation is for the inlet-control curve on Figure 8, and the second tabulation is for the outlet control curves.

### Data for Inlet-Control Curve

<table>
<thead>
<tr>
<th>HW</th>
<th>Q*</th>
<th>HW</th>
</tr>
</thead>
<tbody>
<tr>
<td>.5</td>
<td>21c.f.s.</td>
<td>2.0ft.</td>
</tr>
<tr>
<td>.6</td>
<td>29</td>
<td>2.4</td>
</tr>
<tr>
<td>.7</td>
<td>37</td>
<td>2.8</td>
</tr>
<tr>
<td>.8</td>
<td>46</td>
<td>3.2</td>
</tr>
<tr>
<td>.9</td>
<td>56</td>
<td>3.6</td>
</tr>
<tr>
<td>1.0</td>
<td>65</td>
<td>4.0</td>
</tr>
<tr>
<td>1.1</td>
<td>74</td>
<td>4.4</td>
</tr>
<tr>
<td>1.3</td>
<td>90</td>
<td>5.2</td>
</tr>
<tr>
<td>1.5</td>
<td>102</td>
<td>6.0</td>
</tr>
<tr>
<td>1.7</td>
<td>112</td>
<td>6.8</td>
</tr>
<tr>
<td>2.0</td>
<td>126</td>
<td>8.0</td>
</tr>
<tr>
<td>2.5</td>
<td>145</td>
<td>10.0</td>
</tr>
<tr>
<td>3.0</td>
<td>165</td>
<td>12.0</td>
</tr>
</tbody>
</table>

*From Chart 5 Projecting Inlet (3)

### Data for Outlet-Control Curves

<table>
<thead>
<tr>
<th>Q</th>
<th>dc</th>
<th>H</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Assume)</td>
<td>Chart 16</td>
<td>Chart 11</td>
</tr>
<tr>
<td>(Assume)</td>
<td>(Compute)</td>
<td>HW for Various S_o</td>
</tr>
<tr>
<td>0%</td>
<td>.5%</td>
<td>1%</td>
</tr>
<tr>
<td>20 cfs</td>
<td>1.3 ft.</td>
<td>2.6 ft.</td>
</tr>
<tr>
<td>--------</td>
<td>---------</td>
<td>---------</td>
</tr>
<tr>
<td>40</td>
<td>1.9</td>
<td>3.0</td>
</tr>
<tr>
<td>60</td>
<td>2.3</td>
<td>3.2</td>
</tr>
<tr>
<td>80</td>
<td>2.7</td>
<td>3.4</td>
</tr>
<tr>
<td>100</td>
<td>3.1</td>
<td>3.6</td>
</tr>
<tr>
<td>120</td>
<td>3.3</td>
<td>3.6</td>
</tr>
<tr>
<td>140</td>
<td>3.5</td>
<td>3.8</td>
</tr>
<tr>
<td>160</td>
<td>3.7</td>
<td>3.8</td>
</tr>
</tbody>
</table>

\[
HW = H + h_o - LS_o \quad \text{where } h_o = \frac{d_c + D}{2}
\]

*From Chart 11 - or by Equation 2.

The curves plotted apply only to the type and length of culvert shown. Culverts placed on grades steeper than about 2.5 percent will operate on the inlet control curve for the headwater-discharge range of this plot. If a free outfall condition does not exist a correction for tailwater should be made as instructed in Step 3b, Part II of "Procedure for Selection of Culvert Size".
Figure 8. Hydraulic Performance Curves, 48-Inch C.M. Pipe Culvert with Projecting Inlet

Go to Appendix B
Table 1. Entrance Loss Coefficients

Outlet Control, Full or Partly Full

Entrance head loss \( H_e = \frac{v^2}{2g} \)

