Appendix IV

Application of the HEC-2 Culvert Option

Appendix IV
Table of Contents

Chapter

Page

Table of Contents (continued)

Chapter

Page

Exhibits

List of Figures

Figure Number

Page

List of Tables

Table Number

Page

Chapter 1

Introduction

The HEC-2 program offers three methods for computing head losses through bridge or culvert structures: the **Normal Bridge Method**, the **Special Bridge Method**, and the **Special Culvert Method**. The normal bridge method is based on Manning's equation and uses the standard step method to determine bridge losses. The special bridge method, on the other hand, utilizes a series of hydraulic equations to analyze flow through bridges for a number of different flow conditions. Both of these methods are described in Appendix **III**.

The special culvert method is similar to the special bridge method, except that the Federal Highway Administration's (FHWA) standard equations for culvert hydraulics are used to compute losses through the structure. This appendix describes the application of the special culvert method.

Figure 1.1 illustrates a typical box culvert road crossing. As shown, the culvert is similar to a bridge in many ways. The walls and roof of the culvert correspond to the abutments and low chord of the bridge, respectively.

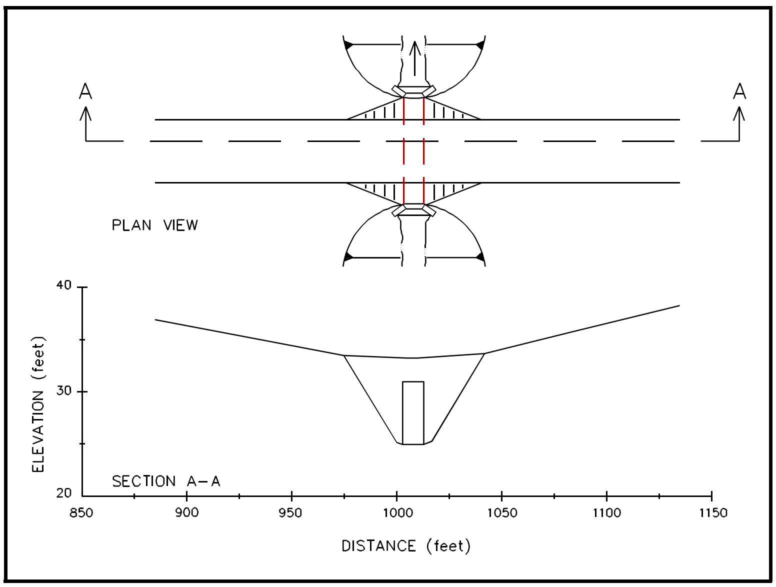

Figure 1.1
Typical Culvert Road Crossing

Because of the similarities between culverts and other types of bridges, the normal bridge and special bridge methods available in the HEC-2 computer program can often be applied to the analysis of culverts. The layout of cross sections, the use of the effective area option, the selection of loss coefficients, and most other aspects of bridge analysis apply to culverts as well.

1.1 Advantages of the Special Culvert Option

The special culvert method offers the following advantages for modeling flow through culverts, when compared with the normal bridge or special bridge methods:

- **Reduced Data Requirements:** For the special bridge or normal bridge methods, the culvert shape must be defined using the ground elevation coordinates (GR records) and the low chord coordinates (BT records). This can be tedious, especially for circular culverts. For the special culvert method, the culvert shape is defined using the pipe diameter for circular culverts, or the height and width of the opening for box culverts.

- **Familiar Hydraulic Coefficients:** The hydraulic capacity of the culvert is described using familiar terminology and coefficients, such as the Manning's roughness coefficient and the entrance loss coefficient.

- **Similarity to FHWA Nomographs:** The HEC-2 special culvert method is based on the same equations as the familiar FHWA culvert nomographs. Therefore, the results of the special culvert option can be easily confirmed using the nomographs.

- **Flexibility in Hydraulic Modeling:** The HEC-2 special culvert method provides a good solution for head loss through a roadway crossing under a wide variety of flow conditions, including low flow conditions.

1.2 Limitations of the Special Culvert Option

The HEC-2 special culvert option is subject to the following limitations:

- **Constant Cross Section:** The culvert cross section, flow rate, and bottom slope are assumed to be constant throughout the length of the culvert.

- **Positive or Horizontal Culvert Slope:** The culvert bottom slope is required to be positive or zero. That is, the invert or flow-line of the culvert cannot be lower in elevation on the upstream side of the culvert than on the downstream side.

- **No Mixed Sizes or Shapes:** Each culvert road crossing is assumed to be composed of only one culvert or a number of identical culverts.

- **No Super-Critical Profiles:** The special culvert option may be used in subcritical profile computations only.

1.3 Converting Special Bridge Models to Special Culvert Models

The special culvert option has been designed to operate like the special bridge option whenever possible. This similarity makes it easy to convert existing special bridge models to special culvert models. The following steps are required:

1) Change the value of the variable IBRID in Field 3 of the X2 record from 1 to 2 to indicate that the special culvert option will be used in place of the special bridge method.

2) Delete the value of the variable CMOM in Field 8 of the X2 record. This variable is used only for the special bridge option and is not required for the special culvert option. Although the program will ignore any value entered for this variable, it is good practice to leave Field 8 blank when using the special culvert option, in order to avoid confusion.

3) Replace the SB record with an SC record. Copy the values of variables COFQ (Field 3), RDLEN (Field 4), ELCHU (Field 9), and ELCHD (Field 10) from the SB record to the SC record. These variables are used by the special culvert method as well as the special bridge method. Make sure that ELCHU is equal to or higher than ELCHD.

4) Enter the appropriate values for the number of identical culverts (CUNO) and the culvert n-value (CUNV) in Field 1 of the SC record. Also enter the culvert entrance loss coefficient (ENTLC) in Field 2, the height of the culvert opening (RISE) in Field 5, the length of the culvert (CULVLN) in Field 7, and the Federal Highway Administration chart number (CHRT) and scale number (SCL) in Field 8 of the SC record. For box culverts, the width of the culvert opening (SPAN) should also be entered in Field 6 of the SC record. Chapter 3 of this appendix describes all of these input values.

5) Check the remaining input data to be sure that the modeling guidelines described in Chapter 3 of this appendix have been followed. Important items to check include the cross section layout and spacing, the definition of the top of road for weir flow, and the specification of effective flow areas.

The converted culvert model should now be ready for analysis using the special culvert method.

1.4 Using this Appendix

This appendix is intended to get you started in using the HEC-2 special culvert option quickly and easily, and also to provide a reference should questions or problems arise in the future. Chapter 2 of this appendix provides background information on culvert hydraulics and the terminology associated with culverts. Chapter 3 provides a complete discussion of the HEC-2 special culvert option, including the layout of all required cross sections, the sources of all required data for the culvert, and the appropriate values for all hydraulic coefficients. Chapter 4 presents three complete examples of the HEC-2 special culvert option, including complete listing of input data, results, and a discussion.

All equations and other material in this appendix are presented using standard English or American units of measurement. However, the special culvert option has been designed and implemented to work equally well with corresponding metric (S.I.) units.

Chapter 2

Culvert Hydraulics

This chapter introduces the basic concepts of culvert hydraulics which are used in the HEC-2 special culvert option.

2.1 Introduction to Culvert Terminology

A **culvert** is a relatively short length of closed conduit which connects two open channel segments or bodies of water. Two types of culverts are most commonly used: **pipe culverts**, which are circular in cross section, and **box culverts**, which are rectangular in cross section. Figures 2.1 and 2.2 illustrate pipe culverts and box culverts, respectively.

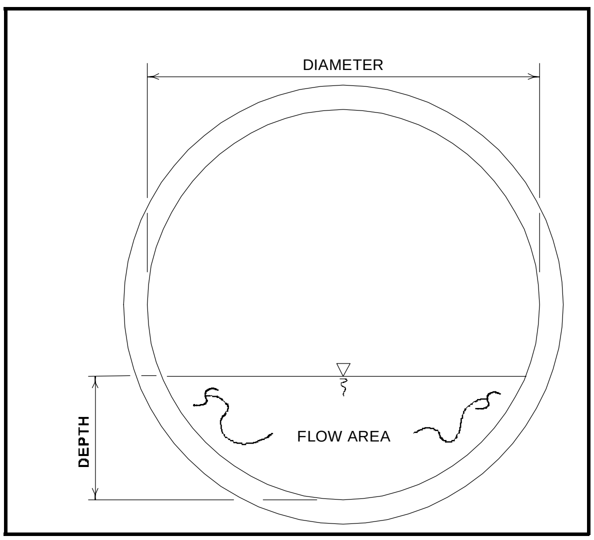

Figure 2.1
Cross-Section of a Pipe Culvert

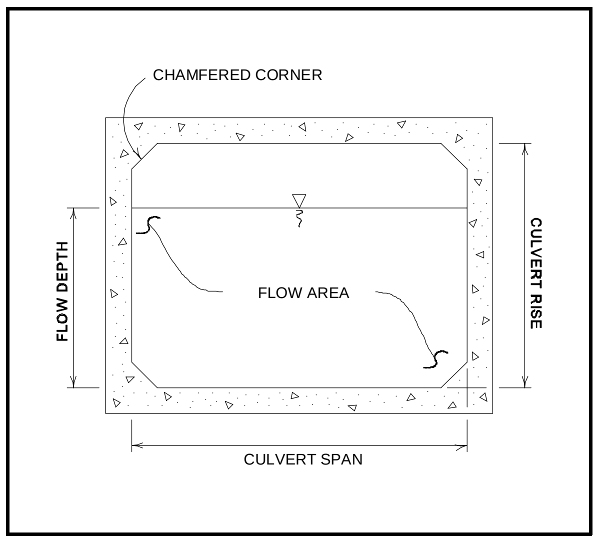

Figure 2.2
Cross-Section of a Box Culvert

Culverts are made up of an **entrance** where water flows into the culvert, and a **barrel**, which is the closed conduit portion of the culvert. The total flow capacity of a culvert depends upon the characteristics of the entrance as well as the culvert barrel.

The **tailwater** at a culvert is the depth of water on the discharge or downstream side of the culvert, as measured from the downstream flow-line of the culvert. The **flow-line** is the lowest point on the inside of the culvert at a particular cross section. It is sometimes called the **invert**. The tailwater depth depends on the flow rate and hydraulic conditions downstream of the culvert.

The **headwater** at a culvert is the depth of water on the entrance or upstream side of the culvert, as measured from the upstream flow-line of the culvert. The headwater is related to the tailwater as follows:

	Tailwater
+	Energy Loss Through Culvert
-	Drop in Flow-Line Elevation Through Culvert
=	Headwater

2.2 Flow Analysis for Culverts

The analysis of flow in culverts is quite complicated. It is common to use the concepts of "inlet control" and "outlet control" to simplify the analysis. **Inlet control** flow occurs when the flow capacity of the culvert entrance is less than the flow capacity of the culvert barrel. **Outlet control** flow occurs when the culvert capacity is limited by downstream conditions or by the flow capacity of the culvert barrel. The HEC-2 special culvert method computes the headwater required to produce a given flow rate through the culvert for inlet control conditions and for outlet control conditions. The higher headwater "controls" the design and determines the type of flow in the culvert for a given flow rate and tailwater condition.

For inlet control, the required headwater is computed by assuming that the culvert inlet acts as an orifice or as a weir. Therefore, the inlet control capacity depends primarily on the geometry of the culvert entrance.

For outlet control, the required headwater is computed by taking the depth of flow at the culvert outlet, adding all head losses, and subtracting the change in flow-line elevation of the culvert from the upstream to downstream end. The HEC-2 special culvert option considers the entrance losses, the friction loss in the culvert barrel, and the loss of velocity head at the outlet in computing the outlet control headwater of the culvert.

2.3 Computing Inlet Control Headwater

For inlet control conditions, the capacity of the culvert is limited by the capacity of the culvert opening, rather than by conditions farther downstream. Extensive laboratory tests by the National Bureau of Standards, the Bureau of Public Roads, and other entities resulted in a series of equations which describe the inlet control headwater under various conditions. These equations form the basis of the FHWA inlet control nomographs shown in the exhibit [FHWA, 1972].

The FHWA inlet control equations are used by the HEC-2 special culvert option in computing the inlet control headwater. The equations are adapted slightly to allow the use of metric units.

The nomographs in the exhibit of this appendix are considered to be accurate to within about 10 percent in determining the required inlet control headwater ([FHWA, 1972]. The nomographs were computed assuming a culvert slope of 0.02 feet per foot (2 percent). For different culvert slopes, the nomographs are less accurate because inlet control headwater changes with slope. However, the special culvert option of HEC-2 considers the slope in computing the inlet control headwater. Therefore, the special culvert option should be more accurate than the nomographs, especially for slopes other than 0.02 feet per foot.

2.4 Computing Outlet Control Headwater

For outlet control flow, the required headwater must be computed considering several conditions within the culvert and downstream of the culvert. Figure 2.3 illustrates the logic of the outlet control computations:

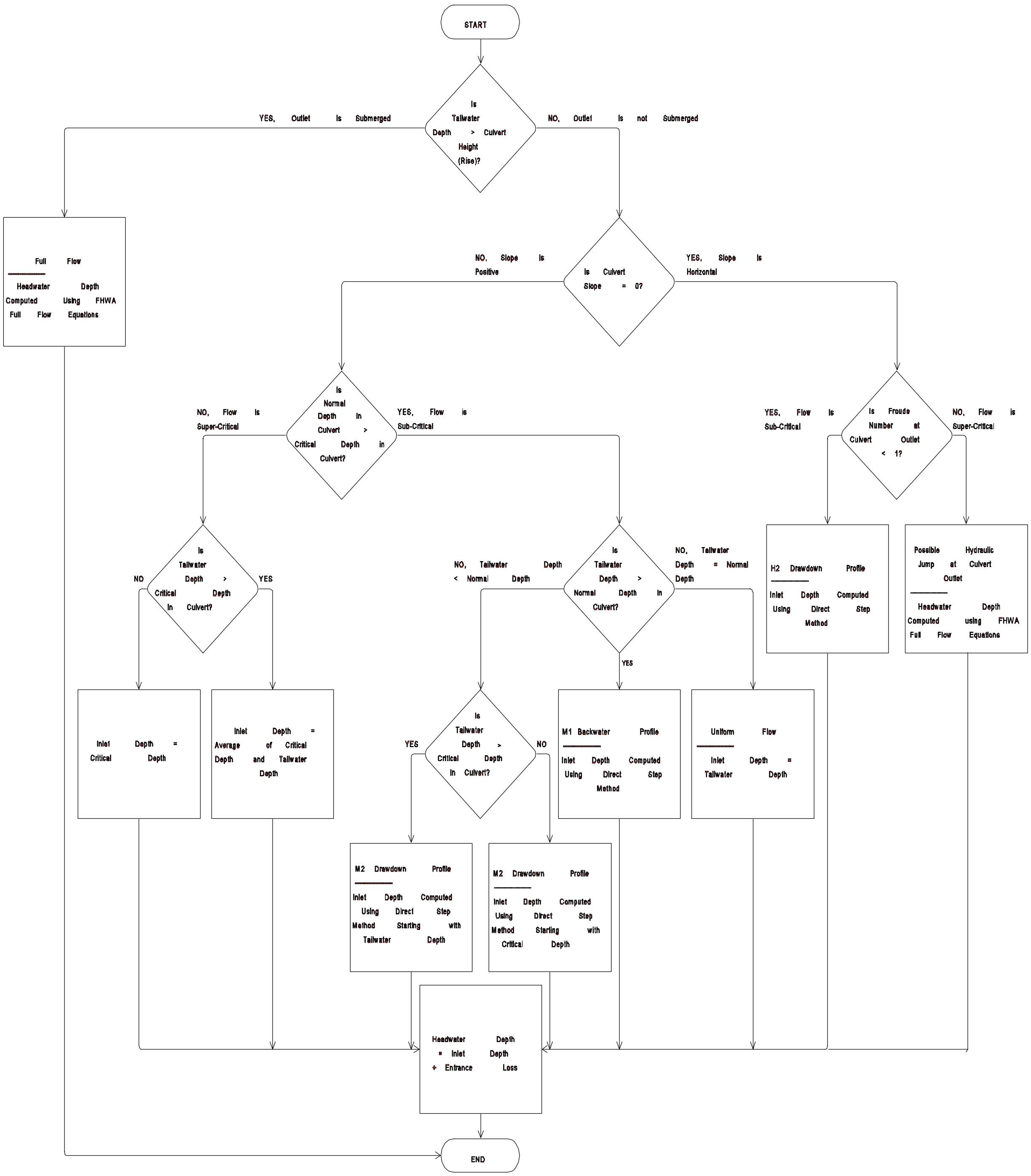

Figure 2.3
Flow Chart for Outlet Control Computations

2.4.1 FHWA Full Flow Equations

For culverts flowing full, the total **head loss**, or energy loss, through the culvert is measured in feet. The head loss, L_H, is computed using the following formula:

$$L_H = L_E + L_F + L_X \qquad \text{(IV-1)}$$

in which:

L_F = friction loss (feet)

L_E = entrance loss (feet)

L_X = exit loss (feet)

The friction loss in the culvert is computed using Manning's formula, which is expressed as follows:

$$L_F = L\left(\frac{Qn}{1.486AR^{2/3}}\right)^2 \qquad \text{(IV-2)}$$

in which:

L_F = friction Loss (feet)

L = culvert length (feet)

Q = flow rate in the culvert (cfs)

n = Manning's roughness coefficient

A = area of flow (square feet)

R = hydraulic radius (feet) = $\dfrac{\text{flow area}}{\text{wetted perimeter}}$

The entrance loss is computed as described in Section 3.2.3 of this appendix. The exit loss is assumed to equal the velocity head in the culvert.

2.4.2 Direct Step Water Surface Profile Computations

For culverts flowing partially full, the water surface profile in the culvert is computed using the direct step method. This method is very efficient, because no iterations are required to determine the flow depth for each step. The water surface profile is computed for small increments of depth (usually between 0.01 and 0.05 feet). If the flow depth equals the height of the culvert before the profile reaches the upstream end of the culvert, the friction loss through the remainder of the culvert is computed assuming full flow.

The direct step method computes the flow depth in the culvert at the inlet. The entrance loss, computed as described in Section 3.2.3 of this appendix, is added to the computed flow depth in the culvert to compute the outlet control headwater.

2.4.3 Normal Depth of Flow in the Culvert

Normal depth is the depth at which uniform flow will occur in an open channel. In other words, for a uniform channel of infinite length, carrying a constant flow rate, flow in the channel would be at a constant depth at all points along the channel, and this would be the normal depth.

Normal depth often represents a good approximation of the actual depth of flow within a channel segment. For inlet control conditions, the depth of flow within the culvert is assumed to be equal to normal depth. This assumption is only valid if the culvert barrel is sufficiently long to allow the flow depth to stabilize at normal depth.

For both box culverts and pipe culverts, the program computes normal depth using an iterative approach to arrive at a value which satisfies Manning's equation:

$$Q = \frac{1.486}{n} A R^{(2/3)} \sqrt{S} \qquad \text{(IV-3)}$$

in which:

Q = flow rate in the channel (cfs)

n = Manning's roughness coefficient

A = area of flow (square feet)

R = hydraulic radius (feet) = $\frac{\text{flow area}}{\text{wetted perimeter}}$

S = slope of energy grade line (feet per foot)

2.4.4 Critical Depth of Flow in the Culvert

Critical depth occurs when the flow in a channel has minimum specific energy. **Specific energy** refers to the sum of the depth of flow and the velocity head. At critical depth, the velocity head is equal to one-half the average depth of flow. Critical depth depends only on the channel shape and flow rate.

The depth of flow at the culvert outlet is assumed to be equal to critical depth for culverts operating under outlet control with low tailwater. Critical depth may also influence the inlet control headwater for unsubmerged conditions.

The special culvert option computes the critical depth in a pipe culvert by an iterative procedure, which arrives at a value satisfying the following equation:

$$\frac{Q^2}{g} = \frac{A^3}{T} \qquad \text{(IV-4)}$$

in which:

Q = flow rate in the channel (cfs)

g = acceleration due to gravity (32.2 ft/sec^2)

A= cross-sectional area of flow (square feet)

T= top width of flow (feet)

Critical depth for box culverts is computed by the following equation [AISI, 1980]:

$$y_c = \sqrt[3]{\frac{q^2}{g}} \qquad \text{(IV-5)}$$

in which:

y_c = critical depth (ft)

q = unit discharge per linear foot of width (cfs/ft)

g = acceleration due to gravity (32.2 ft/sec^2)

2.4.5 Super-Critical Culvert Flow

The special culvert option allows super-critical flow in the culvert as a temporary condition in an otherwise sub-critical stream profile. The simple assumptions shown in Figure 2.3 are used to compute the headwater depth for super-critical culvert flow.

2.4.6 Horizontal Culvert Slope

The special culvert option also allows horizontal culvert slopes. The primary difference is that normal depth is not computed for a horizontal culvert. Outlet control is either computed by direct step for partial full tailwater or the full flow equation.

Chapter 3

Using the Special Culvert Method

HEC-2 computes the energy losses caused by culverts in two parts:

1) the losses due to expansion and contraction of flow on the downstream and upstream sides of the structure

2) the energy loss through the roadway structure itself.

The special culvert method has the capability to compute energy losses at a roadway culvert crossing for a number of different flow conditions, including inlet control flow, outlet control flow, weir flow over the roadway, or any possible combination of these flow conditions. The special culvert method uses hydraulic formulas to determine what flow conditions exist, what portion of the total flow rate falls into each condition, and what change in energy head and water surface elevation will occur through the culvert structure for a given total flow rate.

This chapter describes the use of the HEC-2 special culvert method for computing both types of energy losses. The layout of channel cross sections around the culvert is described, as is the information required to describe the culvert and roadway structures.

3.1 Cross Sections for Culvert Modeling

The number of HEC-2 cross sections required to analyze a given bridge, culvert, or related structure varies according to the modeling method selected.

The special culvert method requires the same cross sections as the special bridge method. Four cross sections are required for a complete bridge model. This total includes one cross section sufficiently downstream of the culvert that flow is not affected by the culvert, one at the downstream end of the culvert, one at the upstream end of the culvert, and one cross section located far enough upstream that the culvert again has no effect on flow. Figure 3.1 illustrates the cross sections required for a special culvert model.

3.1.1 Cross Section 1 of Special Culvert Model

Cross section 1 for a special culvert model should be located at a point where flow has expanded from its constricted top width within the culvert to its unrestrained top width downstream of the culvert. The cross section spacing downstream of the culvert should be based on a 4 to 1 expansion of flow. In other words, the maximum rate at which flow can expand after being constricted in the culvert is assumed to be one foot laterally for every four feet traveled in the downstream direction. (See Appendix III, "Application of HEC-2 Bridge Routines" for a more complete discussion of cross section locations.) The entire area of cross section 1 is usually considered to be effective in conveying flow.

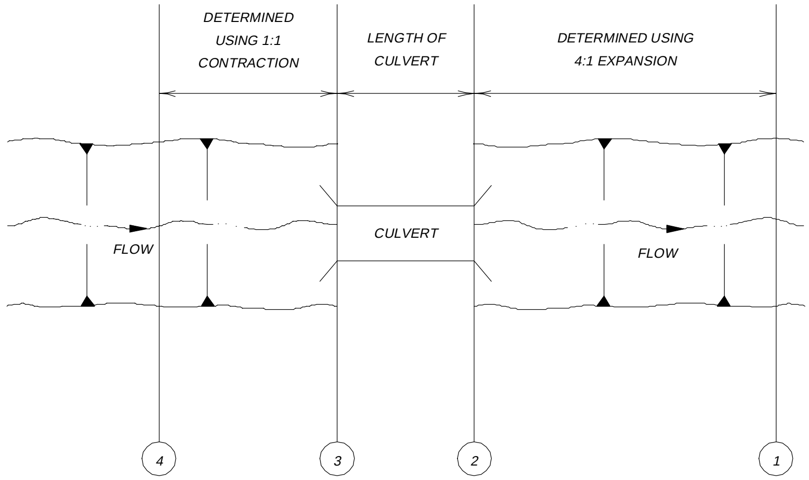

Figure 3.1
Cross Section Layout for Special Culvert Method

3.1.2 Cross Section 2 of Special Culvert Model

Cross section 2 of a special culvert model is located at the downstream end of the culvert. It does not include any of the culvert structure or embankments, but represents the physical shape of the channel just downstream of the culvert. The shape of the culvert itself is entered on an SC record between cross sections 2 and 3 of the special culvert model. No BT (bridge table) records are included for cross section 2.

