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CHAPTER THIRTY-FOUR

ENERGY DISSIPATORS

34-1.0 INTRODUCTION

34-1.01 Overview

The failure or damage of a culvert or detention-basin outlet structure can be traced to unchecked erosion. Erosive forces which are at work in the natural drainage network are often exacerbated by the construction of a highway or by other urban development. Interception and concentration of overland flow or constriction of a natural waterway inevitably result in an increased erosion potential. To protect the culvert and adjacent areas, it can be necessary to use an energy dissipator.

34-1.02 Definition

An energy dissipater is a device designed to protect downstream areas from erosion by reducing the velocity of flow to acceptable limits.

34-1.03 Purpose

This Chapter provides the information as follows:

1. design procedures which are based on FHWA Hydraulic Engineering Circular Number 14 (HEC 14) *Hydraulic Design of Energy Dissipators for Culverts and Channels*, September 1983, revised in 1995; and

2. results of analysis using the HYDRAIN system and the HY8 software.

34-1.04 Symbols

See Figure 34-1A, Symbols, Definitions, and Units.

34-2.0 DESIGN CRITERIA

34-2.01 Overview

34-2.01(01) Policy

Policy is a set of goals that establish a definite course of action or method of action and that are selected to guide and determine present and future decisions (see Section 28-4.0). Policy is implemented through design criteria for making decisions.

34-2.01(02) Design Criteria

Design criteria are the standards by which a policy is carried out or placed into action. They form the basis for the selection of the final design configuration. Listed below by categories are the design criteria which should be considered for an energy-dissipator design.

34-2.02 Dissipator-Type Selection

The dissipator type selected for a site must be appropriate to the location. The terms internal and external are used to indicate the location of the dissipator in relation to the culvert. An external dissipator is located outside of the culvert. An internal dissipator is located within the culvert barrel. The following applies to type selection.

1. Internal Dissipator. An internal dissipater is used as follows:

   a. the scour hole at the culvert outlet is unacceptable;
   b. the right of way is limited;
   c. debris is not a problem; and
   d. moderate velocity reduction is needed.

2. Natural Scour Hole. A natural scour hole is used as follows:

   a. undermining of the culvert outlet will not occur or it is practicable to be checked by a cutoff wall;

   b. the expected scour hole will not cause costly property damage; and

   c. there is no nuisance effect.

   3. External Dissipator. An external dissipator is used where the outlet scour hole is not acceptable, and a moderate amount of debris is present.

4. Stilling Basin. A stilling basin is used where the outlet scour hole is not acceptable, and debris is present.

34-2.03 Design Limitations

The following applies.

1. Ice Buildup. If ice buildup is a factor, it should be mitigated by sizing the structure to not obstruct the winter low flow, and by using an external dissipator.

2. Flood Frequency. The flood frequency used in the design of the energy dissipator device should be the same flood frequency used for the culvert design.

3. Maximum Culvert-Exit Velocity. The culvert-exit velocity should be less than 2.5 m/s, or should be mitigated by using channel stabilization and energy dissipation.

4. Tailwater Relationship. The downstream hydraulic conditions should be evaluated to determine a tailwater depth and the maximum velocity for an open channel. A lake, pond, or large water body should be evaluated using the high-water elevation that has the same frequency as the design flood for the culvert.

34-2.04 Design Options

34-2.04(01) Material Selection

The material selected for the dissipator should be based on a comparison of the total cost over the design life of alternate materials and should not be made using first cost as the only criterion. This comparison should consider replacement cost, the difficulty of construction, and traffic delay.

34-2.04(02) Culvert Outlet Type

In choosing a dissipator, the selected culvert end treatment has the following implications.

1. A culvert end which is projecting or mitered to the fill slope offers no outlet protection.

2. Headwalls provide embankment stability and erosion protection. They provide protection from buoyancy and reduce damage to the culvert.

3. Commercial end sections add little cost to the culvert and may require less maintenance, retard embankment erosion, and incur less damage from maintenance.

4. Aprons do not reduce outlet velocity but, if used, should extend at least one culvert height downstream. They shall not protrude above the normal streambed elevation.

5. Wingwalls are used where the sideslopes of the channel are unstable, where the culvert is skewed to the normal channel flow, to redirect outlet velocity, or to retain fill.