<table>
<thead>
<tr>
<th>Type of Structure and Design of Entrance</th>
<th>Coefficient ( k_e )</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Pipe, Concrete</strong></td>
<td></td>
</tr>
<tr>
<td>Projecting from fill, socket end (groove-end)</td>
<td>0.2</td>
</tr>
<tr>
<td>Projecting from fill, sq. cut end</td>
<td>0.5</td>
</tr>
<tr>
<td>Headwall or headwall and wingwalls</td>
<td></td>
</tr>
<tr>
<td>Socket end of pipe (groove-end)</td>
<td>0.2</td>
</tr>
<tr>
<td>Square-edge</td>
<td>0.5</td>
</tr>
<tr>
<td>Rounded (radius = 1/12D)</td>
<td>0.2</td>
</tr>
<tr>
<td>Mitered to conform to fill slope</td>
<td>0.7</td>
</tr>
<tr>
<td>*End-Section conforming to fill slope</td>
<td>0.5</td>
</tr>
<tr>
<td>Beveled edges, 33.7° or 45° bevels</td>
<td>0.2</td>
</tr>
<tr>
<td>Side-or slope-tapered inlet</td>
<td>0.2</td>
</tr>
<tr>
<td><strong>Pipe, or Pipe-Arch Corrugated Metal</strong></td>
<td></td>
</tr>
<tr>
<td>Projecting from fill (no headwall)</td>
<td>0.9</td>
</tr>
<tr>
<td>Headwall or headwall and wingwalls square-edge</td>
<td>0.5</td>
</tr>
<tr>
<td>Mitered to conform to fill slope, paved or unpaved slope</td>
<td>0.7</td>
</tr>
<tr>
<td>*End-Section conforming to fill slope</td>
<td>0.5</td>
</tr>
<tr>
<td>Beveled edges, 33.7° or 45° bevels</td>
<td>0.2</td>
</tr>
<tr>
<td>Side-or slope-tapered inlet</td>
<td>0.2</td>
</tr>
<tr>
<td><strong>Box, Reinforced Concrete</strong></td>
<td></td>
</tr>
<tr>
<td>Headwall parallel to embankment (no wingwalls)</td>
<td>0.5</td>
</tr>
<tr>
<td>Square-edged on 3 edges</td>
<td>0.5</td>
</tr>
<tr>
<td>Rounded on 3 edges to radius of 1/12 barrel</td>
<td>0.2</td>
</tr>
<tr>
<td>Wingwalls at 30° to 75° to barrel</td>
<td>0.2</td>
</tr>
<tr>
<td>Square-edged at crown</td>
<td>0.4</td>
</tr>
<tr>
<td>Crown edge rounded to radius of 1/12 barrel</td>
<td>0.2</td>
</tr>
<tr>
<td>Wingwall at 10° to 25° to barrel</td>
<td>0.2</td>
</tr>
<tr>
<td>Square-edged at crown</td>
<td>0.5</td>
</tr>
</tbody>
</table>
*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. Some end sections, incorporating a closed taper in their design have a superior hydraulic performance. These latter sections can be designed using the information given for the beveled inlet, Part I.

Table 2. Manning’s n for Natural Stream Channels
(Surface width at flood stage less than 100 ft.)

| 1. Fairly regular section:                          |  
|----------------------------------------------------|---|
| a. Some grass and weeds, little or no brush        | 0.030--0.035 |
| b. Dense growth of weeds, depth of flow            |      |
| materially greater than weed height                | 0.035--0.05 |
| c. Some weeds, light brush on banks                | 0.035-0.05 |
| d. Some weeds, heavy brush on banks                | 0.05-0.07  |
| e. Some weeds, dense willows on banks              | 0.06-0.08  |
| f. For trees within channel, with branches submerged at high stage, increase all above values by | 0.01-0.02  |

| 2. Irregular sections, with pools, slight channel meander; increase values given above about | 0.01 --0.02 |

| 3. Mountain streams, no vegetation in channel, banks usually steep, trees and brush along banks submerged at high stage: |  
|----------------------------------------------------|---|
| 1. Bottom of gravel, cobbles, and few boulders     | 0.04--0.05  |
| 2. Bottom of cobbles, with large boulders          | 0.05--0.07  |

*From “Design Charts for Open Channel Flow”, (see references).
Appendix C : HEC 5
Illustrative Problems

PROJECT: T-46 (1)

HYDROLOGIC AND CHANNEL INFORMATION

\[ Q_1 = \frac{180 \text{ cfs}}{225 \text{ cfs}} = Q_{25}, \quad \text{TW}_1 = \frac{3.5}{4.0} \]