The HEC-2 effective area option is used to restrict the effective flow area of cross section 2 to the flow area allowed by the edges of the culverts, until flow overtops the roadway. An NC record is placed just before cross section 2 to change the expansion and contraction coefficients, as described in Section 3.1.5. Figure 3.2 illustrates cross section 2 of a typical special culvert model of a circular culvert. As indicated, the GR records are not required to define the culvert shape for the special culvert model. On Figure 3.3, the channel bank locations are indicated by small circles and the stations and elevations are indicated by triangles.

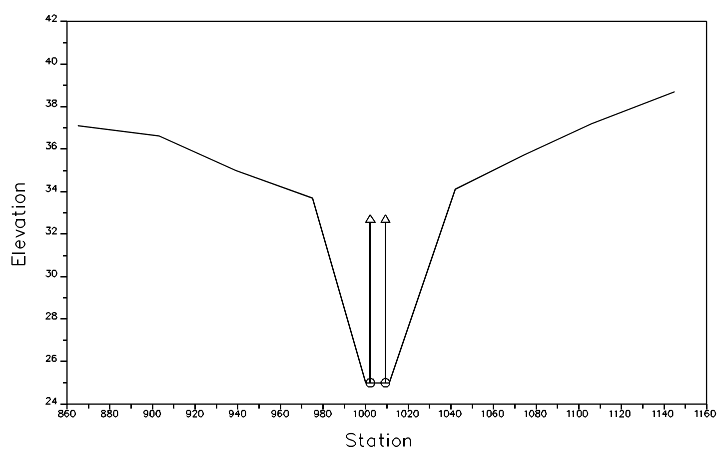

Figure 3.2
Cross Section 2 of Special Culvert Model

Cross sections 1 and 2 are located so as to create a channel reach downstream of the culvert in which the HEC-2 program can accurately compute the friction losses and expansion losses downstream of the culvert.

3.1.3 Cross Section 3 of Special Culvert Model

Cross section 3 of a special culvert model is located at the upstream end of the culvert, and represents the physical configuration of the channel immediately upstream of the culvert.

The special culvert method uses a combination of BT records, an SC record, and an X2 record to describe the culvert or culverts and the roadway embankment. The SC record describing the culvert crossing is located between the data for cross section 2 and cross section 3. The data for cross section 3 includes an X2 record which instructs the HEC-2 program to perform culvert loss computations. In addition, cross section 3 includes BT records describing the top of roadway profile for weir flow computations. The BT records used for the special culvert method are not required to include low chord elevations, since the special culvert method does not use these elevations.

The HEC-2 effective area option is used to restrict the effective flow area of cross section 3 to the flow area allowed by the edges of the culverts, until flow overtops the roadway. Figure 3.3 illustrates cross section 3 of a typical special culvert model of a circular culvert, including the roadway profile defined on BT records, and the culvert shape defined on the SC record. As indicated, the GR records are not required to define the culvert shape for the special culvert model. On Figure 3.3, the channel bank locations are indicated by small circles and the stations and elevations of effective area control are indicated by triangles.

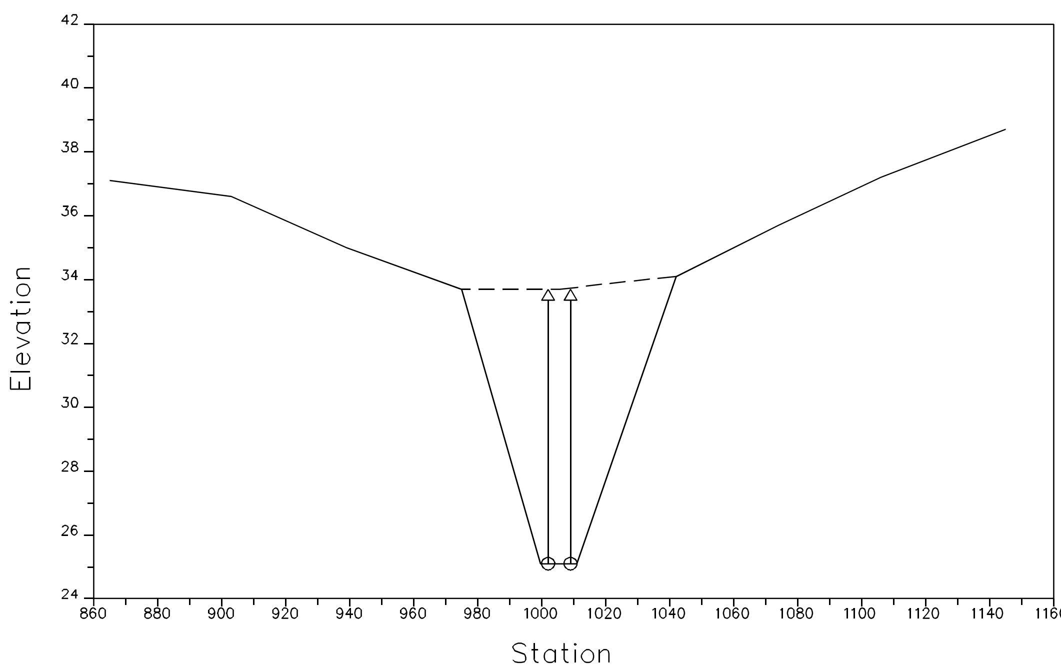

Figure 3.3
Cross Section 3 of Special Culvert Model

3.1.4 Cross Section 4 of Special Culvert Model

The final cross section in the special culvert model is located at a point where flow has not yet begun to contract from its unrestrained top width upstream of the culvert to its constricted top width in the culvert. This distance is determined assuming a one to one contraction of flow. In other words, the maximum rate at which flow can contract to pass through the culvert opening is assumed to be one foot laterally for every one foot traveled in the downstream direction.

The entire area of cross section 4 is usually considered to be effective in conveying flow. An NC record is placed just after cross section 4 to change the expansion and contraction coefficients, as described in Section 3.1.5.

3.1.5 Expansion and Contraction Coefficients

User-defined coefficients are required to compute head losses due to the contraction and expansion of flows upstream and downstream of a culvert. These losses are computed by multiplying an expansion or contraction coefficient by the absolute difference in velocity head between two cross sections. Normally, the greatest expansion loss occurs between the first two cross sections of a bridge model, as flow expands from the width of the culvert opening to the full width of the channel or floodplain. Similarly, the greatest contraction loss occurs between the last two cross sections of the bridge model, as flow contracts from the full width of the channel or floodplain to the width of the culvert opening.

If the velocity head increases in the downstream direction, a contraction coefficient is applied. When the velocity head decreases in the downstream direction, an expansion coefficient is used. Some recommended values of the expansion and contraction coefficients are indicated in Table 3.1. As indicated by the tabulated values, the expansion of flow causes more energy loss than does contraction, and head losses increase with the abruptness of the transition.

Table 3.1
Expansion and Contraction Coefficients

Description of Transition	Contraction Coefficient	Expansion Coefficient
No Transition Loss Computed	0.0	0.0
Gradual Transitions	0.1	0.3
Bridge Cross Sections	0.3	0.5
Abrupt Transitions (including most culverts)	0.6	0.8

When redefining expansion and contraction coefficients for a culvert, the coefficients should be changed to the desired values for the culvert just after the first cross section in the culvert model and changed back to the previous values just after the final cross section.

3.2 Defining the Culvert with the SC Record

The special culvert (SC) record is required to input coefficients for inlet control, outlet control, and weir flow for analysis by the special culvert method. Geometric properties of the culvert such as diameter (in the case of pipe culverts) and span and rise (in the case of box culverts) are also input on the SC record. The SC record is only required when using the special culvert method. Appendix VIII summarizes the information provided on the SC record. The following sections of this appendix provide a more complete description of each item.

3.2.1 CUNO: Number of Identical Culverts

The number of identical culverts is the value left of the decimal point in Field 1 of the SC record. For example, a value of 3.012 in Field 1 of the SC record indicates that three identical culverts are present at the current cross section. (Note: the 0.012 value right of the decimal point indicates that the culvert n-value is 0.012, as described in Section 3.2.2.)

If multiple culverts are specified, HEC-2 automatically divides the flow rate equally among the culverts and analyzes each culvert separately. All of the culverts must be identical; they must have the same cross-sectional shape, upstream and downstream invert elevations, roughness coefficients, and inlet shapes.

3.2.2 CUNV: Manning's Roughness Coefficient

The Manning's roughness coefficient is the value right of the decimal point in Field 1 of the SC record. For example, a value of 3.012 in Field 1 of the SC record indicates that the culvert has a roughness coefficient of 0.012. (Note: the 3 value left of the decimal point indicates that there are three identical culverts at this location, as described in Section 3.2.1.)

HEC-2 uses Manning's equation to compute friction losses in the culvert barrel, as described in Section 2.4 of this appendix. The roughness of the culvert is represented by Manning's roughness coefficient, commonly called the **n-value**. Suggested values for Manning's n-value are listed in Table 3.2 and Table 3.3, and in many hydraulics reference books. Roughness coefficients should be adjusted according to individual judgment of the culvert condition.

3.2.3 ENTLC: Entrance Loss Coefficient

The entrance loss coefficient is input in Field 2 of the SC record.

Entrance losses are computed as a fraction of the **velocity head** or kinetic energy of flow in the culvert. The velocity head in the culvert is computed as:

$$H_V = \frac{V^2}{2g} \qquad \text{(IV-6)}$$

in which:

H_V = velocity head in the culvert (feet)

V = flow velocity in the culvert (ft/sec)

g = acceleration due to gravity (32.2 ft/sec^2)

Table 3.2
Manning's 'n' for Corrugated Metal Pipe

Type of Pipe and Diameter	Unpaved	25% Paved	Fully Paved
Annular 2.67 x 1/2 in. (all diameters)	**0.024**	**0.021**	**0.021**
Helical 1.50 x 1/4 in.:			
8 inch diameter	0.012		
10 inch diameter	0.014		
Helical 2.67 x 1/2 inc.:			
12 inch diameter	0.011		
18 inch diameter	0.014		
24 inch diameter	0.016	0.015	0.012
36 inch diameter	0.019	0.017	0.012
48 inch diameter	0.020	0.020	0.012
60 inch diameter	0.021	0.019	0.012
Annular 3 x 1 in. (all diameters)	0.027	0.023	0.012
Helical 3 x 1 in.:			
48 inch diameter	0.023	0.020	0.012
54 inch diameter	0.023	0.020	0.012
60 inch diameter	0.024	0.021	0.012
66 inch diameter	0.025	0.022	0.012
72 inch diameter	0.026	0.022	0.012
78 inch & larger	0.027	0.023	0.012
Corrugations 6 x 2 in.:			
60 inch diameter	0.033	0.028	
72 inch diameter	0.032	0.027	
120 inch diameter	0.030	0.026	
180 inch diameter	0.028	0.024	

[AISI, 1980]

The velocity head is multiplied by the **entrance loss coefficient** to estimate the amount of energy lost as flow enters the culvert. A higher value for the coefficient gives a higher head loss. As shown in Table 3.4, entrance losses can vary from about 0.2 to about 0.5 times the velocity head for box culverts. Table 3.5 indicates that values of the entrance loss coefficient range from 0.2 to about 0.8 for pipe culverts. For a sharp-edged culvert entrance with no rounding, 0.5 is recommended. For a well-rounded entrance, 0.2 is appropriate. An example of a fairly well-rounded entrance is the socket end of a concrete pipe section.

Table 3.3
Manning's 'n' for Closed Conduits Flowing Partly Full

Type of Channel and Description	Minimum	Normal	Maximum
Brass, smooth:	**0.009**	**0.010**	**0.013**
Steel:			
Lockbar and welded	0.010	0.012	0.014
Riveted and spiral	0.013	0.016	0.017
Cast Iron:			
Coated	0.010	0.013	0.014
Uncoated	0.011	0.014	0.016
Wrought Iron:			
Black	0.012	0.014	0.015
Galvanized	0.013	0.016	0.017
Corrugated Metal:			
Subdrain	0.017	0.019	0.021
Storm Drain	0.021	0.024	0.030
Lucite:	**0.008**	**0.009**	**0.010**
Glass:	**0.009**	**0.010**	**0.013**
Cement:			
Neat, surface	0.010	0.011	0.013
Mortar	0.011	0.013	0.015
Concrete:			
Culvert, straight and free of debris	0.010	0.011	0.013
Culvert with bends, connections, and some debris	0.011	0.013	0.014
Finished	0.011	0.012	0.014
Sewer with manholes, inlet, etc., straight	0.013	0.015	0.017
Unfinished, steel form	0.012	0.013	0.014
Unfinished, smooth wood form	0.012	0.014	0.016
Unfinished, rough wood form	0.015	0.017	0.020
Wood:			
Stave	0.010	0.012	0.014
Laminated, treated	0.015	0.017	0.020
Clay:			
Common drainage tile	0.011	0.013	0.017
Vitrified sewer	0.011	0.014	0.017
Vitrified sewer with manholes, inlet, etc.	0.013	0.015	0.017
Vitrified subdrain with open joint	0.014	0.016	0.018
Brickwork:			
Glazed	0.011	0.013	0.015
Lined with cement mortar	0.012	0.015	0.017
Sanitary sewers coated with sewage slime with bends and connections	0.012	0.013	0.016
Paved invert, sewer, smooth bottom	0.016	0.019	0.020
Rubble masonry, cemented	0.018	0.025	0.030

[Chow, 1959]

Table 3.4
Entrance Loss Coefficient for Box Culverts

Type of Structure and Design of Entrance	Coefficient
Headwall Parallel to Embankment (no wingwalls):	
Square-edged on three edges	0.50
Three edges rounded to radius of 1/12 barrel dimension	0.20
Wingwalls at 15 to 45 degrees to Barrel:	
Square-edge top corner	0.40
Top corner rounded to radius of 1/12 barrel dimension	0.20

Source: "Street and Highway Drainage," Institute of Transportation and Traffic Engineering, University of California at Berkeley, 1969.

Table 3.5
Entrance Loss Coefficient for Pipe Culverts

Type of Structure and Design of Entrance	Coefficient
Concrete Pipe Projecting from Fill (no headwall):	
Socket end of pipe	0.20
Square cut end of pipe	0.50
Concrete Pipe with Headwall or Headwall and Wingwalls:	
Socket end of pipe	0.10
Square cut end of pipe	0.50
Rounded entrance, with rounding radius = 1/12 of diameter	0.10
Corrugated Metal Pipe:	
Projecting from fill (no headwall)	0.80
With headwall or headwall and wingwalls, square edge	0.50

3.2.4 COFQ: Weir Flow Coefficient

Weir flow over a roadway is computed in the special culvert method using exactly the same methods used in the HEC-2 special bridge method. The standard weir equation is used:

$$Q = CLH^{1.5} \tag{IV-7}$$

in which:

Q = flow rate (cfs)

C = COFQ = weir flow coefficient

L = weir length (feet)

H = weir head (feet)

For flow over a typical bridge deck, a weir coefficient of 2.6 is recommended. A weir coefficient of 3.0 is recommended for flow over elevated roadway approach embankments. The weir flow coefficient will generally be near 3.0 for special culvert models because the roadway embankment for a culvert is often similar to a roadway approach embankment. More detailed information on weir discharge coefficients may be found in Tables 3.6 and 3.7.

Table 3.6
Broad-Crested Weir Coefficients

Breadth of Crest of Weir in Feet	Measured Head in Feet (H)				
	1.0	2.0	3.0	4.0	5.0
5	2.68	2.65	2.66	2.70	2.79
10	2.68	2.64	2.64	2.64	2.64
15	2.63	2.63	2.63	2.63	2.63

[Brater/King, 1976]

When the weir (roadway) is submerged by high tailwater, the weir flow coefficient is automatically reduced by the HEC-2 program. The program adjusts for weir submergence based on either the curves in "Hydraulics of Bridge Waterways" [FHWA, 1978], or the Waterways Experiment Station's Design Chart 111-4 [U.S. Army Corps of Engineers, 1953]. The "Hydraulics of Bridge Waterways" method, the default method of the program, is based on a trapezoidal-shaped roadway embankment, whereas the WES method is based on a ogee-shaped spillway.

Use of the WES method is designed by a negative weir coefficient COFQ in Field 3 of the SC record. The "Hydraulics of Bridge Waterways" method is designated by a positive weir coefficient COFQ.

Table 3.7
Trapezoidal Weir Coefficients

Slope of Upstream Face (H:V)	Slope of Downstrea m Face (H:V)	Width of Crest (feet	Measured Head in Feet (H)						
			0.50	1.00	1.50	2.00	3.00	4.00	5.00
1:1	1:1	0	4.14	4.08	3.75	3.75	3.75	3.75	3.75
2:1	2:1	0	3.81	3.87	3.87	3.87	3.87	3.87	3.87
2:1	2:1	.67	3.13	3.43	3.61	3.56	3.58	3.62	3.68

[Brater/King, 1976]
Note: A weir crest width of zero indicates a triangular weir.

3.2.5 RISE: Pipe Culvert Diameter or Box Culvert Height

The value in Field 5 of the SC record is used as the inside diameter of a pipe culvert or the inside height of a box culvert.

Box culverts are described by the **span** and **rise**, which are the horizontal and vertical dimensions of the culvert opening, respectively. For example, a "4 by 3 box culvert" has a span of 4 feet and a rise of 3 feet.

The inside height of the culvert opening is important not only in determining the total flow area of the culvert, but also in determining whether the headwater and tailwater elevations are adequate to submerge the inlet or outlet of the culvert.

3.2.6 SPAN: Box Culvert Span (Width of Opening)

Box culverts are essentially rectangular in cross section. For analysis of box culverts, the horizontal dimension of the rectangle, measured in feet, is input in Field 6 of the SC record. If Field 6 contains a zero or is blank, the culvert is assumed to be a circular culvert with the diameter provided in Field 5.

Most box culverts have **chamfered** corners on the inside, as indicated in Figure 2.2. The chamfers are ignored by the special culvert option in computing the cross-sectional area of the culvert opening. Some manufacturers' literature contains the true cross-sectional area of each size of box culvert, considering the reduction in area caused by the chamfered corners. If you wish to consider the loss in area due to the chamfers, then you should reduce the span of the culvert. You should not reduce the rise of the culvert, because the program uses the culvert rise to determine the submergence of the culvert entrance and outlet.

3.2.7 CULVLN: Culvert Length

The culvert length is input in Field 7 of the SC record. It is measured in feet along the center-line of the culvert. The culvert length is used to determine the friction loss in the culvert barrel and the slope of the culvert.

3.2.8 CHRT and SCL: FHWA Chart Number and Scale Number

The culvert FHWA chart number and scale number are input in Field 8 of the SC record. The FHWA chart number is entered left of the decimal point and the FHWA scale number is entered right of the decimal point. For example, a value of 1.2 in Field 8 of the SC record indicates FHWA chart number 1 and FHWA scale number 2.

The FHWA chart number and scale number refer to a series of nomographs published by the Bureau of Public Roads (now called the Federal Highway Administration) in 1965 [BPR, 1965], which allowed the inlet control headwater to be computed for different types of culverts operating under a wide range of flow conditions. These nomographs and others constructed using the original methods were republished [FHWA, 1985]. The exhibit of this appendix contains copies of all the pipe culvert and box culvert nomographs from the 1985 FHWA publication.

Each of the FHWA charts has from two to four separate scales representing different culvert entrance designs. The appropriate FHWA chart number and scale number should be chosen according to the type of culvert and culvert entrance. Tables 3.8 and 3.9 may be used for guidance in selecting the FHWA chart number and scale number.

Table 3.8
FHWA Chart and Scale Numbers for Pipe Culverts

Chart Number	Scale Number	Description
1		**Concrete Pipe Culvert**
	1	Square edge entrance with headwall (See Figure 3.4)
	2	Groove end entrance with headwall (See Figure 3.4)
	3	Groove end entrance, pipe projecting from fill (See Figure 3.6)
2		**Corrugated Metal Pipe Culvert**
	1	Headwall (See Figure 3.4)
	2	Mitered to conform to slope (See Figure 3.5)
	3	Pipe projecting from fill (See Figure 3.6)
3		**Concrete Pipe Culvert; Beveled Ring Entrance (See Figure 3.7)**
	1(A)	Small bevel: b/D = 0.042; a/D = 0.063; c/D = 0.042; d/D = 0.083
	2(B)	Large bevel; b/D = 0.083; a/D = 0.125; c/D = 0.042; d/D = 0.125

NOTE: For chart 3, enter scale number 1 for scale A and scale number 2 for scale B. See chart 3 in Exhibit A of this appendix for detail.

Chart numbers 1, 2, and 3 apply only to pipe culverts. Similarly, chart number 8, 9, 10, 11, 12, and 13 apply only to box culverts. The HEC-2 program checks the chart number to assure that it is appropriate for the type of culvert being analyzed. HEC-2 also checks the value of the Scale Number to assure that it is available for the given chart number. For example, a scale number of 4 would be available for chart 11, but not for chart 12.

Table 3.8 lists the FHWA chart and scale numbers for pipe culverts. Figures 3.4 through 3.7 can be used as guidance in determining which chart and scale numbers to select for various types of culvert inlets.

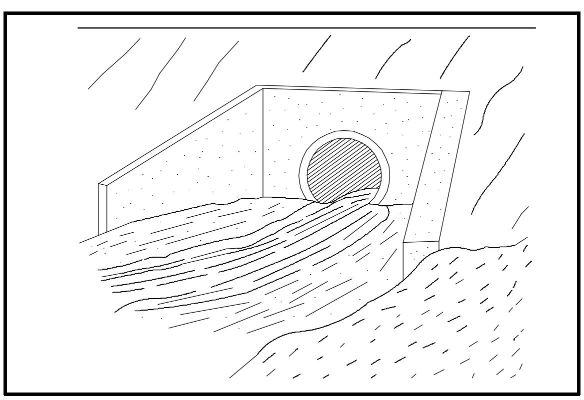

Figure 3.4
Culvert Inlet with Headwall and Wingwalls

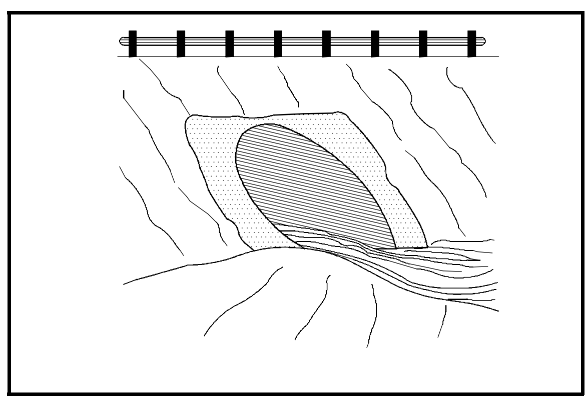

Figure 3.5
Culvert Inlet Mitered to Conform to Slope

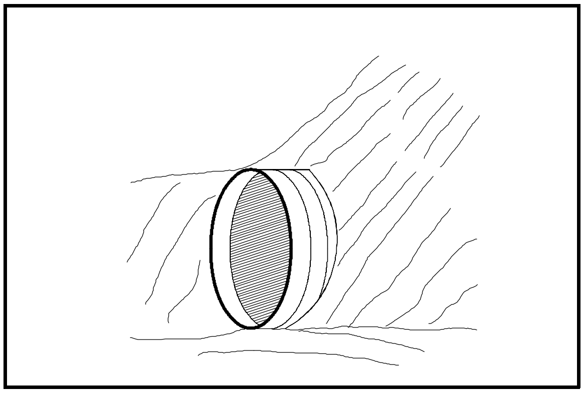

Figure 3.6
Culvert Inlet Projecting from Fill

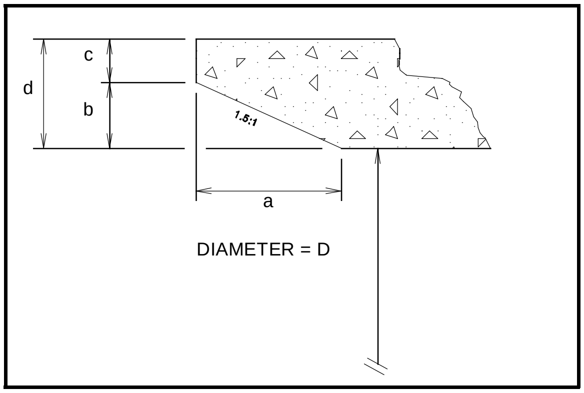

Figure 3.7
Culvert Inlet with Beveled Ring Entrance

Table 3.10 lists the FHWA chart and scale number for box culverts. Figures 3.8 through 3.13 illustrate the culvert inlets corresponding to various box culvert charts.

Table 3.9
FHWA Chart and Scale Numbers for Box Culverts

Chart Number	Scale Number	Description
8		**Box Culvert with Flared Wingwalls (See Figure 3.8)**
	1	Wingwalls flared 30 to 75 degrees
	2	Wingwalls flared 90 or 15 degrees
	3	Wingwalls flared 0 degrees (sides extended straight)
9		**Box Culvert with Flared Wingwalls and Inlet Top Edge Bevel (See Figure 3.9)**
	1	Wingwall flared 45 degrees; inlet top edge bevel = 0.43D
	2	Wingwall flared 18 to 33.7 degrees; inlet top edge bevel = 0.083D
10		**Box Culvert; 90-degree Headwall; Chamfered or Beveled Inlet Edges (See Figure 3.11)**
	1	Inlet edges chamfered 3/4-inch
	2	Inlet edges beveled 1/2-in/ft at 45 degrees (1:1)
	3	Inlet edges beveled 1-in/ft at 33.7 degrees (1:1.5)
11		**Box Culvert; Skewed Headwall; Chamfered or Beveled Inlet Edges (See Figure 3.11)**
	1	Headwall skewed 45 degrees; inlet edges chamfered 3/4-inch
	2	Headwall skewed 30 degrees; inlet edges chamfered 3/4-inch
	3	Headwall skewed 15 degrees; inlet edges chamfered 3/4-inch
	4	Headwall skewed 10 to 45 degrees; inlet edges beveled
12		**Box Culvert; Non-Offset Flared Wingwalls; 3/4-inch Chamfer at Top of Inlet (See Figure 3.12)**
	1	Wingwalls flared 45 degrees (1:1); inlet not skewed
	2	Wingwalls flared 18.4 degrees (3:1); inlet not skewed
	3	Wingwalls flared 18.4 degrees (3:1); inlet skewed 30 degrees
13		**Box Culvert; Offset Flared Wingwalls; Beveled Edge ar Top of Inlet (See Figure 3.13)**
	1	Wingwalls flared 45 degrees (1:1); inlet top edge bevel = 0.042D
	2	Wingwalls flared 33.7 degrees (1.5:1); inlet top edge bevel = 0.083D
	3	Wingwalls flared 18.4 degrees (3:1); inlet top edge bevel = 0.083D

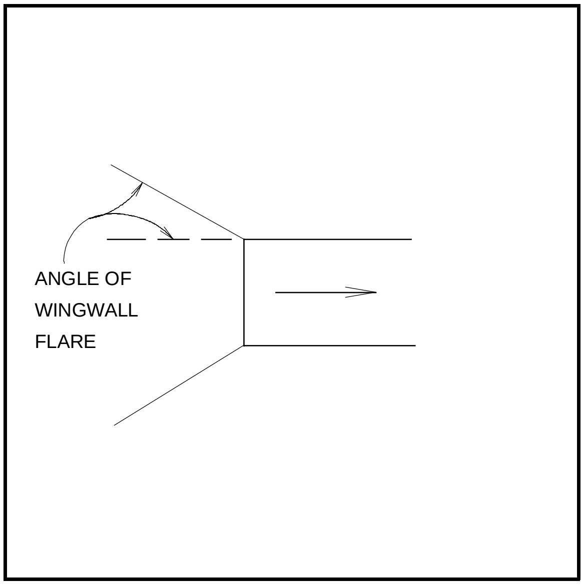

Figure 3.8
Flared Wingwalls (Chart 8)

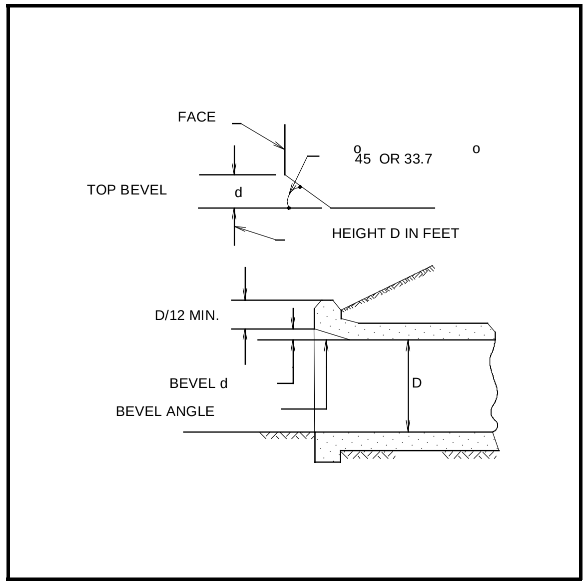

Figure 3.9
Inlet Top Edge Bevel (Chart 9)

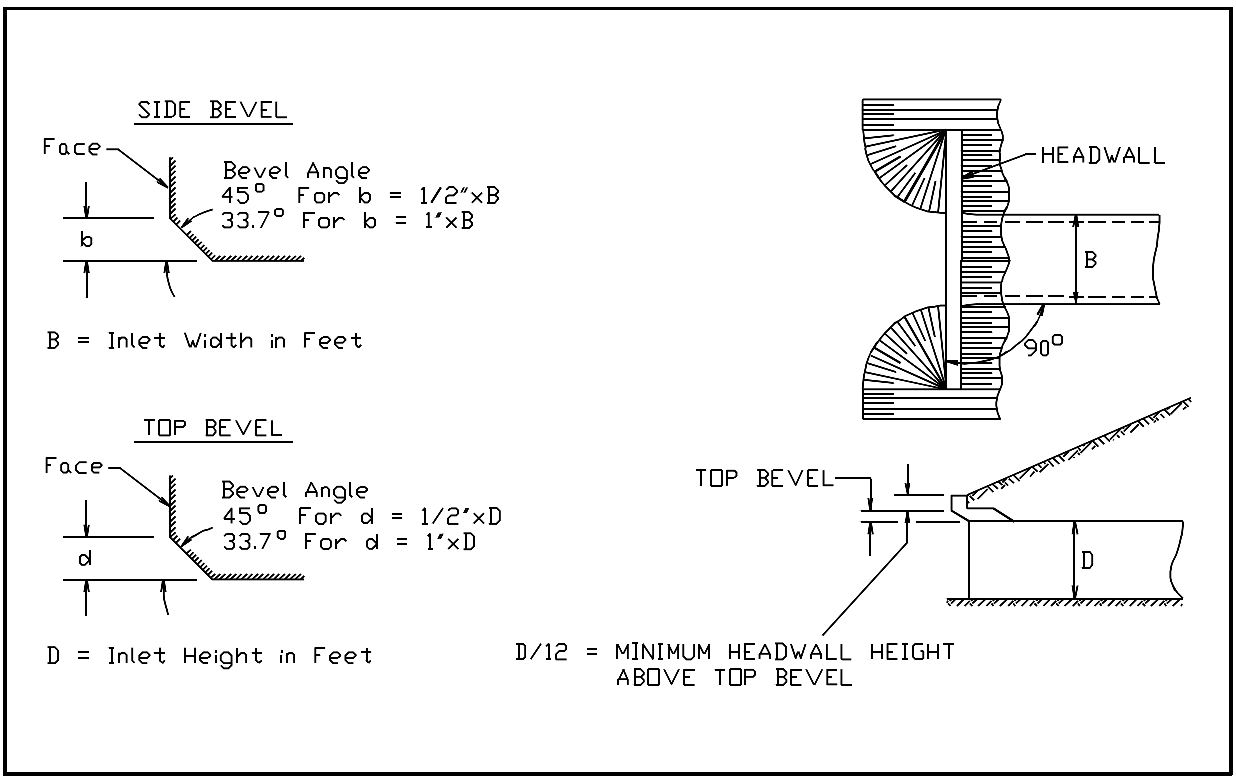

Figure 3.10
Inlet Side and Top Edge Bevel with Ninety Degree Headwall (Chart 10)

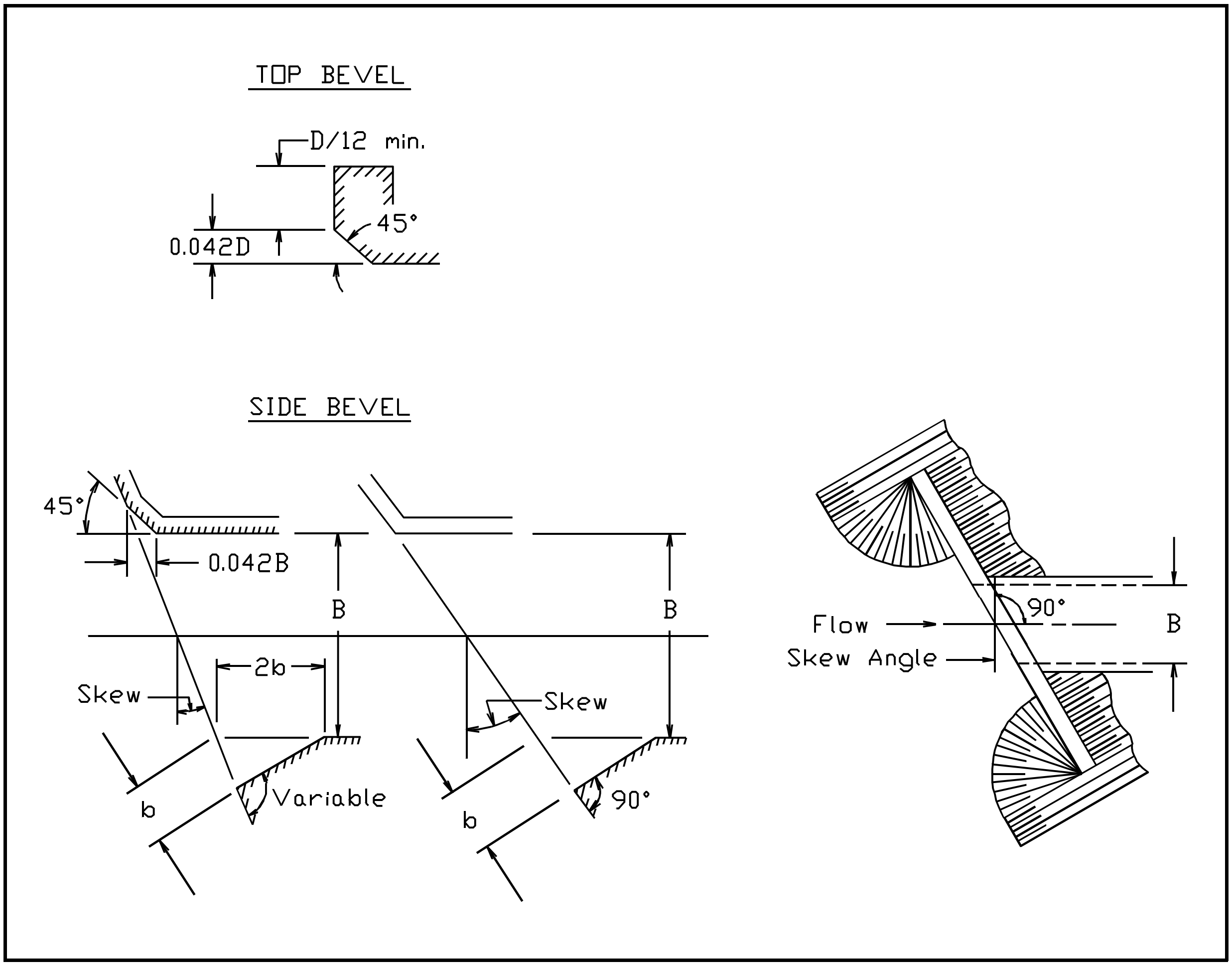

Figure 3.11
Inlet Side and Top Edge Bevel with Skewed Headwall (Chart 11)

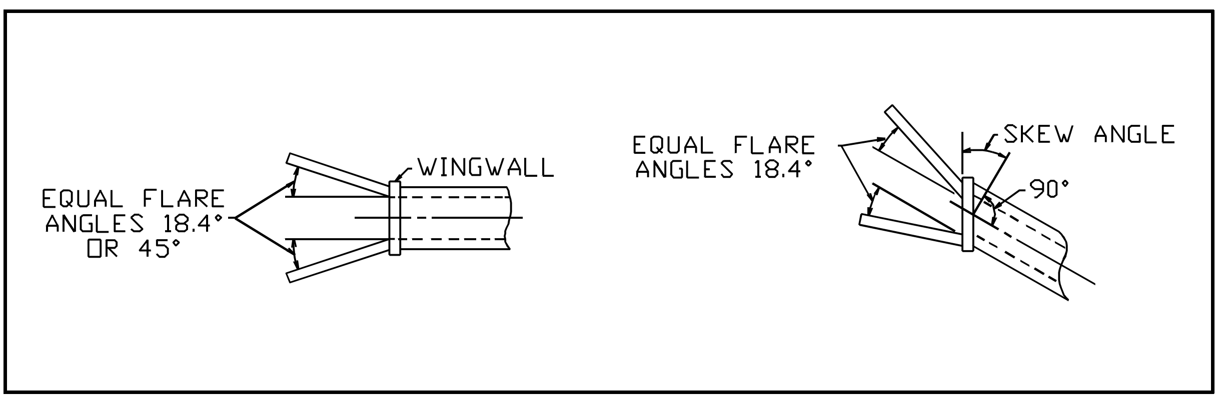

Figure 3.12
Non-Offset Flared Wingwalls (Chart 12)

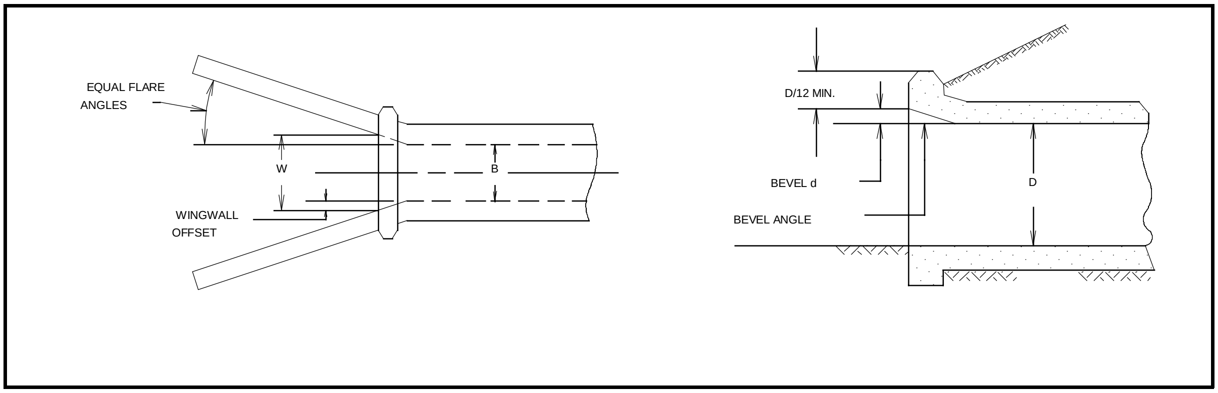

Figure 3.13
Offset Flared Wingwalls (Chart 13)

3.2.9 ELCHU and ELCHD: Culvert Invert Elevations

The culvert flow-line slope is the average drop in elevation per foot of length along the culvert. For example, if the culvert flow-line drops 1 foot in a length of 100 feet, then the culvert flow-line slope is 0.01 feet per foot. Culvert flow-line slopes are sometimes expressed in percent. A slope of 0.01 feet per foot is the same as a one percent slope.

The culvert slope is computed from the upstream flow-line elevation input in Field 9 of the SC record, the downstream flow-line elevation input in Field 10, and the culvert length input in Field 7. The following equation is used to compute the culvert slope:

$$S = \frac{ELCHU - ELCHD}{\sqrt{CULVLN^2 - (ELCHU - ELCHD)^2}} \qquad \text{(IV-8)}$$

As already noted, HEC-2 cannot analyze culverts with adverse (negative) slopes. Most culverts are installed with some "positive slope"; that is, the flow-line of the culvert is slightly lower on the downstream end than the upstream end, so that some flow velocity can be maintained in the culvert even under low flow conditions. A sufficient slope to maintain a minimum flow velocity of 3 feet per second is often required.

The slope of the culvert is used by the program to compute the drop in flow-line between the upstream and downstream ends of the culvert. It is also used to compute the normal depth of flow in the culvert under inlet control conditions.

3.3 Defining the Weir Profile With the BT Records

Weir flow occurs when water begins to flow over the roadway. The HEC-2 program performs weir flow calculations using the standard weir flow equation. Total weir flow is computed by subdividing the roadway crest into segments, computing the discharge for each segment, and summing the discharges.

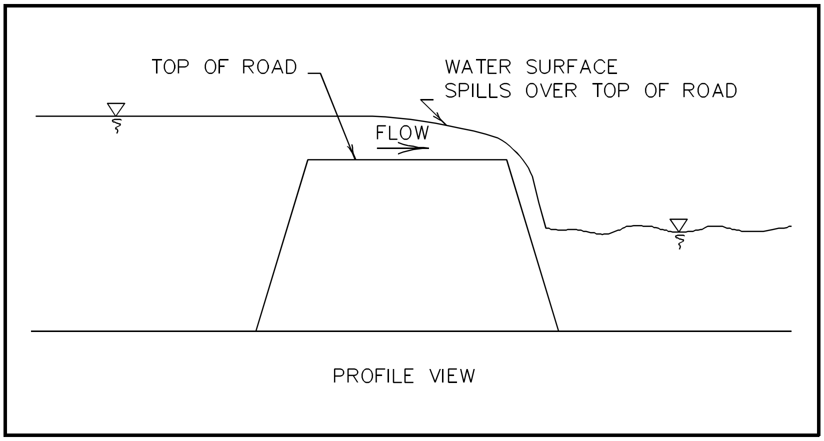

Figure 3.14
Illustration of Weir Flow Conditions

Combinations of culvert flow and weir flow are analyzed by HEC-2 using an iterative procedure. Energy elevations are assumed and discharges computed for each type of flow until the total computed flow rate is within one percent of the actual total flow rate at the roadway crossing.

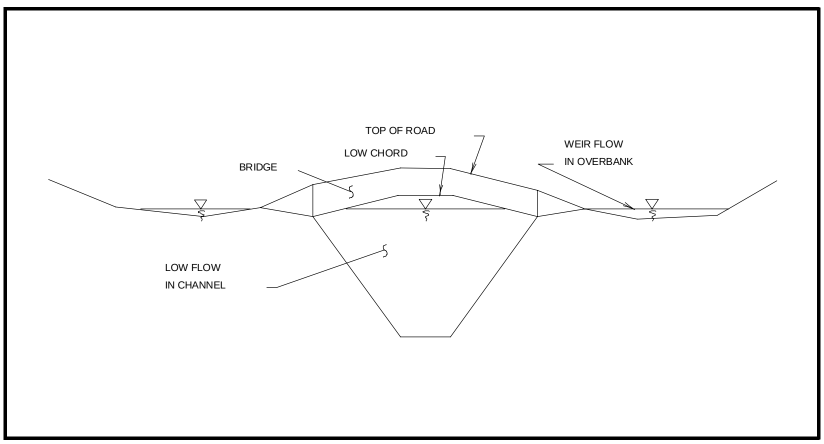

Figure 3.15
Illustration of Combination Flow Conditions

The top-of-road profile for weir flow computations is defined using BT records at cross section 3 of the special culvert model. For the special culvert method, BT stations do not have to match GR stations, because the standard step method is not used for the special culvert method. However, the entire top-of-road profile **must** be coded on the BT records, even if the top-of-road and ground elevations are the same for a portion of the cross section. Weir flow computations are based on the road profile as represented on the BT records **only**. Therefore, if only a portion of the road profile is included on the BT records, the length of the roadway for weir flow computations will be less than the actual length.

Proper definition of the top of roadway is a crucial step in assembling an accurate and reliable HEC-2 culvert model. **Actual top-of-road elevations should always be used in defining the top of roadway at cross section 3 in the special culvert method**. The natural ground elevations in the overbank should not be used to represent the top-of-roadway profile, even though there is a tendency to do so when copying a natural channel cross section for use in the culvert model. An exception to this rule is that natural ground elevations should be used instead of top of road elevations when the roadway is in a cut, i.e., when natural ground is higher than the top of the roadway. Figure 3.16 illustrates this situation.

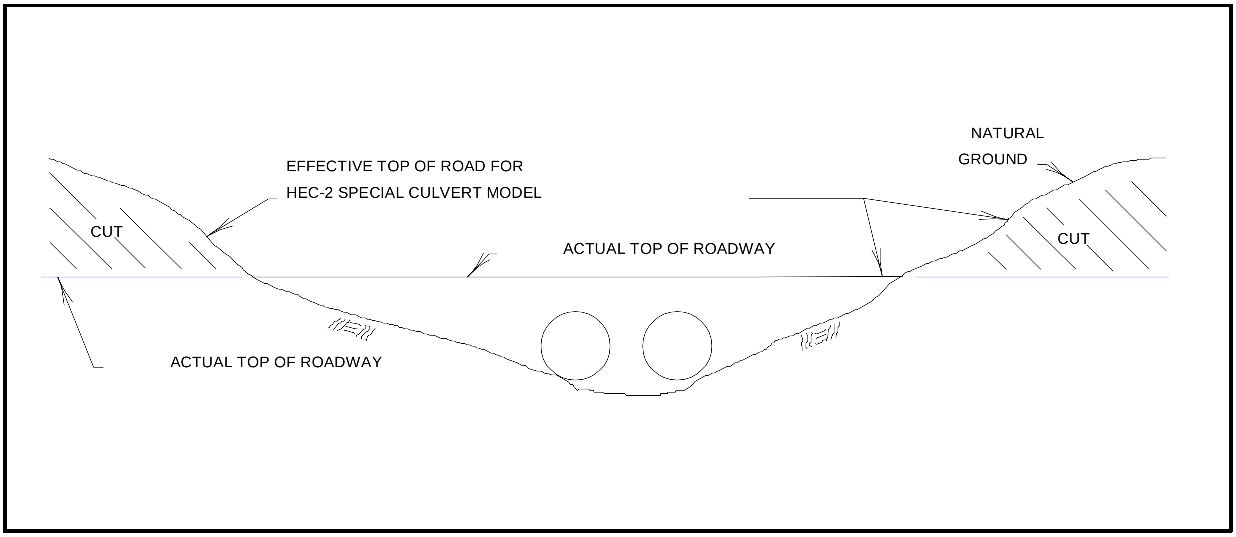

Figure 3.16
Defining the Top-of-Road for Roadways in Open Cuts

Bridge railings or curbs should sometimes be considered when defining the top of roadway. If a railing or curb forms a substantial obstruction to flow over the roadway, the top of the rail or curb should be considered as the effective top-of-road. Figures 3.17 and 3.18 illustrate roadways with solid and open rails.