\( Q_2 = \text{CHECK DISCHARGE, SAY Q}_{50} \)

SKETCH

STATION: 6 + 21

\[ \text{EL.} = 114 \]

\[ \text{AHW} = 10' \]

\[ \text{TW} = 4.5 \]

\[ \text{S}_{0.05} = 0.05 \% \]

\[ L = \frac{120}{200} \]

\[ \text{EL.} = 20' \]

\[ \text{MEAN STREAM VELOCITY} = \frac{10'}{200} \]

\[ \text{MAX. STREAM VELOCITY} = \frac{12'}{200} \]

<table>
<thead>
<tr>
<th>CULVERT DESCRIPTION</th>
<th>0</th>
<th>SIZE</th>
<th>HEADWATER COMPUTATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>(ENTRANCE TYPE)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>CIRCULAR CHAM</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PROJ. ENT.</td>
<td>180</td>
<td>54&quot;</td>
<td></td>
</tr>
<tr>
<td>&quot;</td>
<td>180</td>
<td>54&quot;</td>
<td></td>
</tr>
<tr>
<td>&quot;</td>
<td>225</td>
<td>54&quot;</td>
<td></td>
</tr>
<tr>
<td>&quot;</td>
<td>180</td>
<td>60&quot;</td>
<td></td>
</tr>
<tr>
<td>&quot;</td>
<td>225</td>
<td>60&quot;</td>
<td></td>
</tr>
</tbody>
</table>

\[ \text{INLET CONT.} \]

\[ \text{OUTLET CONTROL} \]

\[ \text{HW=H+h_0-LS}_0 \]

\[ \text{CONTROLING OUTLET VELOCITY} \]

\[ \text{COST} \]

\[ \text{COMMENTS} \]

SUMMARY & RECOMMENDATIONS:
Velocities read from chart 46, 47- "Design charts for open channel flow." (see references). Outlet velocities are about the same for each size, indicating change in size has little effect. Size selected (60 or 54-inch) depends on designer's confidence in flood estimate and damage incurred if a larger flood should occur. Note that TW must be greater than 10.1" for outlet control to govern for the 54" pipe flowing 180 cfs. accurate determination of TW depths is unnecessary in most cases.
HYDROLOGIC AND CHANNEL INFORMATION

\[ Q_1 = \frac{160 \text{ cfs}}{3}, \quad Q_{50} \quad \text{TW}_1 = 3.0' \]

\[ Q_2 = \quad \text{TW}_2 = \quad \]

(\( Q_1 \) = DESIGN DISCHARGE, SAY Q_{25} \)

(\( Q_2 \) = CHECK DISCHARGE, SAY Q_{50} OR Q_{100} )

SKETCH

STATION: 321 + 14

EL 112

AHW = 0.5

EL 100

S_0 = 0.11 %

L = 100'

EL 99.7

TW 3'

MEAN STREAM VELOCITY = 8/sec

MAX STREAM VELOCITY = 10/sec

---

**CULVERT DESCRIPTION**

<table>
<thead>
<tr>
<th>CULVERT DESCRIPTION (ENTRANCE TYPE)</th>
<th>Q</th>
<th>SIZE</th>
<th>O</th>
<th>INLET CONT.</th>
<th>OUTLET CONTROL</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMP (Cyl.) Headwall</td>
<td>160</td>
<td>54&quot;</td>
<td>156 7.0</td>
<td>38 3</td>
<td>3.8 10 111</td>
</tr>
<tr>
<td>&quot;</td>
<td>160</td>
<td>48&quot;</td>
<td>225 9.0</td>
<td>38 3</td>
<td>3.8 10 111</td>
</tr>
<tr>
<td>Concrete (Cyl) Sq. Edged Headwall</td>
<td>160</td>
<td>48&quot;</td>
<td>235 9.4</td>
<td>38 3</td>
<td>3.8 10 75 94</td>
</tr>
<tr>
<td>&quot;</td>
<td>160</td>
<td>54&quot;</td>
<td>167 7.2</td>
<td>38 3</td>
<td>3.8 10 60 72</td>
</tr>
<tr>
<td>Concrete (Cyl) Groove End Headwall</td>
<td>160</td>
<td>48&quot;</td>
<td>195 7.8</td>
<td>38 3</td>
<td>3.8 10 68 78</td>
</tr>
</tbody>
</table>

---

**HEADWATER COMPUTATION**

<table>
<thead>
<tr>
<th>HW</th>
<th>D</th>
<th>HW</th>
<th>Ke</th>
<th>H</th>
<th>dc</th>
<th>S_0 + D/2</th>
<th>TW</th>
<th>h_0</th>
<th>LS_0</th>
<th>HW</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

---

**SUMMARY & RECOMMENDATIONS:**

The selection of a 54" CMP with headwall will keep the headwater below the AWH with a minimum outlet velocity. A 48" concrete pipe with groove edged entrance gives equal HW and slightly higher outlet velocity. Protection of outlet channel might be necessary in some locations.
**HYDROLOGIC AND CHANNEL INFORMATION**

\[ Q_1 = \frac{400 \text{ cfs}}{} \quad Q_{30} = \quad TW_1 = 6.5' \]
\[ Q_2 = \quad \quad \quad \quad \quad \quad TW_2 = \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \quad \Quad
\]

\( Q_1 \) = DESIGN DISCHARGE, SAY \( Q_{30} \)
\( Q_2 \) = CHECK DISCHARGE, SAY \( Q_{50} \) OR \( Q_{100} \)

**MEAN STREAM VELOCITY** = 8'/sec

**MAX. STREAM VELOCITY** = 12'/sec

**SKETCH**

**STATION:** 8+61

**AHW = 8'**

**TW = 6.5'**

**EL. 81'**

**EL. 91'**

**CULVERT DESCRIPTION** (Entrance Type) | Q | SIZE | HEADWATER COMPUTATION
--- | --- | --- | ---
Concrete (Cir) (Grand Proj) | 400 | Assume 1.5 | HW 0.5
" | 400 | 84' | HW 1.18 6.3
" | 400 | 90' | HW 1.05 7.9
" | 400 | 90' | HW 1.29 5.2 6.3 6.5 6.6 6.0 2.4 7.9
Some type 2 pipes | 200 | 54' | HW 1.85 8.3
" | 200 | 60' | 1.86 6.9
" | 200 | 60' | 1.35 6.7
Cir. CMP 96W ( martyr) | 200 | 60' | 1.54 6.7

**INLET CONT** | HW | HW | HW | HW | HW | HW | HW | HW
--- | --- | --- | --- | --- | --- | --- | --- | ---

**OUTLET CONTROL HW=H+ho-Ls0** | HW | HW | HW | HW | HW | HW | HW | HW
--- | --- | --- | --- | --- | --- | --- | --- | ---

**CONTROLLING HW** | HW | HW | HW | HW | HW | HW | HW | HW
--- | --- | --- | --- | --- | --- | --- | --- | ---

**COST** | HW | HW | HW | HW | HW | HW | HW | HW
--- | --- | --- | --- | --- | --- | --- | --- | ---

**COMMENTS**

SUMMARY & RECOMMENDATIONS:

Problem to illustrate use of double pipes if one pipe is too high or not available. Inlet control governs TW submerges outlet for all double barrel. Velocities are computed for both inlet control and for full flow at outlet caused by TW. Two 60-inch concrete pipes or two 60-inch CMP with inlets shown satisfy headwater limitations. Concrete pipe will give considerably higher outlet velocities if tailwater is not effective in causing the culvert to fill at the outlet.
## HYDROLOGIC AND CHANNEL INFORMATION

\[ Q_1 = 120 \text{ cfs}; \quad Q_{S5} = \quad TW_1 = 5.0' \]
\[ Q_2 = \quad TW_2 = \quad (Q_1 = \text{DESIGN DISCHARGE, SAY Q}_{25} \quad (Q_2 = \text{CHECK DISCHARGE, SAY Q}_{50} \text{OR Q}_{100}) \]

**Sketch**

- **Station:** 316.110
- **Mean Stream Velocity:** 12.5 lps
- **Max Stream Velocity:** 15.7 lps