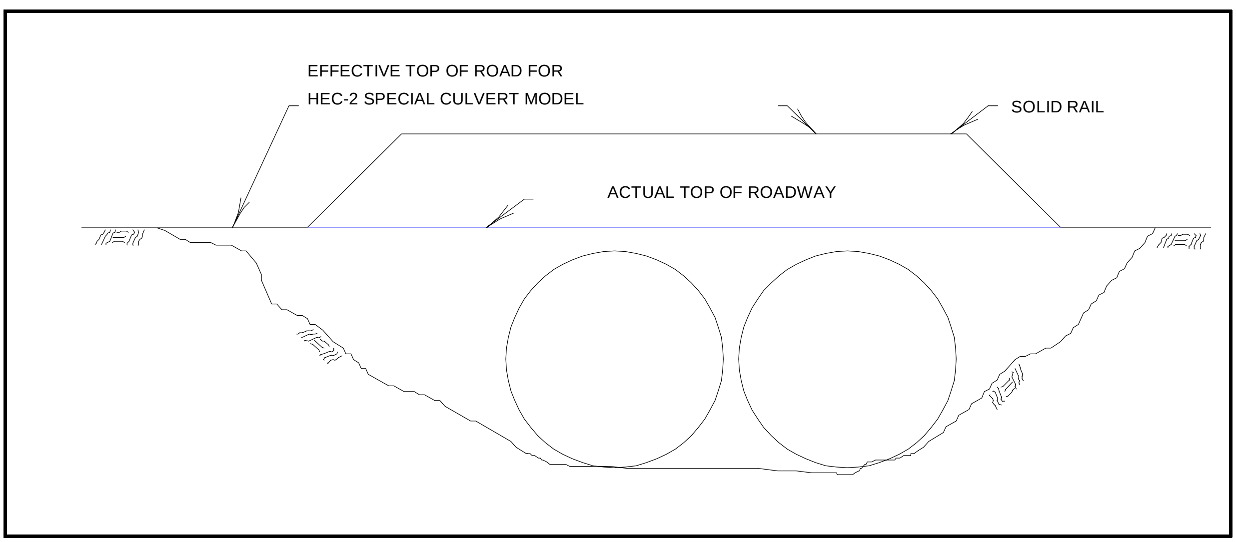

Figure 3.17
Defining the Top-of-Road for Roadways with Solid Rails

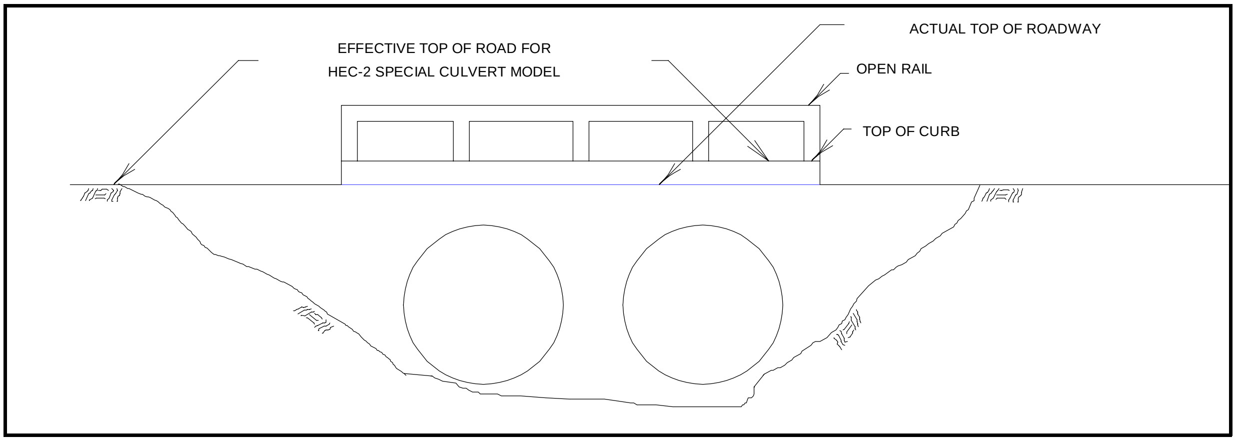

Figure 3.18
Defining the Top-of-Road for Roadways with Open Rails

In lieu of BT records, a horizontal weir may be specified using Field 4 of the SC record and Field 5 of the X2 record. However, this option should be used carefully, because the same weir length will be used for all flow rates. This contrasts with most bridges, in which longer and longer segments of the roadway are inundated as flow rates increase. Figure 3.19 illustrates a horizontal weir.

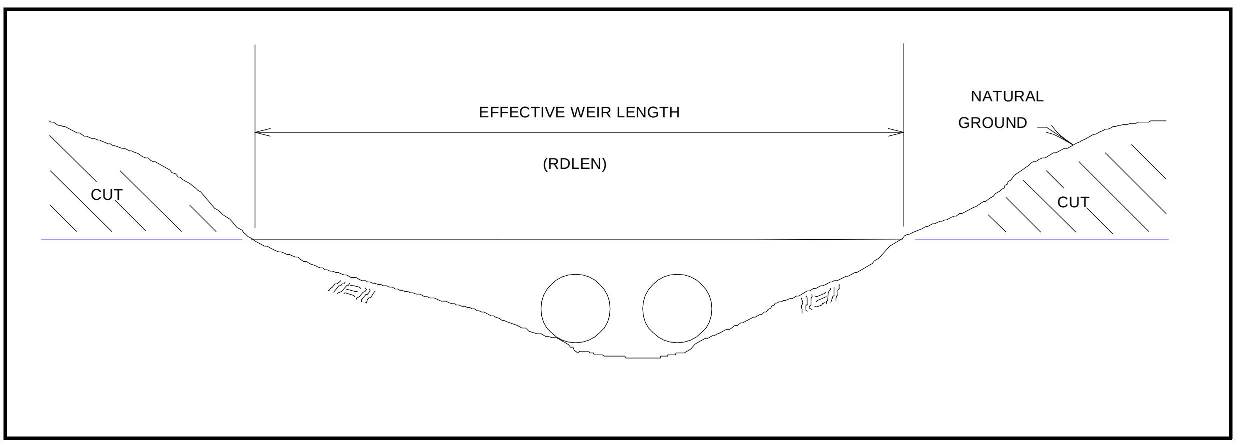

Figure 3.19
Defining a Horizontal Weir for the Special Culvert Method

3.4 Controlling the Special Culvert Option With the X2 Record

An X2 record is required at cross section 3 of the special culvert model. Field 3 of the X2 record should contain a "2" to indicate to HEC-2 that special culvert computations are to be performed.

Other variables on the X2 record are used in the special culvert method as they are in the special bridge method. Field 5 of the X2 record is used to define the minimum top-of-road elevation for use by the HEC-2 program in testing for weir flow. Therefore, when the energy grade line upstream of the roadway exceeds the elevation specified in Field 5 of the X2 record, the program begins to compute weir flow.

3.5 Special Culvert Output

The special culvert method generates detailed output for each cross section. This output includes the following:

1) A listing of the data values read from the SC record.

2) A description of the selected FHWA chart and scale.

3) A statement of whether the culvert operates under inlet control or outlet control.

4) The values of four important variables:

   EGIC - the computed energy grade line elevation for inlet control;
   EGOC - the computed energy grade line elevation for outlet control;
   PCWSEL - the water surface elevation computed by HEC-2 for the previous cross section; and
   ELTRD - the minimum top of road elevation for weir flow.

Summary Table 101 is available to provide the results of the special culvert option. Summary Table 101 includes the following variables:

SECNO - the cross section number
EGOC - the computed energy grade line elevation for outlet control
EGIC - the computed energy grade line elevation for inlet control
H4 - the difference between the computed energy grade elevation upstream and downstream of a culvert.
ELTRD - the minimum top-of-road for weir flow.
QCULV - the computed flow through the culvert. Equivalent to the QCH variable used in special bridge models.
CLASS - an indicator of the type of flow occurring at the roadway crossing. The CLASS variable has several values relating specifically to the special culvert option. Table 3.10 lists these CLASS values.

Table 3.10
CLASS Values for Special Culvert Option

CLASS Value	Description
6	Inlet control, all flow is passing through the culvert.
7	Outlet control, all flow is passing through the culvert.
16	Inlet control, combination of culvert flow and weir flow.
17	Outlet control, combination of culvert flow and weir flow.

The variables QWEIR, CWSEL, VCH, and EG are also used in Summary Table 101 and have the same significance for special culvert models as special bridge models. The special bridge Summary Table 105 is also applicable to special culvert models. In Summary Table 105, the QCH variable contains the value for QCULV.

The special culvert examples in Section 4 of this Appendix illustrate the detailed and summary output for the special culvert option.

Error messages and warnings are also provided for special culvert computations. See special notes 5105 through 5185 in Appendix V (pages V-6 through V-7) for error messages and warnings which pertain to the special culvert option.

Chapter 4

Examples of the Special Culvert Method

This chapter presents four examples of culvert models using the special culvert method. The following examples are included:

1) A road crossing with a single box culvert.

2) A road crossing with a single pipe culvert.

3) A road crossing with multiple box culverts.

4.1 Example of Box Culvert Analysis

As an example of the application of a special culvert model of a box culvert, the culvert illustrated in Figure 4.1 is considered. The culvert underneath the roadway is a 10' X 6' concrete box culvert, 50 feet in length. A Manning's 'n' value of 0.013 is assumed for the culvert. At both ends of the culvert are a vertical headwall and 45 degree wing walls. According to Table 3.9 of this appendix, Scale 1 of FHWA chart 8 is appropriate for this type of culvert. According to Table 3.4 of this appendix, the entrance loss coefficient for this type of entrance is about 0.4, assuming that the top edge of the entrance is not rounded.

A concrete apron extends about 5 feet past the end of the culvert. The roadway on either side of the channel is not elevated. The drop in invert elevation is 0.1 foot through the culvert, so the slope of the culvert invert is 0.2 percent.

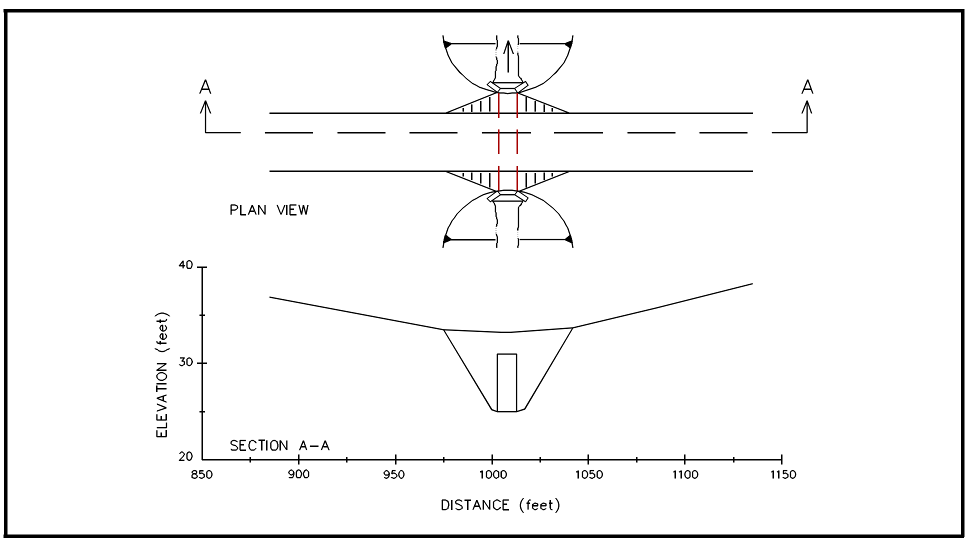

Figure 4.1
Illustration of Box Culvert Example

Cross section 1 of the special culvert model is located downstream of the culvert crossing at a distance determined by the 4:1 flow expansion rule. The flow expands from a top width of 10 feet in the culverts to a maximum of about 60 feet downstream, the spacing between cross sections 1 and 2 should be about 4 X (30 - 5) = 100 feet.

Cross section 2 is located at the downstream end of the culvert. The n-value is changed at cross section 2 because the concrete apron extends past the downstream end of the culvert. The effective area option is used at cross section 2 to restrict flow to the portion of the cross section in and directly above the culvert opening until the roadway is overtopped. Both of the test elevations on the X3 record at cross section 2 are set at 32. These elevations are computed by subtracting the expected head loss through the culvert (about 1.3 feet) from the top-of-road elevations for the left and right sides of the road (each of which is 33.3).

The weir flow coefficient is set at 3.0. This is the recommended value for roadway embankments. The fill over the culvert is assumed to be similar to a roadway embankment.

The downstream channel flow-line elevation is equal to 24.9 for this example. The upstream flow-line elevation is 0.1 foot higher. These values are entered in Fields 9 and 10 of the SC record.

Cross section 3 is located at the upstream end of the culvert. The effective area option is also used at cross section 3 to restrict flow to the portion of the cross section in and directly above the culvert until the roadway is overtopped. The test elevations on the X3 record at cross section 3 are set at the top-of-road elevations for the left and right sides of the road (each of which is 33.3).

Cross section 4 is located upstream of the culvert at a distance determined using the 1:1 contraction rule. Since the flow must contract from a total top width of about 120 feet at cross section 4 to a top width of 10 feet in the culvert, the spacing between cross sections 3 and 4 should be about 60 - 5 = 55 feet. An example output of the box culvert option is shown in Exhibit B of this appendix.

4.2 Example of Pipe Culvert Analysis

This example deals with a roadway crossing over a reinforced concrete pipe culvert. As shown in Figure 4.2, the culvert is a 84-inch reinforced concrete pipe 50 feet in length. A Manning's ‘n’ value of 0.013 is assumed for the culvert. At both ends of the culvert are a vertical headwall and 45 degree wing walls. According to Table 3.9 of this appendix, Scale 1 of FHWA Chart 1 is appropriate for this type of culvert. According to Table 3.6 of this appendix, the entrance loss coefficient for this type of entrance is about 0.5, assuming that the top edge of the entrance is not rounded.

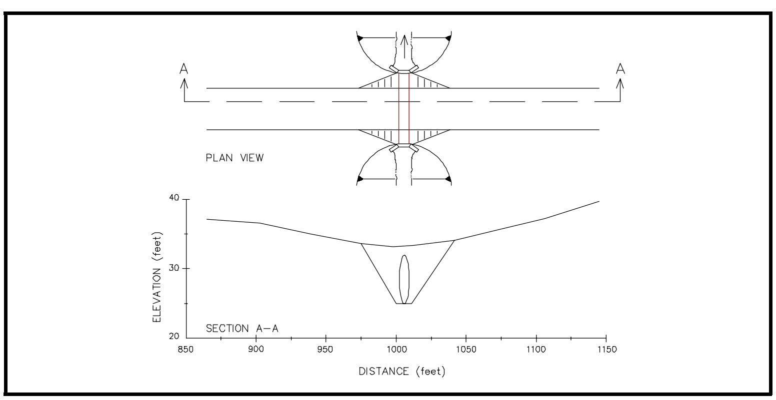

Figure 4.2
Pipe Culvert Example

A concrete apron extends about 5 feet past the end of the culvert. The roadway on either side of the channel is not elevated. The drop in invert elevation is 0.1 foot through the culvert, so the slope of the culvert invert is 0.2 percent.

Cross section 1 of the special culvert model is located downstream of the culvert crossing at a distance determined by the 4:1 flow expansion rule.

Cross section 2 is located at the downstream end of the culvert. The n-value is changed at cross section 2 because the concrete apron extends past the downstream end of the culvert. The effective area option is used at cross section 2 to restrict flow to the portion of the cross section in and directly above the culvert opening until the roadway is overtopped. Both of the test elevations on the X3 record at cross section 2 are set at 32.9. These elevations are computed by subtracting the expected head loss through the culvert (about 0.8 feet) from the top-of-road elevations for the left and right sides of the road (each of which is 33.7).

The weir flow coefficient is set at 3.0. This is the recommended value for roadway embankments. The fill over the culvert is assumed to be similar to a roadway embankment.

The downstream channel flow-line elevation is equal to 25 for this example. The upstream flow-line elevation is 0.1 foot higher. These values are entered in Fields 9 and 10 of the SC record.

Cross section 3 is located at the upstream end of the culvert. The effective area option is also used at cross section 3 to restrict flow to the portion of the cross section in and directly above the culvert until the roadway is overtopped. The test elevations on the X3 record at cross section 3 are set at the top-of-road elevations for the left and right sides of the road (each of which is 33.7).

Cross section 4 is located upstream of the culvert at a distance determined using the 1:1 contraction rule. An example output of the pipe culvert option is shown in Exhibit C of this appendix.

4.3 Multiple Culverts Example

This example deals with a situation where the roadway crossing consists of two 72-inch reinforced concrete pipe culverts. As illustrated on Figure 4.3, the culverts are 50 feet in length. A Manning's 'n' value of 0.013 is assumed for the culverts. At each end of the culverts is a vertical headwall and 45 degree wingwalls. According to Table 3.8 (page IV-21), Scale 1 of FHWA Chart 1 is appropriate for this type of culvert. According to Table 3.5 (page IV-18), the entrance loss coefficient for this type of entrance is about 0.5, assuming that the top edge of the entrance is not rounded.

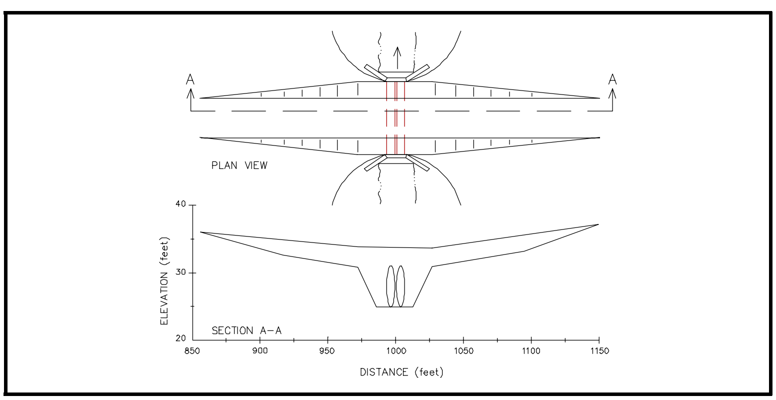

Figure 4.3
Illustration of Multiple Culverts Example

A concrete apron extends about 5 feet past the end of the culvert. The roadway on either side of the channel is not elevated. The drop in invert elevation is 0.1 foot through the culvert, so the slope of the culvert invert is 0.2 percent. Elevated roadway approach embankments extend into the floodplain on each side of the bridge.

Cross section 1 of the special culvert model is located downstream of the culvert crossing at a distance determined by the 4:1 flow expansion rule.

Cross section 2 is located at the downstream end of the culvert. The n-value is changed at cross section 2 because the concrete apron extends past the downstream end of the culvert. The effective area option is used at cross section 2 to restrict flow to the portion of the cross section in and directly above the culvert opening until the roadway is overtopped. Both of the test elevations on the X3 record at cross section 2 are set at 32.5. These elevations are computed by subtracting the expected head loss through the culvert (about 1.3 feet) from the top-of-road elevations for the left and right sides of the road (each of which is 33.8).

The weir flow coefficient is set at 3.0. This is the recommended value for roadway embankments. The fill over the culvert is assumed to be similar to a roadway embankment.

The downstream channel flow-line elevation is equal to 25 for this example. The upstream flow-line elevation is 0.1 foot higher. These values are entered in Fields 9 and 10 of the SC record.

Cross section 3 is located at the upstream end of the culvert. The effective area option is also used at cross section 3 to restrict flow to the portion of the cross section in and directly above the culvert until the roadway is overtopped. The test elevations on the X3 record at cross section 3 are set at the top-of-road elevations for the left and right sides of the road (each of which is 33.8).

Cross section 4 is located upstream of the culvert at a distance determined using the 1:1 contraction rule.

The results of a multi-profile HEC-2 run for this example may be found in Figure 4.6. Solutions for culvert flow and combination culvert flow and weir flow conditions are determined by the HEC-2 program. An example output of multiple culverts is shown in Exhibit D of this appendix.

Chapter 5

References and Bibliography

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Bonner, Vernon R., *Computing Water Surface Profiles with HEC-2 on a Personal Computer*, U.S. Army Corps of Engineers, Hydrologic Engineering Center, Training Document 26.

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Featherstone, R. E. and C. Nalluri, *Civil Engineering Hydraulics*, Granada Publishing Limited, London, 1982. This book is fairly theoretical, but with many examples.

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Federal Highway Administration (FHWA), *Capacity Charts for the Hydraulic Design of Highway Culverts*, Hydraulic Engineering Circular No. 10, U.S. Department of Transportation, March 1978. This is a good reference on culvert hydraulics and design. The capacity charts can be used to check the results of the HEC-2 Special Culvert Option.

Federal Highway Administration (FHWA), *Hydraulic Design of Highway Culverts*, Hydraulic Design Series No. 5, U.S. Department of Transportation, September 1985. This is an invaluable reference for hydraulic engineers. If you design or analyze culverts, you need this book. The hydraulic charts in this publication can be used to check the results of the HEC-2 Special Culvert Option.

French, Richard H., *Open Channel Hydraulics*, McGraw-Hill, Inc. New York, 1985. This is a comprehensive, up-to-date text on open-channel flow.

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Shearman, J.O., et al, *Bridge Waterways Analysis Model: Research Report*, Report No. FHWA/RD-86/108, U.S. Department of Transportation, Federal Highway Administration, July 1986.

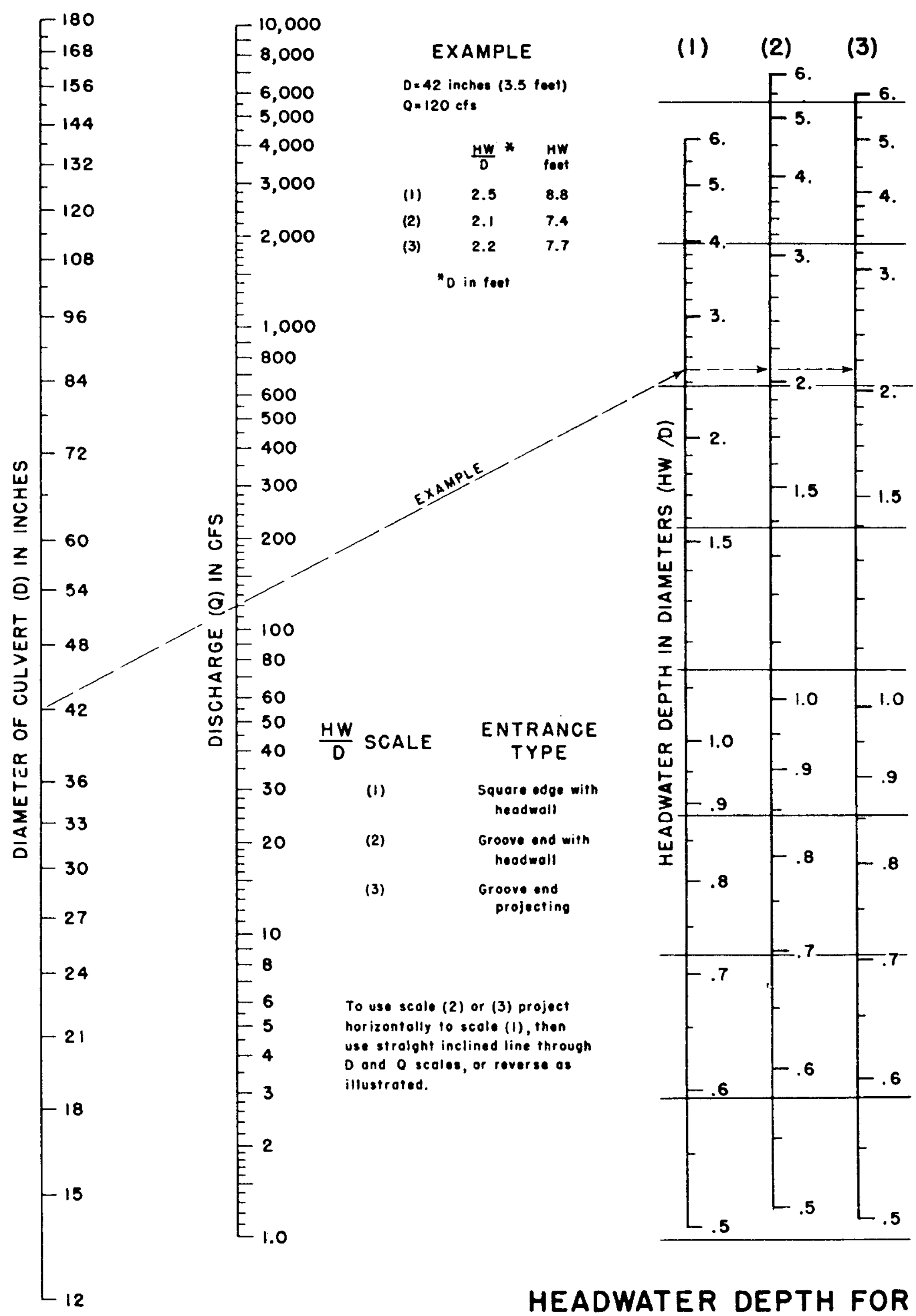
Zelensky, Paul N., *Approximate Method for Computing Backwater Profiles in Corrugated Metal Pipes*, Federal Highway Administration, Offices of Research & Development, Report No. FHWA-RD-76-42, April 1976. This report presents an approximate method for backwater computations in structural plate corrugated metal pipes with 6 x 2 inch corrugations.