### CULVERT DESCRIPTION

<table>
<thead>
<tr>
<th>DESCRIPTION (ENTRY TYPE)</th>
<th>Q</th>
<th>SIZE</th>
<th>HEADWATER COMPUTATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>CMP (Con) Mitered</td>
<td>120</td>
<td>5'8&quot;</td>
<td>HW = 1.25, H = 5.6'</td>
</tr>
<tr>
<td>CMP Arch Mitered</td>
<td>120</td>
<td>6'0&quot;</td>
<td>HW = 0.97, H = 4.9'</td>
</tr>
<tr>
<td>Concrete Box 30° WW.</td>
<td>120</td>
<td>4'6&quot;</td>
<td>HW = 1.23, H = 4.9'</td>
</tr>
<tr>
<td>Concrete Oval Graded Top</td>
<td>120</td>
<td>6'0&quot;</td>
<td>HW = 1.51, H = 4.8'</td>
</tr>
<tr>
<td>Concrete Cyl Graded Top</td>
<td>120</td>
<td>5'4&quot;</td>
<td>HW = 1.11, H = 5.0'</td>
</tr>
</tbody>
</table>

**INLET CONT.**

<table>
<thead>
<tr>
<th>HW</th>
<th>HW</th>
<th>Ke</th>
<th>H</th>
<th>d_c</th>
<th>( d_c + D )</th>
<th>TW</th>
<th>n_o</th>
<th>LS_o</th>
<th>HW</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.25</td>
<td>1.25</td>
<td>5.6'</td>
<td>2.5</td>
<td>3.0</td>
<td>3.0</td>
<td>4.0</td>
<td>4.0</td>
<td>10.0</td>
<td>4.9</td>
</tr>
<tr>
<td>0.97</td>
<td>0.97</td>
<td>4.9'</td>
<td>2.5</td>
<td>3.0</td>
<td>3.0</td>
<td>4.0</td>
<td>4.0</td>
<td>10.0</td>
<td>4.6</td>
</tr>
<tr>
<td>1.23</td>
<td>1.23</td>
<td>4.9'</td>
<td>2.0</td>
<td>3.0</td>
<td>3.0</td>
<td>3.0</td>
<td>3.0</td>
<td>10.0</td>
<td>4.9</td>
</tr>
<tr>
<td>1.51</td>
<td>1.51</td>
<td>4.8'</td>
<td>2.9</td>
<td>3.0</td>
<td>3.0</td>
<td>3.0</td>
<td>3.0</td>
<td>10.0</td>
<td>4.8</td>
</tr>
<tr>
<td>1.11</td>
<td>1.11</td>
<td>5.0'</td>
<td>1.7</td>
<td>3.0</td>
<td>3.0</td>
<td>3.0</td>
<td>3.0</td>
<td>10.0</td>
<td>5.0</td>
</tr>
</tbody>
</table>

**COMMENTS**

- HW high, try 60"
- Need more cover
- Check box culvert

### SUMMARY & RECOMMENDATIONS:

In-place cost, availability, location, cover requirements, etc., should be considered by the designer in selecting culvert. CM pipe arch culverts or concrete oval pipes might be a solution where cover is limited.
References


CHART 5

HEADWATER DEPTH FOR
C. M. PIPE CULVERTS
WITH INLET CONTROL

EXAMPLE

\[ \frac{HW}{D} \] (feet)

(1) 1.8 5.4
(2) 2.1 6.3
(3) 2.2 6.6

\*in feet

To use scale (2) or (3), project horizontally to scale (1), then use straight rule line through D and D scales, or reverse as illustrated.

HEADWATER DEPTH IN DIAMETERS (HW/D)

ENTRANCE TYPE

(1) Headwell
(2) Mitered to conform to slope
(3) Projecting

D M L

12 18 24 30 36

STANDARD CM

DIAMETER OF CULVERT (D) IN INCHES

DISCHARGE (Q) IN C.F.S.

EXAMPLE

0 = 36 inches (3.0 feet)
0 = 66 c.f.s

LEN缤纷

Go Back to Part II

Go to Chart 6

BUREAU OF PUBLIC ROADS JAN. 1933
CHART 6

EXAMPLE

Size: 36" x 22" Q = 20 cfs

\[
\begin{align*}
\text{HW} & = \frac{Q}{D} \\
(1) & = 1.10 \\
(2) & = 1.15 \\
(3) & = 1.22
\end{align*}
\]

"O" in feet

HEADWATER DEPTH IN TERMS OF RISE (HW/D)

ENTRANCE TYPE

(1) Headwall

(2) Mitered to conform to slope

(3) Projecting

To use scale (2) or (3), project horizontally to scale (1), then use straight inclined line through B and O scales, or reverse as illustrated.

HEADWATER DEPTH FOR C. M. PIPE-ARCH CULVERTS WITH INLET CONTROL

ADDITIONAL SIZES NOT DIMENSIONED ARE LISTED IN FABRICATOR'S CATALOG

BUREAU OF PUBLIC ROADS JAN 1963
HEADWATER DEPTH FOR CIRCULAR PIPE CULVERTS WITH BEVELED RING INLET CONTROL

FEDERAL HIGHWAY ADMINISTRATION
MAY 1973
HEAD FOR
CONCRETE BOX CULVERTS
FLOWING FULL
n = 0.012
HEAD FOR
CONCRETE PIPE CULVERTS
FLOWING FULL
n = 0.012

For outlet crown not submerged, compute \( H_w \) by methods described in the design procedure.
CHART 10

HEAD FOR

OVAl CONCRETE PIPE CULVERTS
LONG AXIS HORIZONTAL OR VERTICAL
FLOWING FULL

n = 0.012

NOTE
Dimensions on the scale are ordered for long axis horizontal installation. They should be reversed for long axis vertical.
CHART II

SUBMERGED OUTLET CulVERT FLOWING FULL

For outlet crown not submerged, compute HW by methods described in the design procedure.

HEAD FOR
STANDARD
C. M. PIPE CulVERTS
FLOWING FULL
n = 0.024

BUREAU OF PUBLIC ROADS JAN. 1963
HEAD FOR STRUCTURAL PLATE CORR. METAL PIPE CULVERTS FLOWING FULL

n = 0.0328 TO 0.0302

BUREAU OF PUBLIC ROADS JAN. 1953
For outlet crown not submerged, compute HW by methods described in the design procedure.

HEAD FOR
STRUCTURAL PLATE
CORRUGATED METAL
PIPE ARCH CULVERTS
18 IN. CORNER RADIUS
FLOWING FULL
n = 0.0327 TO 0.0306
Go to Part III
CHART 1

EXAMPLE

D' x 2' Box 0.75 cfs
Q/B = 15 cfs/ft

Inlet HW

D' Width

feet

(1) 1.75 3.5
(2) 1.90 3.8
(3) 2.05 4.1

HEADWATER DEPTH IN TERMS OF HEIGHT (HW/D')

HEADWATER DEPTH FOR BOX CULVERTS WITH INLET CONTROL

ANGLE OF WINGWALL FLARE

SCALE

(1) 30° to 75°

(2) 90° and 15°

(3) 0° (extensions of sides)

To use scale (2) or (3) project horizontally to scale (1), then use straight inclined line through D' and 0 scales, or reverse as illustrated.
CHART 2

EXAMPLE
Q = 42 inches (3.5 feet)
Q = 120 cfs

<table>
<thead>
<tr>
<th>HW</th>
<th>HW^2</th>
<th>HW feet</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1)</td>
<td>2.5</td>
<td>8.6</td>
</tr>
<tr>
<td>(2)</td>
<td>2.1</td>
<td>4.4</td>
</tr>
<tr>
<td>(3)</td>
<td>2.2</td>
<td>7.7</td>
</tr>
</tbody>
</table>

Diameters of Culvert (D) in inches

Discharge (Q) in cfs

Headwater Depth in diameters (HW/D)

HEADWATER DEPTH FOR CONCRETE PIPE CULVERTS WITH INLET CONTROL

To use scale (2) or (3) project horizontally to scale (1), then use straight inclined line through D and Q scales, or reverse as illustrated.