Exhibit A

Federal Highway Administration

Culvert Charts

CHART 1

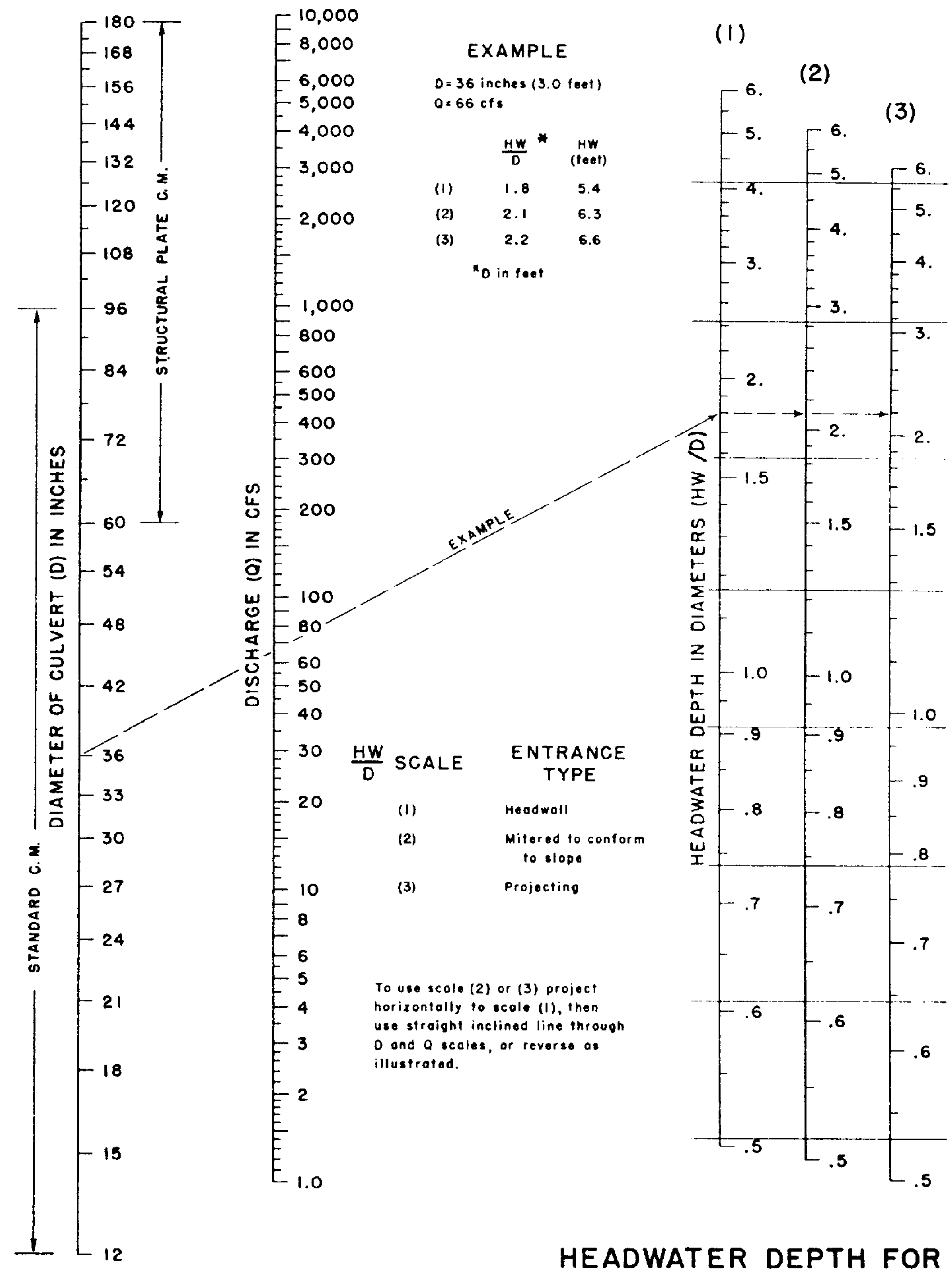


HEADWATER DEPTH FOR CONCRETE PIPE CULVERTS WITH INLET CONTROL

HEADWATER SCALES 2&3 REVISED MAY 1964

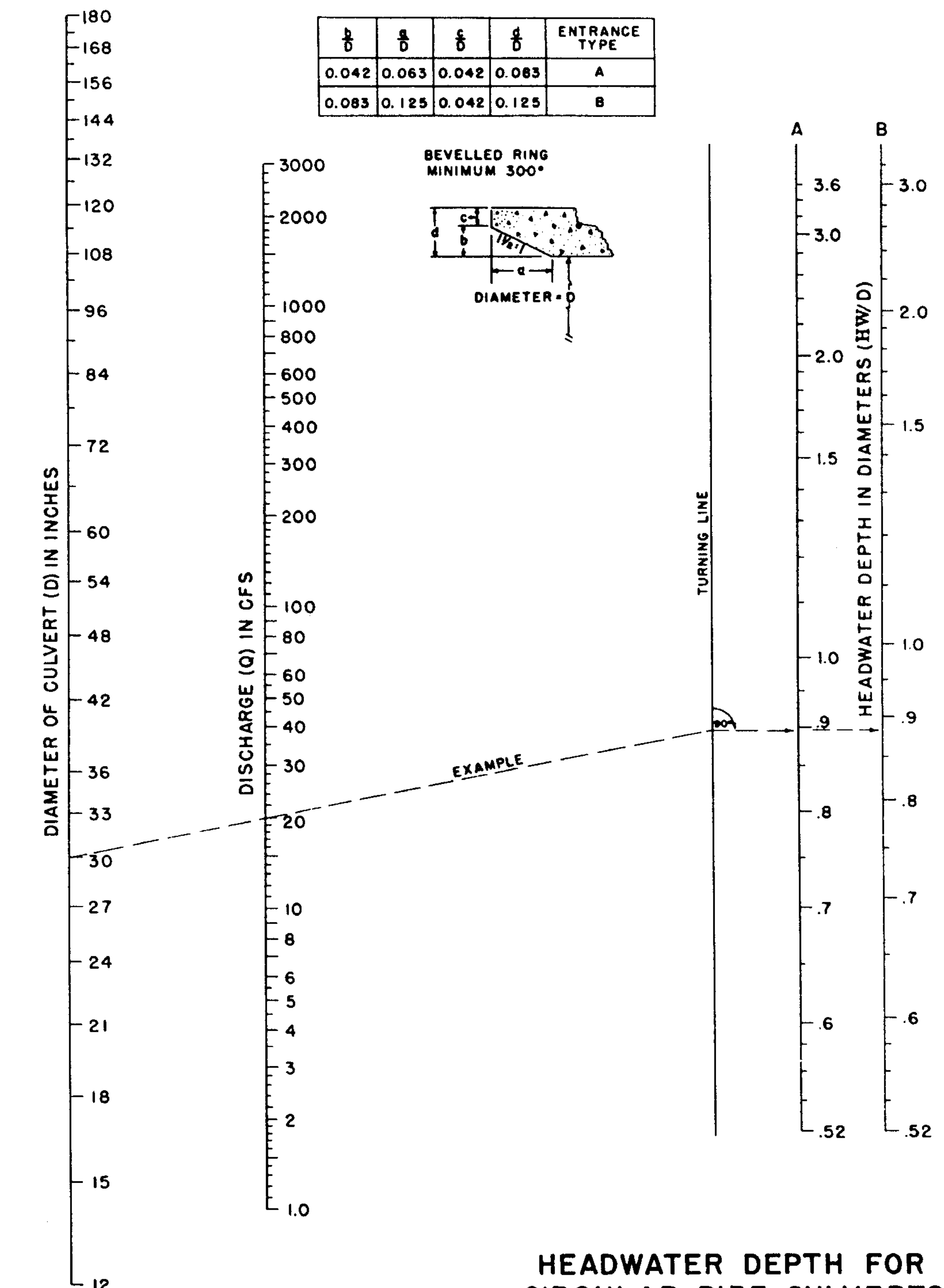
BUREAU OF PUBLIC ROADS JAN. 1963

CHART 2



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

BUREAU OF PUBLIC ROADS JAN. 1963

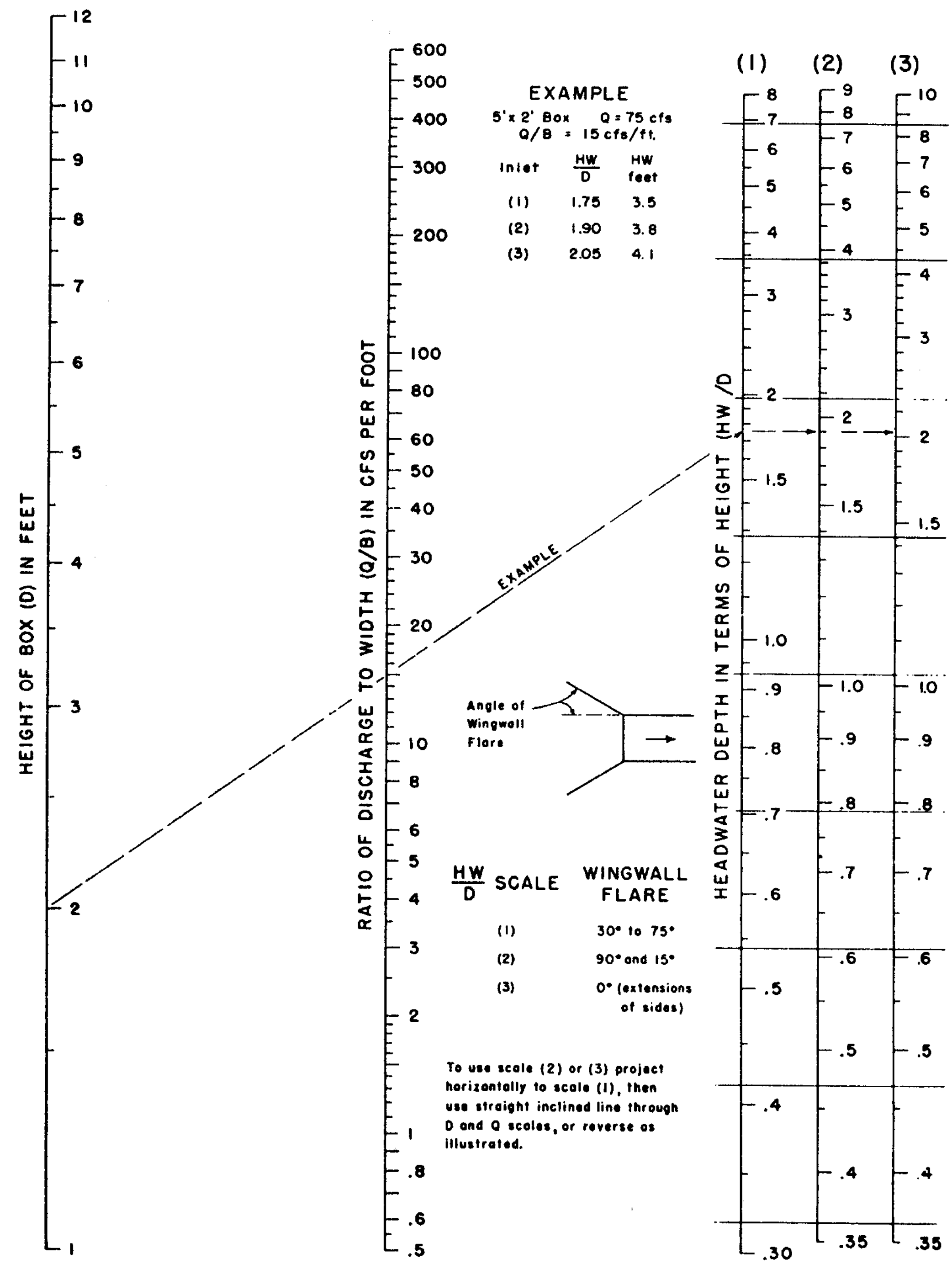


$\frac{b}{D}$	$\frac{a}{D}$	$\frac{c}{D}$	$\frac{d}{D}$	ENTRANCE TYPE
0.042	0.063	0.042	0.083	A
0.083	0.125	0.042	0.125	B

HEADWATER DEPTH FOR CIRCULAR PIPE CULVERTS WITH BEVELED RING INLET CONTROL

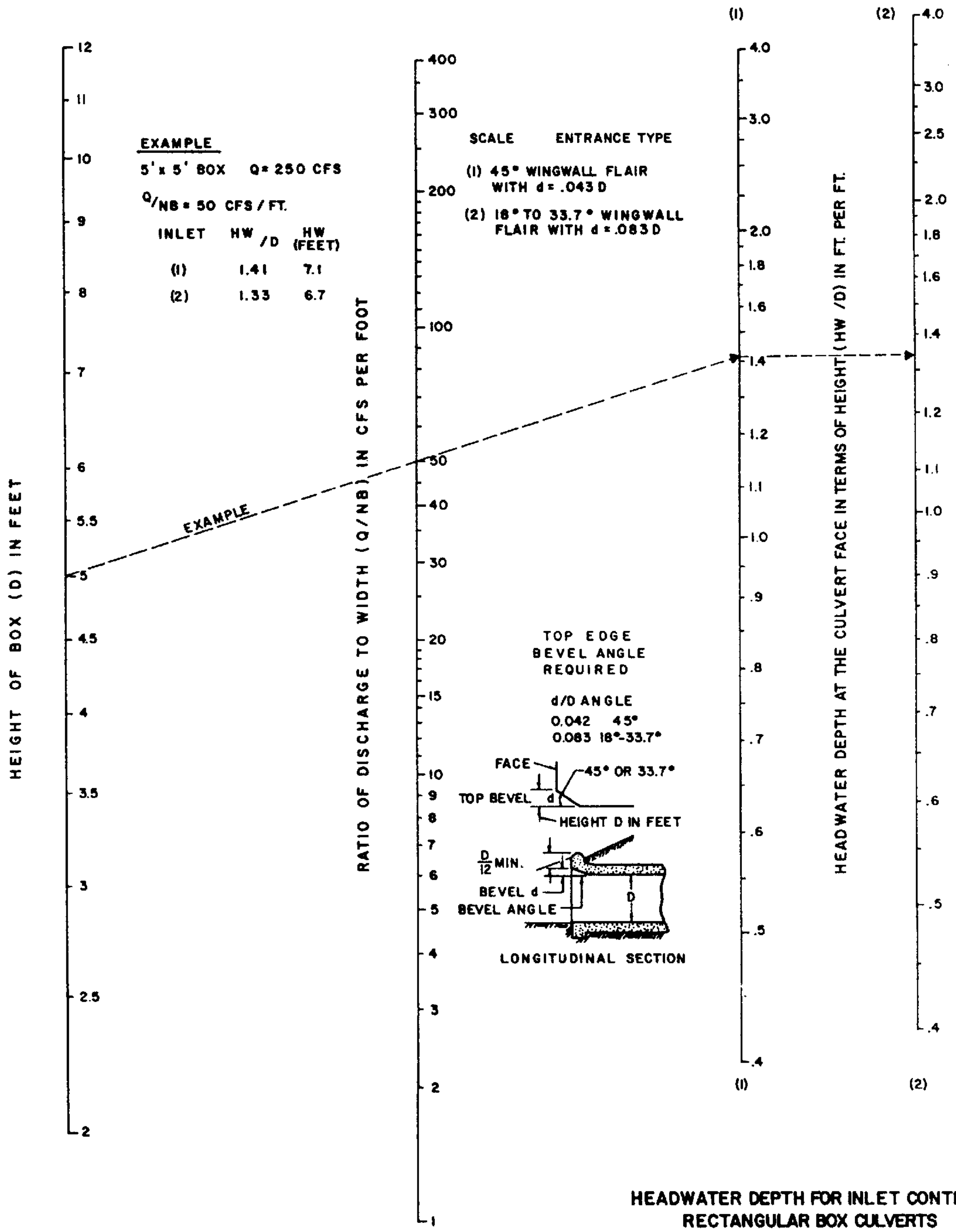
)ERAL HIGHWAY ADMINISTRATION
MAY 1973

CHART 8



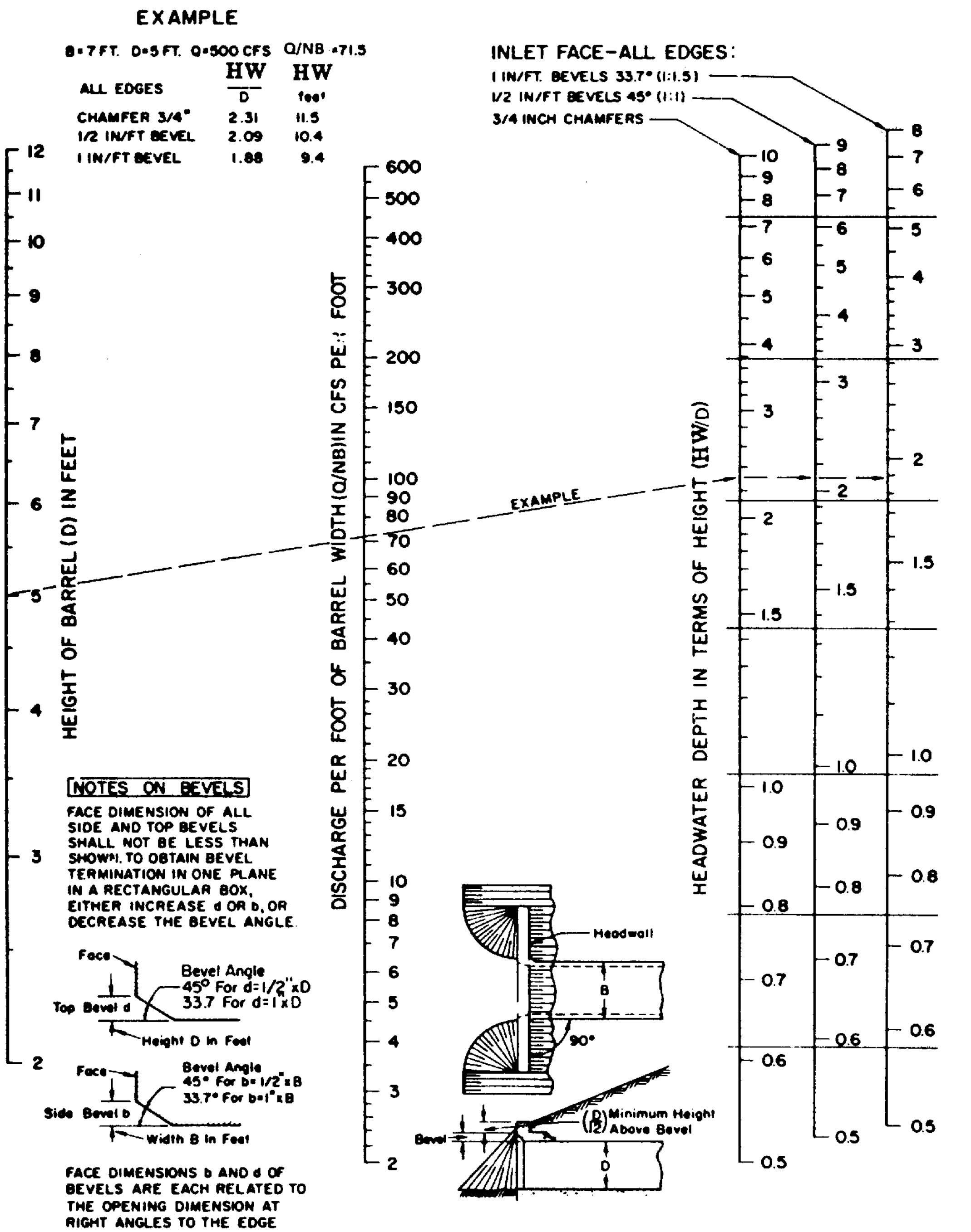
HEADWATER DEPTH FOR BOX CULVERTS WITH INLET CONTROL

BUREAU OF PUBLIC ROADS JAN. 1963



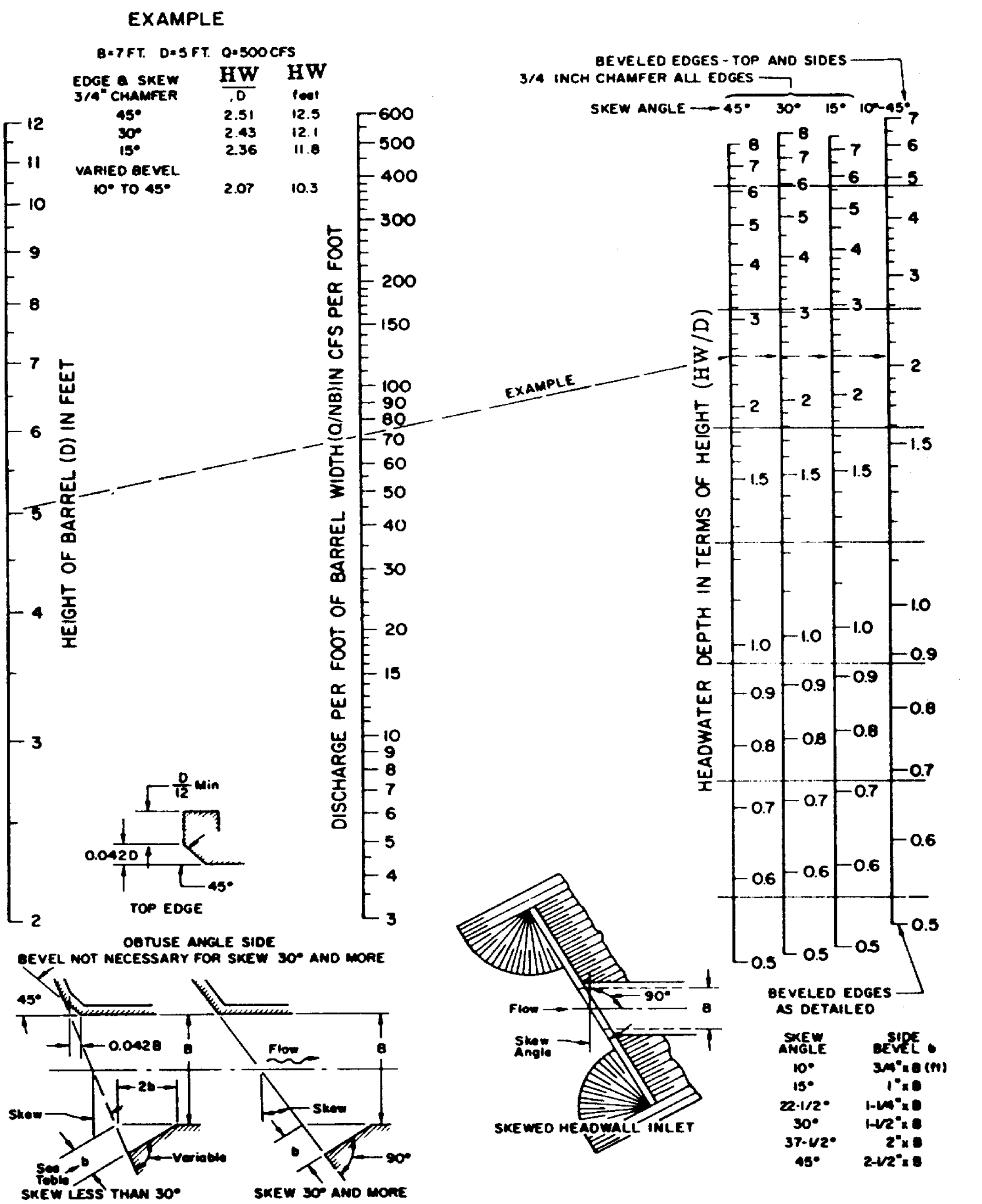
**HEADWATER DEPTH FOR INLET CONTROL
RECTANGULAR BOX CULVERTS
FLARED WINGWALLS 18° TO 33.7° & 45°
WITH BEVELED EDGE AT TOP OF INLET**