HEADWATER SCALES 2 & 3
BUREAU OF PUBLIC ROADS JAN. 1963
REVISED MAY 1964

5-22
**Example**

Size 76" x 48"

Q = 500 cfs

<table>
<thead>
<tr>
<th>HW'</th>
<th>HW</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>11.2</td>
</tr>
<tr>
<td>2</td>
<td>8.9</td>
</tr>
<tr>
<td>3</td>
<td>9.2</td>
</tr>
</tbody>
</table>

*0 in feet

**To use scale (2) or (3):**

Draw a straight line through known values of size and discharge to intersect scale (1). From point on scale (1), project horizontally to solution on either scale (2) or (3).

**Headwater depth in terms of rise (HW/D):**

**Entrance type:**

- (1) Square edge with headwall
- (2) Groove edge with headwall
- (3) Groove edge projecting

**Headwater depth for oval concrete pipe culverts long axis horizontal with inlet control**

**Chart 3**

**Revised by:**

Bureau of Public Roads Jan 1965
CHART 4

EXAMPLE
Size: 36" x 60" 9 x 200 cfs

HW
D

(1) 2.6 13.0
(2) 2.0 10.0
(3) 2.1 10.5

* D in feet

To use scale (2) or (3)
Draw a straight line
through known values
of size and discharge
to intersect scale (1)
From point on scale (1)
project horizontally to
solution on either scale
(2) or (5)

HEADWATER DEPTH IN TERMS OF RISE (HW/D)

SCALE

ENTRANCE TYPE

(1) Square edge with
headwall
(2) Groove end with
headwall
(3) Groove end
projecting

HEADWATER DEPTH FOR
OVAL CONCRETE PIPE CULVERTS
LONG AXIS VERTICAL
WITH INLET CONTROL

BUREAU OF PUBLIC ROADS JAN 1963
List of Tables for HEC 5-Hydraulic Charts for the Selection of Highway Culverts

Back to Table of Contents

Table 1. Entrance Loss Coefficients

Table 2. Manning’s n for Natural Stream Channels (Surface width at flood stage less than 100 ft.)

Back to Table of Contents
List of Charts & Forms for HEC 5-Hydraulic Charts for the Selection of Highway Culverts

Back to Table of Contents

Chart 1. Headwater Depth for Box Culverts with Inlet Control
Chart 2. Headwater Depth for Concrete Pipe Culverts with Inlet Control
Chart 3. Headwater Depth for Oval Concrete Pipe Culverts Long Axis Horizontal with Inlet Control
Chart 4. Headwater Depth for Oval Concrete Pipe Culverts Long Axis Vertical with Inlet Control
Chart 5. Headwater Depth for C.M. Pipe Culverts with Inlet Control
Chart 6. Headwater Depth for C.M. Pipe-Arch Culverts with Inlet Control
Chart 7. Headwater Depth for Circular Pipe Culverts with Beveled Ring Inlet Control.
Chart 8. Head for Concrete Box Culverts Flowing Full, n=0.012
Chart 9. Head for Concrete Pipe Culverts Flowing Full, n=0.012
Chart 10. Head for Oval Concrete Pipe Culverts, Long Axis Horizontal or Vertical Flowing Full, n=0.012
Chart 11. Head for Standard C.M. Pipe Culverts Flowing Full, n=0.024
Chart 12. Head for Standard C.M. Pipe-Arch Culverts Flowing Full, n=0.024
Chart 13. Head for Structural Plate, Corrugated Metal Pipe Culverts Flowing Full, n=0.0328 to 0.0302
Chart 14. Head for Structural Plate, Corrugated Metal Pipe Arch Culverts, 18 in. Corner Radius, Flowing Full, n=0.0327 to 0.0306
Chart 15. Critical Depth, Rectangular Section
Chart 16. Critical Depth, Circular Pipe
Chart 17. Critical Depth, Oval Concrete Pipe, Long Axis Horizontal
Chart 18. Critical Depth, Oval Concrete Pipe, Long Axis Vertical
Chart 19. Critical Depth, Standard C.M. Pipe-Arch
Chart 20. Critical Depth, Structural Plate, C.M. Pipe-Arch

Back to Table of Contents
List of Equations for HEC 5-Hydraulic Charts for the Selection of Highway Culverts

Equation 1
Equation 2
Equation 3

Back to Table of Contents