CHART 10



HEADWATER DEPTH FOR INLET CONTROL
RECTANGULAR BOX CULVERTS
90° HEADWALL
CHAMFERED OR BEVELED INLET EDGES

FEDERAL HIGHWAY ADMINISTRATION
MAY 1973

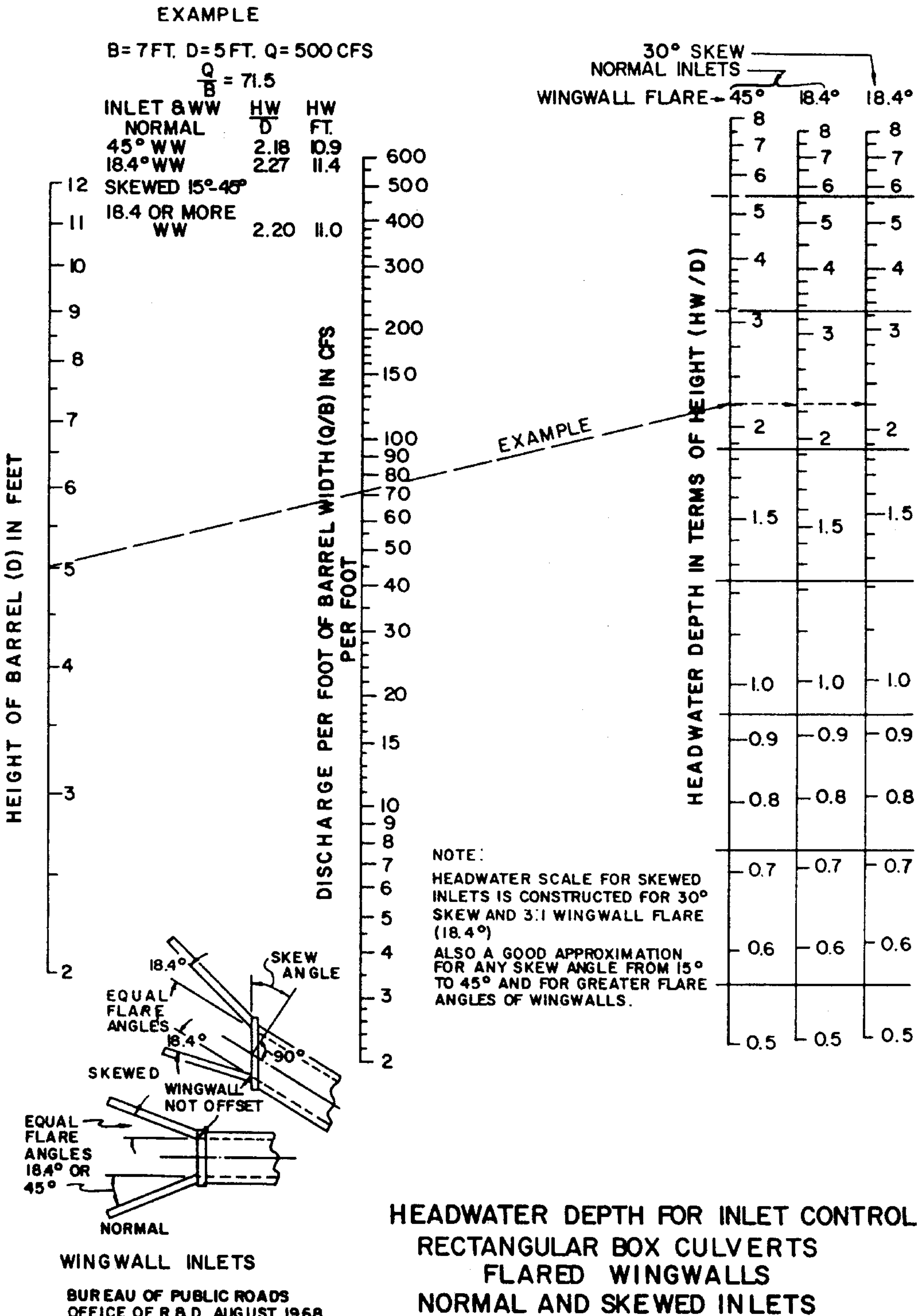


BEVELED INLET EDGES
DESIGNED FOR SAME CAPACITY AT ANY SKEW

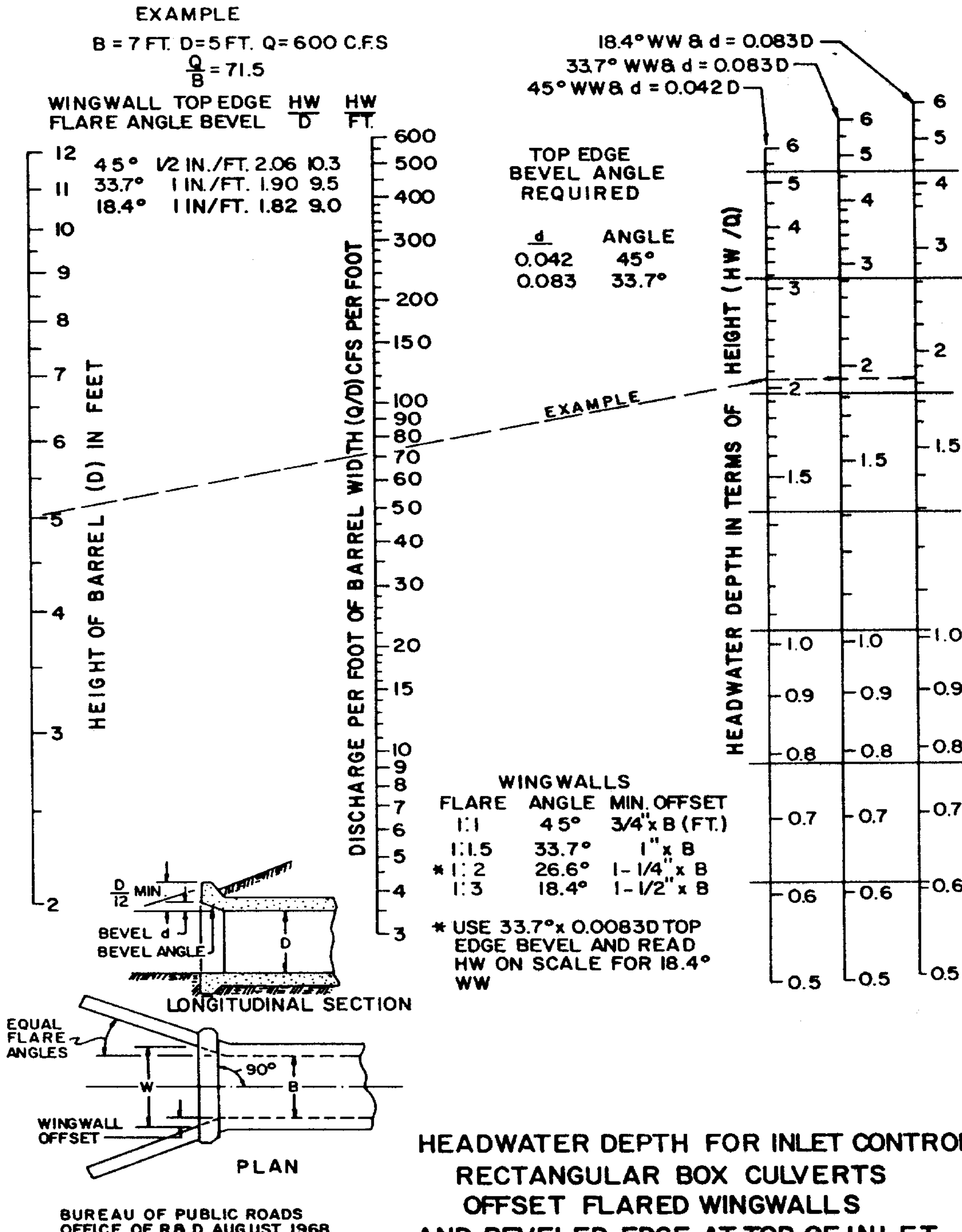
FEDERAL HIGHWAY ADMINISTRATION
MAY 1973

HEADWATER DEPTH FOR INLET CONTROL
SINGLE BARREL BOX CULVERTS
SKEWED HEADWALLS
CHAMFERED OR BEVELED INLET EDGES

CHART 12



HEADWATER DEPTH FOR INLET CONTROL
RECTANGULAR BOX CULVERTS
FLARED WINGWALLS
NORMAL AND SKEWED INLETS
3/4" CHAMFER AT TOP OF OPENING



**HEADWATER DEPTH FOR INLET CONTROL
RECTANGULAR BOX CULVERTS
OFFSET FLARED WINGWALLS
AND BEVELED EDGE AT TOP OF INLET**

Exhibit B

Box Culvert Example

Computer Run

```
*********************************************                    ****************************************
*  HEC-2 WATER SURFACE PROFILES             *                    *  U.S. ARMY CORPS OF ENGINEERS        *
*                                           *                    *  HYDROLOGIC ENGINEERING CENTER       *
*  Version   4.6.0;  February 1991          *                    *  609 SECOND STREET, SUITE D          *
*                                           *                    *  DAVIS, CALIFORNIA 95616-4687        *
*  RUN DATE    06FEB91    TIME  13:50:28    *                    *       (916) 756-1104                 *
*********************************************                    ****************************************


                            X     X  XXXXXXX   XXXXX           XXXXX
                            X     X  X        X     X         X     X
                            X     X  X        X                     X
                            XXXXXXX  XXXX     X        XXXXX   XXXXX
                            X     X  X        X               X
                            X     X  X        X     X         X
                            X     X  XXXXXXX   XXXXX          XXXXXXX

                                      ☼☼☼☼☼☼☼☼☼☼☼☼☼☼☼☼☼☼☼☼☼
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  06FEB91      13:50:28                                                                           PAGE    1

                                                                     THIS RUN EXECUTED 06FEB91    13:50:28
*************************************
 HEC-2 WATER SURFACE PROFILES

 Version   4.6.0;  February 1991
*************************************

T1      SINGLE BOX CULVERT EXAMPLE - with 10 x 6 foot box
T3      SIMPLE CREEK                 Profile 1

J1  ICHECK    INQ       NINV      IDIR      STRT      METRIC    HVINS     Q         WSEL      FQ

               2                           .00015                                   30.0

J2  NPROF     IPLOT     PRFVS     XSECV     XSECH     FN        ALLDC     IBW       CHNIM     ITRACE

      1                  -1

        USE J3 RECORDS TO REQUEST CUSTOM SUMMARY TABLE
        AND REGULAR SPECIAL CULVERT SUMMARY TABLES 101 AND 105

J3  VARIABLE CODES FOR SUMMARY PRINTOUT

     38        66        42         1         2        43        26         4         58
    101       105

        USE NC RECORD TO SET RIVER LOSS COEFFICIENTS

NC      0.1       0.1      0.04       0.1       0.3
QT        3       150       300       400

        CROSS-SECTION 1 OF SPECIAL CULVERT MODEL - DOWNSTREAM OF CULVERT
X1        1        10       975      1042
GR     37.1       865      36.6       903        35       939      33.7       975      24.9      1000
GR     24.9      1011      34.1      1042      35.7      1074      35.7      1106      38.7      1145

        USE NC RECORD TO SET EXPANSION AND CONTRACTION COEFFICIENTS FOR CULVERT

NC                                    0.3       0.5

        CROSS-SECTION 2 OF SPECIAL CULVERT MODEL - AT DOWNSTREAM CULVERT FACE
          LEFT AND RIGHT BANKS REDEFINED TO LIMIT FLOW TO WIDTH OF CULVERT
NH        3       0.1       975      0.04      1042       0.1      1135
X1        2        10      1003      1013       100       100       100
        USE X3 RECORD TO RESTRICT EFFECTIVE FLOW AREA TO CULVERT WIDTH
X3       10                                                                  32.5      32.5
GR     36.9       885      34.9       938      33.5       975      25.2      1003        25      1003
GR       25      1013      25.3      1013      33.7      1042      35.8      1085      38.3      1135

        SC RECORD DEFINES A SINGLE 10X6 CONCRETE BOX CULVERT


                                      ☼☼☼☼☼☼☼☼☼☼☼☼☼☼☼☼☼☼☼☼☼
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SC    1.013       0.4       3.0                 6.0      10.0        50       8.1        25      24.9

        CROSS-SECTION 3 OF SPECIAL CULVERT MODEL - AT UPSTREAM CULVERT FACE
        USE NH FOR N-VALUES AT CROSS-SECTION 3 BECAUSE OF CONCRETE APRON
NH        3       0.1       975      0.04      1042       0.1      1135
X1        3        10      1003      1013        50        50        50
X2                            2                33.3
X3       10                                                                  33.3      33.3
BT       -8       885      36.9                 938      34.9                 975      33.5
BT               1003      33.3                1013      33.3                1042      33.7
BT               1085      35.8                1135      38.3
GR     36.9       885      34.9       938      33.5       975      25.2      1003      25.1      1003
GR     25.1      1013      25.3      1013      33.7      1042      35.8      1085      38.3      1135


NC      0.1       0.1      0.04

        CROSS-SECTION 4 OF SPECIAL CULVERT MODEL - UPSTREAM OF CULVERT
X1        4        10       975      1042        25        25        25
GR     37.1       865      36.6       903        35       939      33.7       975      25.1      1000
GR     25.1      1011      34.1      1042      35.7      1074      37.2      1106      38.7      1145
```

✡✡✡✡✡✡✡✡✡✡✡✡✡✡✡✡✡✡✡✡

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  SECNO      DEPTH      CWSEL      CRIWS      WSELK      EG         HV         HL         OLOSS      L-BANK ELEV
  Q          QLOB       QCH        QROB       ALOB       ACH        AROB       VOL        TWA        R-BANK ELEV
  TIME       VLOB       VCH        VROB       XNL        XNCH       XNR        WTN        ELMIN      SSTA
  SLOPE      XLOBL      XLCH       XLOBR      ITRIAL     IDC        ICONT      CORAR      TOPWID     ENDST

*PROF 1

CCHV=     .100 CEHV=     .300
*SECNO 1.000
    1.000      5.40      30.30        .00      30.00      30.31        .02        .00        .00      33.70
    150.0        .0      150.0         .0         .0      149.9         .0         .0         .0      34.10
      .00       .00       1.00        .00       .000       .040       .000       .000      24.90     984.66
  .000151        0.         0.         0.          0          0          4        .00      44.53    1029.19

CCHV=     .300 CEHV=     .500
1490 NH CARD USED
*SECNO 2.000

3302 WARNING:  CONVEYANCE CHANGE OUTSIDE OF ACCEPTABLE RANGE,  KRATIO =   .47

3495 OVERBANK AREA ASSUMED NON-EFFECTIVE, ELLEA=       32.50 ELREA=       32.50

    2.000      5.27      30.27        .00        .00      30.40        .13        .03        .06      25.20
    150.0        .0      150.0         .0         .0       52.7         .0         .2         .1      25.30
      .01       .00       2.85        .00       .000       .040       .000       .000      25.00    1003.00
  .000682      100.       100.       100.          2          0          0        .00      10.00    1013.00

SPECIAL CULVERT

SC  CUNO       CUNV       ENTLC      COFQ       RDLEN      RISE       SPAN       CULVLN     CHRT       SCL        ELCHU      ELCHD
     1          .013        .40       3.00        .00       6.00      10.00      50.00        8          1        25.00      24.90

CHART  8 - BOX CULVERT WITH FLARED WINGWALLS; NO INLET TOP EDGE BEVEL
SCALE  1 - WINGWALLS FLARED 30 TO 75 DEGREES

1490 NH CARD USED
*SECNO 3.000

SPECIAL CULVERT OUTLET CONTROL
EGIC =     28.021  EGOC =     30.452  PCWSE=     30.272  ELTRD=     33.300

SPECIAL CULVERT

      EGIC       EGOC         H4      QWEIR      QCULV        VCH      ACULV      ELTRD     WEIRLN
     28.02      30.45        .05         0.       150.      2.871       60.0      33.30         0.
```

✡✡✡✡✡✡✡✡✡✡✡✡✡✡✡✡✡✡✡✡

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  SECNO      DEPTH      CWSEL      CRIWS      WSELK      EG         HV         HL         OLOSS      L-BANK ELEV
  Q          QLOB       QCH        QROB       ALOB       ACH        AROB       VOL        TWA        R-BANK ELEV
  TIME       VLOB       VCH        VROB       XNL        XNCH       XNR        WTN        ELMIN      SSTA
  SLOPE      XLOBL      XLCH       XLOBR      ITRIAL     IDC        ICONT      CORAR      TOPWID     ENDST

3495 OVERBANK AREA ASSUMED NON-EFFECTIVE, ELLEA=       33.30 ELREA=       33.30

    3.000      5.22      30.32        .00        .00      30.45        .13        .05        .00      25.20
    150.0        .0      150.0         .0         .0       52.2         .0         .3         .1      25.30
      .01       .00       2.87        .00       .000       .040       .000       .000      25.10    1003.00
  .000686       50.        50.        50.          2          0          0        .00      10.00    1013.00

*SECNO 4.000

3302 WARNING:  CONVEYANCE CHANGE OUTSIDE OF ACCEPTABLE RANGE,  KRATIO =  2.14

    4.000      5.38      30.48        .00        .00      30.49        .02        .01        .03      33.70
    150.0        .0      150.0         .0         .0      151.0         .0         .4         .1      34.10
      .02       .00        .99        .00       .000       .040       .000       .000      25.10     984.37
  .000150       25.        25.        25.          2          0          0        .00      45.15    1029.52
```

✡✡✡✡✡✡✡✡✡✡✡✡✡✡✡✡✡✡✡✡

06FEB91 13:50:28 PAGE 5

T1 SINGLE BOX CULVERT EXAMPLE - Profile 2

J1 ICHECK	INQ	NINV	IDIR	STRT	METRIC	HVINS	Q	WSEL	FQ
	3			.00015				32.0	

J2 NPROF	IPLOT	PRFVS	XSECV	XSECH	FN	ALLDC	IBW	CHNIM	ITRACE
2		-1							

```
                                                         ********************

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    SECNO      DEPTH      CWSEL      CRIWS      WSELK      EG         HV         HL         OLOSS      L-BANK ELEV
    Q          QLOB       QCH        QROB       ALOB       ACH        AROB       VOL        TWA        R-BANK ELEV
    TIME       VLOB       VCH        VROB       XNL        XNCH       XNR        WTN        ELMIN      SSTA
    SLOPE      XLOBL      XLCH       XLOBR      ITRIAL     IDC        ICONT      CORAR      TOPWID     ENDST

*PROF 2

CCHV=     .100 CEHV=      .300
*SECNO 1.000
     1.000       7.40      32.30        .00      32.00      32.32        .02        .00        .00      33.70
     300.0         .0      300.0         .0         .0      251.2         .0         .0         .0      34.10
       .00        .00       1.19        .00       .000       .040       .000       .000      24.90     978.99
   .000151         0.         0.         0.          0          0          4        .00      56.93    1035.92


CCHV=     .300 CEHV=      .500
1490 NH CARD USED
*SECNO 2.000

3302 WARNING:  CONVEYANCE CHANGE OUTSIDE OF ACCEPTABLE RANGE,  KRATIO =   .40


3495 OVERBANK AREA ASSUMED NON-EFFECTIVE, ELLEA=       32.50 ELREA=        32.50

     2.000       7.20      32.20        .00        .00      32.47        .27        .03        .12      25.20
     300.0         .0      300.0         .0         .0       72.0         .0         .4         .1      25.30
       .01        .00       4.17        .00       .000       .040       .000       .000      25.00    1003.00
   .000964       100.       100.       100.          2          0          0        .00      10.00    1013.00


SPECIAL CULVERT

SC  CUNO       CUNV       ENTLC      COFQ       RDLEN      RISE       SPAN       CULVLN     CHRT       SCL        ELCHU      ELCHD
     1          .013        .40       3.00        .00       6.00      10.00      50.00      8          1          25.00      24.90

CHART  8 - BOX CULVERT WITH FLARED WINGWALLS; NO INLET TOP EDGE BEVEL
SCALE  1 - WINGWALLS FLARED 30 TO 75 DEGREES

1490 NH CARD USED
*SECNO 3.000

SPECIAL CULVERT OUTLET CONTROL
EGIC =     29.865  EGOC =      32.787  PCWSE=      32.203  ELTRD=      33.300

SPECIAL CULVERT

     EGIC       EGOC         H4      QWEIR      QCULV        VCH      ACULV      ELTRD     WEIRLN
     29.86      32.79        .32         0.       300.      4.035       60.0      33.30         0.


                                                         ********************


   06FEB91      13:50:28                                                                                                    PAGE    7

    SECNO      DEPTH      CWSEL      CRIWS      WSELK      EG         HV         HL         OLOSS      L-BANK ELEV
    Q          QLOB       QCH        QROB       ALOB       ACH        AROB       VOL        TWA        R-BANK ELEV
    TIME       VLOB       VCH        VROB       XNL        XNCH       XNR        WTN        ELMIN      SSTA
    SLOPE      XLOBL      XLCH       XLOBR      ITRIAL     IDC        ICONT      CORAR      TOPWID     ENDST

3495 OVERBANK AREA ASSUMED NON-EFFECTIVE, ELLEA=       33.30 ELREA=        33.30

     3.000       7.43      32.53        .00        .00      32.79        .25        .32        .00      25.20
     300.0         .0      300.0         .0         .0       74.4         .0         .5         .1      25.30
       .01        .00       4.03        .00       .000       .040       .000       .000      25.10    1003.00
   .000845        50.        50.        50.          2          0          0        .00      10.00    1013.00

*SECNO 4.000

3302 WARNING:  CONVEYANCE CHANGE OUTSIDE OF ACCEPTABLE RANGE,  KRATIO =  2.67

     4.000       7.75      32.85        .00        .00      32.86        .02        .01        .07      33.70
     300.0         .0      300.0         .0         .0      275.7         .0         .6         .1      34.10
       .02        .00       1.09        .00       .000       .040       .000       .000      25.10     977.48
   .000119        25.        25.        25.          2          0          0        .00      60.20    1037.68


                                                         ********************


   06FEB91      13:50:28                                                                                                    PAGE    8

T1       SINGLE BOX CULVERT EXAMPLE - Profile 3

J1  ICHECK     INQ        NINV       IDIR       STRT       METRIC     HVINS      Q          WSEL       FQ

                4                             .00015                                        34.0

J2  NPROF      IPLOT      PRFVS      XSECV      XSECH      FN         ALLDC      IBW        CHNIM      ITRACE

       3                    -1


                                                         ********************


   06FEB91      13:50:28                                                                                                    PAGE    9

    SECNO      DEPTH      CWSEL      CRIWS      WSELK      EG         HV         HL         OLOSS      L-BANK ELEV
    Q          QLOB       QCH        QROB       ALOB       ACH        AROB       VOL        TWA        R-BANK ELEV
    TIME       VLOB       VCH        VROB       XNL        XNCH       XNR        WTN        ELMIN      SSTA
    SLOPE      XLOBL      XLCH       XLOBR      ITRIAL     IDC        ICONT      CORAR      TOPWID     ENDST
```

```
*PROF 3

CCHV=     .100 CEHV=      .300
*SECNO 1.000
     1.000      8.42     33.32       .00     34.00     33.34       .03       .00       .00     33.70
     400.0        .0     400.0        .0        .0     312.5        .0        .0        .0     34.10
       .00       .00      1.28       .00      .000      .040      .000      .000     24.90    976.09
   .000149        0.        0.        0.         0         0         4       .00     63.27   1039.36


CCHV=     .300 CEHV=      .500
1490 NH CARD USED
*SECNO 2.000
     2.000      8.33     33.33       .00       .00     33.36       .03       .01       .00     25.20
     400.0     125.3     150.4     124.3     111.5      83.3     111.3        .7        .1     25.30
       .02      1.12      1.81      1.12      .040      .040      .040      .000     25.00    975.57
   .000149      100.      100.      100.         0         0         0       .00     65.16   1040.73

SPECIAL CULVERT

SC  CUNO       CUNV      ENTLC     COFQ      RDLEN     RISE      SPAN      CULVLN    CHRT      SCL       ELCHU     ELCHD
     1          .013      .40      3.00       .00      6.00     10.00     50.00     8         1         25.00     24.90

CHART  8 - BOX CULVERT WITH FLARED WINGWALLS; NO INLET TOP EDGE BEVEL
SCALE  1 - WINGWALLS FLARED 30 TO 75 DEGREES

1490 NH CARD USED
*SECNO 3.000
SPECIAL CULVERT

     EGIC      EGOC        H4     QWEIR     QCULV       VCH     ACULV     ELTRD    WEIRLN
     30.93     34.37       .62       87.      316.     1.585      60.0     33.30       85.


     3.000      8.85     33.95       .00       .00     33.98       .02       .62       .00     25.20
     400.0     131.1     140.3     128.5     131.6      88.5     129.8       1.1        .2     25.30
       .03      1.00      1.59       .99      .040      .040      .040      .000     25.10    963.06
   .000103       50.       50.       50.         2         0         0       .00     84.10   1047.16


*SECNO 4.000
     4.000      8.86     33.96       .00       .00     33.98       .02       .00       .00     33.70
     400.0        .0     400.0        .0        .9     346.3        .0       1.3        .3     34.10
       .04       .04      1.15       .00      .100      .040      .000      .000     25.10    967.94
   .000113       25.       25.       25.         0         0         0       .00     73.56   1041.50
```

✧✧✧✧✧✧✧✧✧✧✧✧✧✧✧✧✧✧✧✧

06FEB91 13:50:28 PAGE 10

THIS RUN EXECUTED 06FEB91 13:50:34

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**************************************
 HEC-2 WATER SURFACE PROFILES

 Version   4.6.0;  February 1991
**************************************
```

NOTE- ASTERISK (*) AT LEFT OF CROSS-SECTION NUMBER INDICATES MESSAGE IN SUMMARY OF ERRORS LIST

SIMPLE CREEK

SUMMARY PRINTOUT

	SECNO	CUMDS	ELMIN	CWSEL	CRIWS	Q	VCH	TOPWID	KRATIO
	1.000	.00	24.90	30.30	.00	150.00	1.00	44.53	.00
	1.000	.00	24.90	32.30	.00	300.00	1.19	56.93	.00
	1.000	.00	24.90	33.32	.00	400.00	1.28	63.27	.00
*	2.000	100.00	25.00	30.27	.00	150.00	2.85	10.00	.47
*	2.000	100.00	25.00	32.20	.00	300.00	4.17	10.00	.40
	2.000	100.00	25.00	33.33	.00	400.00	1.81	65.16	1.00
	3.000	150.00	25.10	30.32	.00	150.00	2.87	10.00	1.00
	3.000	150.00	25.10	32.53	.00	300.00	4.03	10.00	1.07
	3.000	150.00	25.10	33.95	.00	400.00	1.59	84.10	1.20
*	4.000	175.00	25.10	30.48	.00	150.00	.99	45.15	2.14
*	4.000	175.00	25.10	32.85	.00	300.00	1.09	60.20	2.67
	4.000	175.00	25.10	33.96	.00	400.00	1.15	73.56	.96

✧✧✧✧✧✧✧✧✧✧✧✧✧✧✧✧✧✧✧✧

06FEB91 13:50:28 PAGE 11

SIMPLE CREEK

SUMMARY PRINTOUT TABLE 101

SECNO	EGOC	ELLC	EGIC	ELTRD	QCULV	QWEIR	CLASS	H4	DEPTH	CWSEL	VCH	EG
3.000	30.45	.00	28.02	33.30	150.00	.00	7.00	.05	5.22	30.32	2.87	30.45
3.000	32.79	.00	29.86	33.30	300.00	.00	7.00	.32	7.43	32.53	4.03	32.79
3.000	34.37	.00	30.93	33.30	315.60	87.11	17.00	.62	8.85	33.95	1.59	33.98

☼☼☼☼☼☼☼☼☼☼☼☼☼☼☼☼☼☼☼☼☼☼

SIMPLE CREEK

SUMMARY PRINTOUT TABLE 105

	SECNO	CWSEL	HL	OLOSS	TOPWID	QLOB	QCH	QROB
	1.000	30.30	.00	.00	44.53	.00	150.00	.00
	1.000	32.30	.00	.00	56.93	.00	300.00	.00
	1.000	33.32	.00	.00	63.27	.00	400.00	.00
*	2.000	30.27	.03	.06	10.00	.00	150.00	.00
*	2.000	32.20	.03	.12	10.00	.00	300.00	.00
	2.000	33.33	.01	.00	65.16	125.34	150.40	124.26
	3.000	30.32	.05	.00	10.00	.00	150.00	.00
	3.000	32.53	.32	.00	10.00	.00	300.00	.00
	3.000	33.95	.62	.00	84.10	131.12	140.33	128.54
*	4.000	30.48	.01	.03	45.15	.00	150.00	.00
*	4.000	32.85	.01	.07	60.20	.00	300.00	.00
	4.000	33.96	.00	.00	73.56	.04	399.96	.00

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SUMMARY OF ERRORS AND SPECIAL NOTES

```
WARNING SECNO=      2.000  PROFILE=  1  CONVEYANCE CHANGE OUTSIDE ACCEPTABLE RANGE
WARNING SECNO=      2.000  PROFILE=  2  CONVEYANCE CHANGE OUTSIDE ACCEPTABLE RANGE

WARNING SECNO=      4.000  PROFILE=  1  CONVEYANCE CHANGE OUTSIDE ACCEPTABLE RANGE
WARNING SECNO=      4.000  PROFILE=  2  CONVEYANCE CHANGE OUTSIDE ACCEPTABLE RANGE
```

Exhibit C

Pipe Culvert Example

Computer Run

```
*********************************************                    ****************************************
*  HEC-2 WATER SURFACE PROFILES             *                    *  U.S. ARMY CORPS OF ENGINEERS        *
*                                           *                    *  HYDROLOGIC ENGINEERING CENTER       *
*  Version   4.6.0;  February 1991          *                    *  609 SECOND STREET, SUITE D          *
*                                           *                    *  DAVIS, CALIFORNIA 95616-4687        *
*  RUN DATE    06FEB91    TIME   13:52:23   *                    *         (916) 756-1104               *
*********************************************                    ****************************************
```

```
X     X  XXXXXXX   XXXXX           XXXXX
X     X  X        X     X         X     X
X     X  X        X                     X
XXXXXXX  XXXX     X         XXXXX   XXXXX
X     X  X        X                X
X     X  X        X     X          X
X     X  XXXXXXX   XXXXX           XXXXXXX
```



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                                                                THIS RUN EXECUTED 06FEB91    13:52:24
**************************************
 HEC-2 WATER SURFACE PROFILES

 Version   4.6.0;  February 1991
**************************************

T1       SINGLE PIPE CULVERT EXAMPLE - Seven foot pipe
T3       EASY CREEK                        Profile 1

J1  ICHECK    INQ       NINV      IDIR      STRT      METRIC    HVINS     Q         WSEL      FQ

               2                           .00015                                   31.0

J2  NPROF     IPLOT     PRFVS     XSECV     XSECH     FN        ALLDC     IBW       CHNIM     ITRACE

     1                  -1


           USE J3 RECORDS TO REQUEST CUSTOM SUMMARY TABLE
         AND REGULAR SPECIAL CULVERT SUMMARY TABLES 101 AND 105

J3  VARIABLE CODES FOR SUMMARY PRINTOUT

     38        66        42         1         2        43        26         4         58
    101       105

         USE NC RECORD TO SET RIVER LOSS COEFFICIENTS

NC       0.1       0.1      0.04       0.1       0.3
QT         3       200       280       400

         CROSS-SECTION 1 OF SPECIAL CULVERT MODEL - DOWNSTREAM OF CULVERT
X1         1        10       975      1042
GR      37.1       865      36.6       903        35       939      33.7       975      24.9      1000
GR      24.9      1011      34.1      1042      35.7      1074      35.7      1106      38.7      1145

         USE NC RECORD TO SET EXPANSION AND CONTRACTION COEFFICIENTS FOR CULVERT

NC                                     0.3       0.5
         CROSS-SECTION 2 OF SPECIAL CULVERT MODEL - AT DOWNSTREAM CULVERT FACE
           LEFT AND RIGHT BANKS REDEFINED TO LIMIT FLOW TO WIDTH OF CULVERT
NH         3        .1       975       .04      1042        .1      1145
X1         2        12      1003      1010       100       100       100
         USE X3 RECORD TO RESTRICT EFFECTIVE FLOW AREA TO CULVERT WIDTH
X3        10                                                                  32.2      32.2
GR      37.1       865      36.6       903        35       939      33.7       975        25      1000
GR        25      1003        25      1010        25      1011      34.1      1042      35.7      1074
GR      37.2      1106      38.7      1145

         SC RECORD DEFINES A SINGLE 84-INCH CONCRETE PIPE CULVERT
```



```
SC     1.013       0.5       3.0                 7.0                  50       1.1      25.1      25.0

NH         3        .1       975       .04      1042        .1      1145
         CROSS-SECTION 3 AT UPSTREAM CULVERT FACE - FLOW LIMITED TO CULVERT WIDTH
X1         3        12      1003      1010        50        50        50
X2                             2                33.3
X3        10                                                                  33.3      33.3
BT       -10       865      37.1                 903      36.6                 939        35
BT                 975      33.7                1003      33.7                1010      33.7
BT                1042      34.1                1074      35.7                1106      37.2
BT                1145      38.7
GR      37.1       865      36.6       903        35       939      33.7       975      25.1      1000
GR      25.1      1003      25.1      1010      25.1      1011      34.1      1042      35.7      1074
GR      37.2      1106      38.7      1145

NC       0.1       0.1       .04

         CROSS-SECTION 4 - A FULL-FLOW SECTION UPSTREAM FROM THE CULVERT
X1         4        10       975      1042        25        25        25
GR      37.1       865      36.6       903        35       939      33.7       975      25.1      1000
GR      25.1      1011      34.1      1042      35.7      1074      37.2      1106      38.7      1145
```

```
   06FEB91      13:52:24                                                                                          PAGE    3

    SECNO      DEPTH      CWSEL      CRIWS      WSELK      EG         HV         HL         OLOSS      L-BANK ELEV
    Q          QLOB       QCH        QROB       ALOB       ACH        AROB       VOL        TWA        R-BANK ELEV
    TIME       VLOB       VCH        VROB       XNL        XNCH       XNR        WTN        ELMIN      SSTA
    SLOPE      XLOBL      XLCH       XLOBR      ITRIAL     IDC        ICONT      CORAR      TOPWID     ENDST

*PROF 1

CCHV=     .100 CEHV=     .300
*SECNO 1.000
     1.000      6.16      31.06       .00      31.00      31.08        .02        .00        .00      33.70
     200.0        .0      200.0        .0         .0      185.5         .0         .0         .0      34.10
       .00       .00       1.08       .00       .000       .040       .000       .000      24.90     982.51
   .000151        0.         0.        0.          0          0          3        .00      49.24    1031.75


CCHV=     .300 CEHV=     .500
1490 NH CARD USED
*SECNO 2.000

3302 WARNING:  CONVEYANCE CHANGE OUTSIDE OF ACCEPTABLE RANGE,  KRATIO =   .31


3495 OVERBANK AREA ASSUMED NON-EFFECTIVE, ELLEA=       32.20 ELREA=       32.20

     2.000      5.92      30.92       .00        .00      31.28        .36        .04        .17      25.00
     200.0        .0      200.0        .0         .0       41.5         .0         .3         .1      25.00
       .01       .00       4.83       .00       .000       .040       .000       .000      25.00    1003.00
   .001574      100.       100.      100.          2          0          0        .00       7.00    1010.00


SPECIAL CULVERT

SC  CUNO       CUNV       ENTLC      COFQ       RDLEN      RISE       SPAN       CULVLN     CHRT       SCL        ELCHU      ELCHD
     1          .013        .50       3.00        .00       7.00        .00      50.00      1          1          25.10      25.00

CHART  1 - CONCRETE PIPE CULVERT; NO BEVELED RING ENTRANCE
SCALE  1 - SQUARE EDGE ENTRANCE WITH HEADWALL

1490 NH CARD USED
*SECNO 3.000

SPECIAL CULVERT OUTLET CONTROL
EGIC =     30.515  EGOC =     31.746  PCWSE=     30.921  ELTRD=      33.700

SPECIAL CULVERT

     EGIC       EGOC         H4      QWEIR      QCULV        VCH      ACULV      ELTRD     WEIRLN
     30.52      31.75        .46        0.       200.      4.513       38.5      33.70         0.


   06FEB91      13:52:24                                                                                          PAGE    4

    SECNO      DEPTH      CWSEL      CRIWS      WSELK      EG         HV         HL         OLOSS      L-BANK ELEV
    Q          QLOB       QCH        QROB       ALOB       ACH        AROB       VOL        TWA        R-BANK ELEV
    TIME       VLOB       VCH        VROB       XNL        XNCH       XNR        WTN        ELMIN      SSTA
    SLOPE      XLOBL      XLCH       XLOBR      ITRIAL     IDC        ICONT      CORAR      TOPWID     ENDST

3495 OVERBANK AREA ASSUMED NON-EFFECTIVE, ELLEA=       33.30 ELREA=       33.30

     3.000      6.33      31.43       .00        .00      31.75        .32        .46        .00      25.10
     200.0        .0      200.0        .0         .0       44.3         .0         .3         .1      25.10
       .01       .00       4.51       .00       .000       .040       .000       .000      25.10    1003.00
   .001260       50.        50.       50.          2          0          0        .00       7.00    1010.00


*SECNO 4.000

3302 WARNING:  CONVEYANCE CHANGE OUTSIDE OF ACCEPTABLE RANGE,  KRATIO =  3.56

     4.000      6.73      31.83       .00        .00      31.84        .01        .01        .09      33.70
     200.0        .0      200.0        .0         .0      217.9         .0         .4         .1      34.10
       .02       .00        .92       .00       .000       .040       .000       .000      25.10     980.44
   .000099       25.        25.       25.          2          0          0        .00      53.74    1034.18


   06FEB91      13:52:24                                                                                          PAGE    5

T1      SINGLE PIPE CULVERT EXAMPLE - Profile 2

J1  ICHECK     INQ        NINV       IDIR       STRT       METRIC     HVINS      Q          WSEL       FQ

                 3                             .00015                                       32.5

J2  NPROF      IPLOT      PRFVS      XSECV      XSECH      FN         ALLDC      IBW        CHNIM      ITRACE

      2                     -1
```

```
   06FEB91      13:52:24                                                                                                      PAGE    6

    SECNO       DEPTH       CWSEL       CRIWS       WSELK       EG          HV          HL          OLOSS       L-BANK ELEV
    Q           QLOB        QCH         QROB        ALOB        ACH         AROB        VOL         TWA         R-BANK ELEV
    TIME        VLOB        VCH         VROB        XNL         XNCH        XNR         WTN         ELMIN       SSTA
    SLOPE       XLOBL       XLCH        XLOBR       ITRIAL      IDC         ICONT       CORAR       TOPWID      ENDST

*PROF 2

CCHV=      .100 CEHV=       .300
*SECNO 1.000
      1.000        7.19       32.09         .00       32.50       32.11         .02         .00         .00       33.70
      280.0          .0       280.0          .0          .0       239.7          .0          .0          .0       34.10
        .00         .00        1.17         .00        .000        .040        .000        .000       24.90      979.57
    .000149          0.          0.          0.           0           0           4         .00       55.66     1035.23

CCHV=      .300 CEHV=       .500
1490 NH CARD USED
*SECNO 2.000

3301 HV CHANGED MORE THAN HVINS


3302 WARNING:  CONVEYANCE CHANGE OUTSIDE OF ACCEPTABLE RANGE,  KRATIO =   .28


3495 OVERBANK AREA ASSUMED NON-EFFECTIVE, ELLEA=       32.20 ELREA=       32.20

      2.000        6.87       31.87         .00         .00       32.40         .53         .04         .25       25.00
      280.0          .0       280.0          .0          .0        48.1          .0          .3          .1       25.00
        .00         .00        5.82         .00        .000        .040        .000        .000       25.00     1003.00
    .001876        100.        100.        100.           2           0           0         .00        7.00     1010.00

SPECIAL CULVERT

SC  CUNO        CUNV        ENTLC       COFQ        RDLEN       RISE        SPAN        CULVLN      CHRT        SCL         ELCHU       ELCHD
     1          .013         .50        3.00         .00        7.00         .00        50.00       1           1          25.10       25.00

CHART  1 - CONCRETE PIPE CULVERT; NO BEVELED RING ENTRANCE
SCALE  1 - SQUARE EDGE ENTRANCE WITH HEADWALL

1490 NH CARD USED
*SECNO 3.000

SPECIAL CULVERT OUTLET CONTROL
EGIC =      31.888  EGOC =      33.204  PCWSE=      31.875  ELTRD=      33.700


   06FEB91      13:52:24                                                                                                      PAGE    7

    SECNO       DEPTH       CWSEL       CRIWS       WSELK       EG          HV          HL          OLOSS       L-BANK ELEV
    Q           QLOB        QCH         QROB        ALOB        ACH         AROB        VOL         TWA         R-BANK ELEV
    TIME        VLOB        VCH         VROB        XNL         XNCH        XNR         WTN         ELMIN       SSTA
    SLOPE       XLOBL       XLCH        XLOBR       ITRIAL      IDC         ICONT       CORAR       TOPWID      ENDST

SPECIAL CULVERT

      EGIC        EGOC          H4       QWEIR       QCULV         VCH       ACULV       ELTRD      WEIRLN
     31.89       33.20         .80          0.        280.       5.205        38.5       33.70          0.

3495 OVERBANK AREA ASSUMED NON-EFFECTIVE, ELLEA=       33.30 ELREA=       33.30

      3.000        7.68       32.78         .00         .00       33.20         .42         .80         .00       25.10
      280.0          .0       280.0          .0          .0        53.8          .0          .4          .1       25.10
        .01         .00        5.20         .00        .000        .040        .000        .000       25.10     1003.00
    .001294         50.         50.         50.           2           0           0         .00        7.00     1010.00

*SECNO 4.000

3302 WARNING:  CONVEYANCE CHANGE OUTSIDE OF ACCEPTABLE RANGE,  KRATIO =  4.05

      4.000        8.22       33.32         .00         .00       33.33         .01         .01         .12       33.70
      280.0          .0       280.0          .0          .0       304.9          .0          .5          .1       34.10
        .02         .00         .92         .00        .000        .040        .000        .000       25.10      976.11
    .000079         25.         25.         25.           2           0           0         .00       63.20     1039.31


   06FEB91      13:52:24                                                                                                      PAGE    8

T1      SINGLE PIPE CULVERT EXAMPLE - Profile 3

J1  ICHECK      INQ         NINV        IDIR        STRT        METRIC      HVINS       Q           WSEL        FQ

                 4                                 .00015                                           33.5

J2  NPROF       IPLOT       PRFVS       XSECV       XSECH       FN          ALLDC       IBW         CHNIM       ITRACE

     3                      -1
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06FEB91      13:52:24                                                                                               PAGE    9

     SECNO     DEPTH     CWSEL     CRIWS     WSELK     EG        HV        HL        OLOSS     L-BANK ELEV
     Q         QLOB      QCH       QROB      ALOB      ACH       AROB      VOL       TWA       R-BANK ELEV
     TIME      VLOB      VCH       VROB      XNL       XNCH      XNR       WTN       ELMIN     SSTA
     SLOPE     XLOBL     XLCH      XLOBR     ITRIAL    IDC       ICONT     CORAR     TOPWID    ENDST


*PROF 3

CCHV=     .100 CEHV=     .300
*SECNO 1.000
     1.000      8.37     33.27       .00     33.50     33.30       .03       .00       .00     33.70
     400.0        .0     400.0        .0        .0     309.7        .0        .0        .0     34.10
       .00       .00      1.29       .00      .000      .040      .000      .000     24.90    976.22
   .000153        0.        0.        0.         0         0         3       .00     62.99   1039.21


CCHV=     .300 CEHV=     .500
1490 NH CARD USED
*SECNO 2.000
     2.000      8.28     33.28       .00       .00     33.31       .03       .01       .00     25.00
     400.0     152.1     104.2     143.7     123.5      58.0     125.3        .7        .1     25.00
       .02      1.23      1.80      1.15      .040      .040      .040      .000     25.00    976.19
   .000139      100.      100.      100.         0         0         0       .00     63.04   1039.23

SPECIAL CULVERT

SC  CUNO       CUNV      ENTLC     COFQ      RDLEN     RISE      SPAN      CULVLN    CHRT      SCL       ELCHU     ELCHD
     1         .013       .50      3.00       .00      7.00       .00     50.00     1         1         25.10     25.00

CHART  1 - CONCRETE PIPE CULVERT; NO BEVELED RING ENTRANCE
SCALE  1 - SQUARE EDGE ENTRANCE WITH HEADWALL

1490 NH CARD USED
*SECNO 3.000
SPECIAL CULVERT

      EGIC      EGOC        H4     QWEIR     QCULV       VCH     ACULV     ELTRD    WEIRLN
     34.17     36.00      1.17      133.      266.     1.430      38.5     33.70       96.


     3.000      9.36     34.46       .00       .00     34.48       .02      1.17       .00     25.10
     400.0     156.8      93.8     149.4     163.2      65.6     161.8       1.1        .2     25.10
       .03       .96      1.43       .92      .040      .040      .040      .000     25.10    953.61
   .000075       50.       50.       50.         1         0         0       .00     95.83   1049.45


*SECNO 4.000
     4.000      9.37     34.47       .00       .00     34.48       .02       .00       .00     33.70
     400.0        .6     399.4        .1       8.1     380.5       1.3       1.3        .3     34.10
       .04       .07      1.05       .04      .100      .040      .100      .000     25.10    953.79
   .000083       25.       25.       25.         0         0         0       .00     95.53   1049.32
```

```
06FEB91      13:52:24                                                                                               PAGE   10

                                                                                     THIS RUN EXECUTED 06FEB91    13:52:30
*************************************
 HEC-2 WATER SURFACE PROFILES

 Version   4.6.0;  February 1991
*************************************


NOTE- ASTERISK (*) AT LEFT OF CROSS-SECTION NUMBER INDICATES MESSAGE IN SUMMARY OF ERRORS LIST


EASY CREEK

SUMMARY PRINTOUT


      SECNO     CUMDS     ELMIN     CWSEL     CRIWS         Q       VCH    TOPWID    KRATIO

      1.000       .00     24.90     31.06       .00    200.00      1.08     49.24       .00
      1.000       .00     24.90     32.09       .00    280.00      1.17     55.66       .00
      1.000       .00     24.90     33.27       .00    400.00      1.29     62.99       .00

*     2.000    100.00     25.00     30.92       .00    200.00      4.83      7.00       .31
*     2.000    100.00     25.00     31.87       .00    280.00      5.82      7.00       .28
      2.000    100.00     25.00     33.28       .00    400.00      1.80     63.04      1.05

      3.000    150.00     25.10     31.43       .00    200.00      4.51      7.00      1.12
      3.000    150.00     25.10     32.78       .00    280.00      5.20      7.00      1.20
      3.000    150.00     25.10     34.46       .00    400.00      1.43     95.83      1.36

*     4.000    175.00     25.10     31.83       .00    200.00       .92     53.74      3.56
*     4.000    175.00     25.10     33.32       .00    280.00       .92     63.20      4.05
      4.000    175.00     25.10     34.47       .00    400.00      1.05     95.53       .95
```

✡✡✡✡✡✡✡✡✡✡✡✡✡✡✡✡✡✡✡✡

06FEB91 13:52:24 PAGE 11

EASY CREEK

SUMMARY PRINTOUT TABLE 101

SECNO	EGOC	ELLC	EGIC	ELTRD	QCULV	QWEIR	CLASS	H4	DEPTH	CWSEL	VCH	EG
3.000	31.75	.00	30.52	33.70	200.00	.00	7.00	.46	6.33	31.43	4.51	31.75
3.000	33.20	.00	31.89	33.70	280.00	.00	7.00	.80	7.68	32.78	5.20	33.20
3.000	36.00	.00	34.17	33.70	265.68	132.80	17.00	1.17	9.36	34.46	1.43	34.48

✡✡✡✡✡✡✡✡✡✡✡✡✡✡✡✡✡✡✡✡

06FEB91 13:52:24 PAGE 12

EASY CREEK

SUMMARY PRINTOUT TABLE 105

	SECNO	CWSEL	HL	OLOSS	TOPWID	QLOB	QCH	QROB
	1.000	31.06	.00	.00	49.24	.00	200.00	.00
	1.000	32.09	.00	.00	55.66	.00	280.00	.00
	1.000	33.27	.00	.00	62.99	.00	400.00	.00
*	2.000	30.92	.04	.17	7.00	.00	200.00	.00
*	2.000	31.87	.04	.25	7.00	.00	280.00	.00
	2.000	33.28	.01	.00	63.04	152.14	104.20	143.66
	3.000	31.43	.46	.00	7.00	.00	200.00	.00
	3.000	32.78	.80	.00	7.00	.00	280.00	.00
	3.000	34.46	1.17	.00	95.83	156.79	93.82	149.39
*	4.000	31.83	.01	.09	53.74	.00	200.00	.00
*	4.000	33.32	.01	.12	63.20	.00	280.00	.00
	4.000	34.47	.00	.00	95.53	.58	399.36	.06

✡✡✡✡✡✡✡✡✡✡✡✡✡✡✡✡✡✡✡✡

06FEB91 13:52:24 PAGE 13

SUMMARY OF ERRORS AND SPECIAL NOTES

```
WARNING SECNO=      2.000  PROFILE=  1  CONVEYANCE CHANGE OUTSIDE ACCEPTABLE RANGE
WARNING SECNO=      2.000  PROFILE=  2  CONVEYANCE CHANGE OUTSIDE ACCEPTABLE RANGE

WARNING SECNO=      4.000  PROFILE=  1  CONVEYANCE CHANGE OUTSIDE ACCEPTABLE RANGE
WARNING SECNO=      4.000  PROFILE=  2  CONVEYANCE CHANGE OUTSIDE ACCEPTABLE RANGE
```

Exhibit D

Multiple Culverts Example

Computer Run

```
**********************************************                    ****************************************
*  HEC-2 WATER SURFACE PROFILES               *                    *  U.S. ARMY CORPS OF ENGINEERS        *
*                                             *                    *  HYDROLOGIC ENGINEERING CENTER       *
*  Version   4.6.0;  February 1991            *                    *  609 SECOND STREET, SUITE D          *
*                                             *                    *  DAVIS, CALIFORNIA 95616-4687        *
*  RUN DATE    06FEB91    TIME   13:53:59     *                    *       (916) 756-1104                 *
**********************************************                    ****************************************


                         X      X  XXXXXXX   XXXXX             XXXXX
                         X      X  X        X     X           X     X
                         X      X  X        X                       X
                         XXXXXXX  XXXX      X          XXXXX   XXXXX
                         X      X  X        X                 X
                         X      X  X        X     X           X
                         X      X  XXXXXXX   XXXXX            XXXXXXX
```

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   06FEB91       13:53:59                                                                          PAGE    1

                                                                THIS RUN EXECUTED 06FEB91     13:53:59
*************************************
 HEC-2 WATER SURFACE PROFILES

 Version   4.6.0;  February 1991
*************************************


T1       MULTIPLE PIPE CULVERTS EXAMPLE - Two six foot culverts
T3       Sample Creek

J1  ICHECK     INQ       NINV      IDIR      STRT      METRIC    HVINS     Q         WSEL      FQ

                2                           .00015                                    30.0

J2  NPROF      IPLOT     PRFVS     XSECV     XSECH     FN        ALLDC     IBW       CHNIM     ITRACE

      1                   -1


         USE J3 RECORDS TO REQUEST CUSTOM SUMMARY TABLE
         AND REGULAR SPECIAL CULVERT SUMMARY TABLES 101 AND 105

J3  VARIABLE CODES FOR SUMMARY PRINTOUT

     38         66         42         1          2         43         26         4         58
    101        105

         USE NC RECORD TO SET REGULAR CHANNEL LOSS COEFFICIENTS

NC       0.1        0.1       0.04       0.1        0.3
QT         3        250        400       500

         CROSS-SECTION 1 OF SPECIAL CULVERT MODEL - DOWNSTREAM OF CULVERTS

X1         1          8        972      1027
GR      36.1        856       32.7       917       30.9        972      24.8        986      24.8      1013
GR        31       1027       33.2      1095       37.2       1150

         USE NC RECORD TO SET EXPANSION AND CONTRACTION COEFFICIENTS FOR CULVERTS

NC                                       0.3        0.5

         CROSS-SECTION 2 OF SPECIAL CULVERT MODEL - AT DOWNSTREAM CULVERT FACE
          LEFT AND RIGHT BANKS ARE REDEFINED TO LIMIT FLOW TO WIDTH OF CULVERT
NH         3        0.1        972      0.04       1027        0.1      1150
X1         2         10        993      1007        200        200       200
         USE X3 RECORD TO RESTRICT EFFECTIVE FLOW TO CULVERT WIDTH (X3.1 = 10)
X3        10                                                                      32.3      32.3
GR      36.1        856       32.7       917       30.9        972        25        986        25       993
GR        25       1007         25      1013         31       1027      33.2       1095      37.2      1150

         SC RECORD DEFINES DUAL 72-INCH CONCRETE PIPE CULVERTS
```

```
   06FEB91       13:53:59                                                                          PAGE    2

SC     2.013        0.5        3.0                  6.0                           50        1.1      25.1      25.0

         CROSS-SECTION 3 AT UPSTREAM CULVERT FACE WITH EFFECTIVE FLOW OPTION
         X2.3 = 2 INDICATES CULVERT OPTION - ROAD OVERFLOW AT 33.7 FEET
         BT DATA DEFINE ROAD PROFILE FOR OVERFLOW CALCULATIONS.
NH         3        0.1        972      0.04       1027        0.1      1150
X1         3         10        993      1007         50         50        50
X2                               2                 33.7
X3        10                                                                      33.7      33.7
BT        -8        856       36.1                  917       34.8                 972      33.9
BT                  993       33.8                 1007       33.8                1027      33.7
BT                 1095       35.7                 1150       37.2
GR      36.1        856       32.7       917       30.9        972      25.1        986      25.1       993
GR      25.1       1007       25.1      1013         31       1027      33.2       1095      37.2      1150
         CROSS-SECTION 4 IS A FULL FLOW SECTION UPSTREAM FROM CULVERT

NC       0.1        0.1       0.04
X1         4          8        972      1027         50         50        50
GR      36.1        856       32.7       917       30.9        972      25.1        986      25.1      1013
GR        31       1027       33.2      1095       37.2       1150
```

```
  06FEB91      13:53:59                                                                                                    PAGE    3

    SECNO      DEPTH      CWSEL      CRIWS      WSELK      EG         HV         HL         OLOSS      L-BANK ELEV
    Q          QLOB       QCH        QROB       ALOB       ACH        AROB       VOL        TWA        R-BANK ELEV
    TIME       VLOB       VCH        VROB       XNL        XNCH       XNR        WTN        ELMIN      SSTA
    SLOPE      XLOBL      XLCH       XLOBR      ITRIAL     IDC        ICONT      CORAR      TOPWID     ENDST


*PROF 1

CCHV=     .100 CEHV=     .300
*SECNO 1.000
     1.000       5.49      30.29        .00      30.00      30.31        .02        .00        .00      30.90
     250.0         .0      250.0         .0         .0      217.0         .0         .0         .0      31.00
       .00        .00       1.15        .00       .000       .040       .000       .000      24.80     973.39
   .000152         0.         0.         0.          0          0          4        .00      52.01    1025.40


CCHV=     .300 CEHV=     .500
1490 NH CARD USED
*SECNO 2.000

3302 WARNING:  CONVEYANCE CHANGE OUTSIDE OF ACCEPTABLE RANGE,  KRATIO =   .41


3495 OVERBANK AREA ASSUMED NON-EFFECTIVE, ELLEA=       32.30 ELREA=       32.30

     2.000       5.28      30.28        .00        .00      30.45        .18        .06        .08      25.00
     250.0         .0      250.0         .0         .0       73.9         .0         .7         .2      25.00
       .02        .00       3.38        .00       .000       .040       .000       .000      25.00     993.00
   .000904       200.       200.       200.          2          0          0        .00      14.00    1007.00


SPECIAL CULVERT

SC  CUNO       CUNV       ENTLC      COFQ       RDLEN      RISE       SPAN       CULVLN     CHRT       SCL        ELCHU      ELCHD
     2          .013        .50       3.00        .00       6.00        .00      50.00      1          1          25.10      25.00

CHART  1 - CONCRETE PIPE CULVERT; NO BEVELED RING ENTRANCE
SCALE  1 - SQUARE EDGE ENTRANCE WITH HEADWALL

1490 NH CARD USED
*SECNO 3.000

SPECIAL CULVERT OUTLET CONTROL
EGIC =      29.499  EGOC =      30.843  PCWSE=      30.275  ELTRD=      33.700

SPECIAL CULVERT

     EGIC       EGOC         H4      QWEIR      QCULV        VCH      ACULV      ELTRD     WEIRLN
     29.50      30.84        .39         0.       250.      3.197       56.5      33.70         0.
```

```
  06FEB91      13:53:59                                                                                                    PAGE    4

    SECNO      DEPTH      CWSEL      CRIWS      WSELK      EG         HV         HL         OLOSS      L-BANK ELEV
    Q          QLOB       QCH        QROB       ALOB       ACH        AROB       VOL        TWA        R-BANK ELEV
    TIME       VLOB       VCH        VROB       XNL        XNCH       XNR        WTN        ELMIN      SSTA
    SLOPE      XLOBL      XLCH       XLOBR      ITRIAL     IDC        ICONT      CORAR      TOPWID     ENDST

3495 OVERBANK AREA ASSUMED NON-EFFECTIVE, ELLEA=       33.70 ELREA=       33.70

     3.000       5.58      30.68        .00        .00      30.84        .16        .39        .00      25.10
     250.0         .0      250.0         .0         .0       78.2         .0         .8         .2      25.10
       .02        .00       3.20        .00       .000       .040       .000       .000      25.10     993.00
   .000748        50.        50.        50.          2          0          0        .00      14.00    1007.00


*SECNO 4.000

3302 WARNING:  CONVEYANCE CHANGE OUTSIDE OF ACCEPTABLE RANGE,  KRATIO =  2.47

     4.000       5.78      30.88        .00        .00      30.90        .02        .01        .04      30.90
     250.0         .0      250.0         .0         .0      236.1         .0         .9         .2      31.00
       .03        .00       1.06        .00       .000       .040       .000       .000      25.10     972.05
   .000122        50.        50.        50.          2          0          0        .00      54.67    1026.72
```

```
  06FEB91      13:53:59                                                                                                    PAGE    5

T1      MULTIPLE PIPE CULVERTS EXAMPLE - Profile two

J1  ICHECK     INQ        NINV       IDIR       STRT       METRIC     HVINS      Q          WSEL       FQ

                3                              .00015                                       32.0

J2  NPROF      IPLOT      PRFVS      XSECV      XSECH      FN         ALLDC      IBW        CHNIM      ITRACE

      2                   -1
```

```
   06FEB91      13:53:59                                                                                                                       PAGE    6

     SECNO      DEPTH      CWSEL      CRIWS      WSELK      EG         HV         HL         OLOSS      L-BANK ELEV
     Q          QLOB       QCH        QROB       ALOB       ACH        AROB       VOL        TWA        R-BANK ELEV
     TIME       VLOB       VCH        VROB       XNL        XNCH       XNR        WTN        ELMIN      SSTA
     SLOPE      XLOBL      XLCH       XLOBR      ITRIAL     IDC        ICONT      CORAR      TOPWID     ENDST


*PROF 2

CCHV=     .100 CEHV=     .300
*SECNO 1.000
     1.000       6.94      31.74        .00      32.00      31.77        .03        .00        .00      30.90
     400.0        1.1      398.1         .8       10.9      295.8        8.6         .0         .0      31.00
       .00        .10       1.35        .09       .100       .040       .100       .000      24.80     946.21
   .000148         0.         0.         0.          0          0          4        .00     103.78    1049.99


CCHV=     .300 CEHV=     .500
1490 NH CARD USED
*SECNO 2.000

3302 WARNING:  CONVEYANCE CHANGE OUTSIDE OF ACCEPTABLE RANGE,  KRATIO =   .37


3495 OVERBANK AREA ASSUMED NON-EFFECTIVE, ELLEA=       32.30 ELREA=       32.30

     2.000       6.68      31.68        .00        .00      31.96        .28        .06        .13      25.00
     400.0         .0      400.0         .0         .0       93.5         .0         .9         .3      25.00
       .01        .00       4.28        .00       .000       .040       .000       .000      25.00     993.00
   .001054       200.       200.       200.          2          0          0        .00      14.00    1007.00


SPECIAL CULVERT

SC  CUNO       CUNV      ENTLC      COFQ       RDLEN      RISE       SPAN       CULVLN     CHRT       SCL        ELCHU      ELCHD
     2          .013       .50       3.00        .00       6.00        .00      50.00       1          1         25.10      25.00

CHART  1 - CONCRETE PIPE CULVERT; NO BEVELED RING ENTRANCE
SCALE  1 - SQUARE EDGE ENTRANCE WITH HEADWALL

1490 NH CARD USED
*SECNO 3.000

SPECIAL CULVERT OUTLET CONTROL
EGIC =     31.125  EGOC =     32.955  PCWSE=     31.678  ELTRD=     33.700

SPECIAL CULVERT

     EGIC       EGOC         H4      QWEIR      QCULV        VCH      ACULV      ELTRD     WEIRLN
     31.12      32.96        .99         0.       400.      3.740       56.5      33.70         0.
```

```
   06FEB91      13:53:59                                                                                                                       PAGE    7

     SECNO      DEPTH      CWSEL      CRIWS      WSELK      EG         HV         HL         OLOSS      L-BANK ELEV
     Q          QLOB       QCH        QROB       ALOB       ACH        AROB       VOL        TWA        R-BANK ELEV
     TIME       VLOB       VCH        VROB       XNL        XNCH       XNR        WTN        ELMIN      SSTA
     SLOPE      XLOBL      XLCH       XLOBR      ITRIAL     IDC        ICONT      CORAR      TOPWID     ENDST

3495 OVERBANK AREA ASSUMED NON-EFFECTIVE, ELLEA=       33.70 ELREA=       33.70

     3.000       7.64      32.74        .00        .00      32.96        .22        .99        .00      25.10
     400.0         .0      400.0         .0         .0      106.9         .0        1.1         .3      25.10
       .02        .00       3.74        .00       .000       .040       .000       .000      25.10     993.00
   .000674        50.        50.        50.          2          0          0        .00      14.00    1007.00


*SECNO 4.000

3302 WARNING:  CONVEYANCE CHANGE OUTSIDE OF ACCEPTABLE RANGE,  KRATIO =  2.99

     4.000       7.91      33.01        .00        .00      33.02        .02        .01        .06      30.90
     400.0        9.7      382.2        8.0       67.2      353.0       62.2        1.4         .4      31.00
       .03        .14       1.08        .13       .100       .040       .100       .000      25.10     911.50
   .000075        50.        50.        50.          2          0          0        .00     177.52    1089.02
```

```
   06FEB91      13:53:59                                                                                                                       PAGE    8

T1       MULTIPLE PIPE CULVERTS EXAMPLE - Profile three

J1  ICHECK    INQ        NINV       IDIR       STRT       METRIC     HVINS      Q          WSEL       FQ

               4                             .00015                                        35.0

J2  NPROF     IPLOT      PRFVS      XSECV      XSECH      FN         ALLDC      IBW        CHNIM      ITRACE

      3                   -1
```

```
  06FEB91      13:53:59                                                                                                 PAGE    9

   SECNO      DEPTH      CWSEL      CRIWS      WSELK      EG         HV         HL         OLOSS      L-BANK ELEV
   Q          QLOB       QCH        QROB       ALOB       ACH        AROB       VOL        TWA        R-BANK ELEV
   TIME       VLOB       VCH        VROB       XNL        XNCH       XNR        WTN        ELMIN      SSTA
   SLOPE      XLOBL      XLCH       XLOBR      ITRIAL     IDC        ICONT      CORAR      TOPWID     ENDST


*PROF 3

CCHV=     .100 CEHV=     .300
*SECNO 1.000
     1.000       7.64      32.44        .00      35.00      32.48        .03        .00        .00      30.90
     500.0        5.6      489.7        4.7       36.4      334.3       32.2         .0         .0      31.00
       .00        .15       1.46        .15       .100       .040       .100       .000      24.80     924.82
   .000149         0.         0.         0.          0          0          4        .00     146.81    1071.63


CCHV=     .300 CEHV=     .500
1490 NH CARD USED
*SECNO 2.000
     2.000       7.48      32.48        .00        .00      32.51        .03        .03        .00      25.00
     500.0      168.3      178.6      153.2      153.5      104.6      141.0        1.8         .7      25.00
       .04       1.10       1.71       1.09       .042       .040       .042       .000      25.00     923.91
   .000144       200.       200.       200.          0          0          0        .00     148.64    1072.55


SPECIAL CULVERT

SC  CUNO       CUNV       ENTLC      COFQ       RDLEN      RISE       SPAN       CULVLN     CHRT       SCL        ELCHU      ELCHD
     2          .013        .50       3.00        .00       6.00        .00      50.00      1          1          25.10      25.00

CHART  1 - CONCRETE PIPE CULVERT; NO BEVELED RING ENTRANCE
SCALE  1 - SQUARE EDGE ENTRANCE WITH HEADWALL

1490 NH CARD USED
*SECNO 3.000

3302 WARNING:  CONVEYANCE CHANGE OUTSIDE OF ACCEPTABLE RANGE,  KRATIO =  1.60

SPECIAL CULVERT

      EGIC       EGOC         H4      QWEIR      QCULV        VCH      ACULV      ELTRD     WEIRLN
     32.34      34.47       1.65        43.       459.      1.209       56.5      33.70        87.


     3.000       9.05      34.15        .00        .00      34.16        .01       1.65        .00      25.10
     500.0      180.2      153.3      166.5      298.1      126.8      285.8        2.5         .9      25.10
       .06        .60       1.21        .58       .049       .040       .049       .000      25.10     890.90
   .000056        50.        50.        50.          1          0          0        .00     217.23    1108.13


*SECNO 4.000
     4.000       9.05      34.15        .00        .00      34.17        .02        .00        .00      30.90
     500.0       27.9      445.8       26.2      148.5      416.1      146.0        3.3        1.1      31.00
       .07        .19       1.07        .18       .100       .040       .100       .000      25.10     890.91
   .000059        50.        50.        50.          0          0          0        .00     217.22    1108.12
```

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  06FEB91      13:53:59                                                                                                 PAGE   10


                                                                                         THIS RUN EXECUTED 06FEB91    13:54:05
*************************************
 HEC-2 WATER SURFACE PROFILES

 Version   4.6.0;  February 1991
*************************************


NOTE- ASTERISK (*) AT LEFT OF CROSS-SECTION NUMBER INDICATES MESSAGE IN SUMMARY OF ERRORS LIST


Sample Creek

SUMMARY PRINTOUT


      SECNO      CUMDS      ELMIN      CWSEL      CRIWS        Q        VCH     TOPWID     KRATIO

       1.000        .00      24.80      30.29        .00     250.00      1.15      52.01        .00
       1.000        .00      24.80      31.74        .00     400.00      1.35     103.78        .00
       1.000        .00      24.80      32.44        .00     500.00      1.46     146.81        .00

*      2.000     200.00      25.00      30.28        .00     250.00      3.38      14.00        .41
*      2.000     200.00      25.00      31.68        .00     400.00      4.28      14.00        .37
       2.000     200.00      25.00      32.48        .00     500.00      1.71     148.64       1.02

       3.000     250.00      25.10      30.68        .00     250.00      3.20      14.00       1.10
       3.000     250.00      25.10      32.74        .00     400.00      3.74      14.00       1.25
*      3.000     250.00      25.10      34.15        .00     500.00      1.21     217.23       1.60

*      4.000     300.00      25.10      30.88        .00     250.00      1.06      54.67       2.47
*      4.000     300.00      25.10      33.01        .00     400.00      1.08     177.52       2.99
       4.000     300.00      25.10      34.15        .00     500.00      1.07     217.22        .97
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06FEB91 13:53:59 PAGE 11

Sample Creek

SUMMARY PRINTOUT TABLE 101

	SECNO	EGOC	ELLC	EGIC	ELTRD	QCULV	QWEIR	CLASS	H4	DEPTH	CWSEL	VCH	EG
	3.000	30.84	.00	29.50	33.70	250.00	.00	7.00	.39	5.58	30.68	3.20	30.84
	3.000	32.96	.00	31.12	33.70	400.00	.00	7.00	.99	7.64	32.74	3.74	32.96
*	3.000	34.47	.00	32.34	33.70	458.93	43.14	17.00	1.65	9.05	34.15	1.21	34.16

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06FEB91 13:53:59 PAGE 12

Sample Creek

SUMMARY PRINTOUT TABLE 105

	SECNO	CWSEL	HL	OLOSS	TOPWID	QLOB	QCH	QROB
	1.000	30.29	.00	.00	52.01	.00	250.00	.00
	1.000	31.74	.00	.00	103.78	1.11	398.09	.80
	1.000	32.44	.00	.00	146.81	5.56	489.74	4.70
*	2.000	30.28	.06	.08	14.00	.00	250.00	.00
*	2.000	31.68	.06	.13	14.00	.00	400.00	.00
	2.000	32.48	.03	.00	148.64	168.27	178.56	153.18
	3.000	30.68	.39	.00	14.00	.00	250.00	.00
	3.000	32.74	.99	.00	14.00	.00	400.00	.00
*	3.000	34.15	1.65	.00	217.23	180.25	153.27	166.48
*	4.000	30.88	.01	.04	54.67	.00	250.00	.00
*	4.000	33.01	.01	.06	177.52	9.73	382.23	8.04
	4.000	34.15	.00	.00	217.22	27.95	445.81	26.24

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06FEB91 13:53:59 PAGE 13

SUMMARY OF ERRORS AND SPECIAL NOTES

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WARNING SECNO=      2.000  PROFILE=  1  CONVEYANCE CHANGE OUTSIDE ACCEPTABLE RANGE
WARNING SECNO=      2.000  PROFILE=  2  CONVEYANCE CHANGE OUTSIDE ACCEPTABLE RANGE

WARNING SECNO=      3.000  PROFILE=  3  CONVEYANCE CHANGE OUTSIDE ACCEPTABLE RANGE

WARNING SECNO=      4.000  PROFILE=  1  CONVEYANCE CHANGE OUTSIDE ACCEPTABLE RANGE
WARNING SECNO=      4.000  PROFILE=  2  CONVEYANCE CHANGE OUTSIDE ACCEPTABLE RANGE
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