34-2.04(03) Safety Considerations

Traffic should be protected from an external energy dissipator by locating it outside the appropriate clear-zone distance as described in Chapter Forty-nine.

34-2.05 Related Designs

34-2.05(01) Culvert

The culvert should be designed independent of the dissipator design (see Chapter Thirty-one), with the exception of an internal dissipater, which may require an iterative solution. The culvert design should be completed before the outlet protection is designed and should include computation of outlet velocity.

34-2.05(02) Downstream Channel

The downstream channel protection should be designed concurrently with the dissipator design (see Chapter Thirty).

34-3.0 DESIGN PHILOSOPHY

34-3.01 Alternative Analysis

Choose alternatives which satisfy the topography, and design policies and criteria.

Analyze alternatives for environmental impact, hydraulic efficiency, and risk and cost.

The selected dissipator should satisfy the selected structural and hydraulic criteria, and should be based on the following:

1. construction and maintenance costs;
2. risk of failure or property damage;
3. traffic safety;
4. environmental or aesthetic considerations;
5. political or nuisance considerations; and
6. land-use requirements.

34-3.02 Design Methods

The designer must choose as follows:

1. to design for local scour or channel degradation;

2. to mitigate or monitor erosion problems;

3. to use a drop structure, internal dissipator, scour hole, external dissipater, or stilling basin; and

4. to use charts or computer software.

34-3.02(01) Types of Scour

The following apply.

1. Local Scour. Local scour is the result of high-velocity flow at the culvert outlet and extends only a limited distance downstream.

2. Channel Degradation. Channel degradation may proceed in a fairly uniform manner over a long length or may be evident in one or more abrupt drops (headcuts) progressing upstream with each runoff event.

34-3.02(02) Scour-Hazard Protection

The following apply.

1. Mitigated. The scour-hazard protection device should be designed by providing protection at the culvert outlet as follows:

a. Initial protection should be sufficient to provide assurance that extensive damage cannot result from one design runoff event.

b. The protection device should be inspected after a major storm to determine if protection must be increased or extended.

2. Monitored. The site should be inspected after a major-storm event to determine if protection is needed.

34-3.02(03) Dissipator Types

The following types are available.

1. Scour Hole. The design of a scour hole is described in Section 34-4.0.

2. Internal Dissipator. This includes the tumbling-flow type and the increased-resistance type.

   This Chapter does not address the design of an internal dissipator. The designer should refer to FHWA HEC 14 *Hydraulic Design of Energy Dissipators for Culverts and Channels*, September 1985, revised in 1995, and FHWA/OH-84/007 *Internal Energy Dissipators*, if design procedure is needed.

3. External Dissipator. This includes the following:

   a. USBR Type VI Impact (see Section 34-9.0);
   b. riprap (see Section 34-8.0);
   c. CSU rigid boundary (see HEC 14);
   d. Contra Costa (see HEC 14);
   e. hook (see HEC 14); and
   f. hydraulic jump (see HEC 14).

4. Stilling Basin. This includes the following:

   a. Saint Anthony Falls (SAF) (see Section 34-7.0);
   b. USBR Type II (see HEC 14);
   c. USBR Type III (see HEC 14); and
   d. USBR Type IV (see HEC 14).

5. Drop Structure. See HEC 14.

34-3.02(04) Computational Methods

The following are available.

1. Charts. Charts are required for a manual solution. Charts required for the design of a scour hole, riprap basin, USBR Type VI impact basin, or SAF basin are included herein. Charts required for the design of another type of energy dissipator are shown in HEC 14.

2. Computer Software. HY-8 (FHWA Culvert Analysis Software) Version 4.1 or later, includes an energy-dissipator module which can be used to analyze most types of energy dissipators described in HEC 14.

34-4.0 DESIGN EQUATIONS

34-4.01 General

An exact theoretical analysis of flow at a culvert outlet is complex because the required information is as follows:

1. analyzing non-uniform and rapidly-varying flow;
2. applying energy and momentum balance;
3. determining where a hydraulic jump will occur;
4. applying the results of hydraulic model studies; and
5. consideration of temporary upstream storage effects.

34-4.02 Approach

The design procedure provided herein is based on the following.

1. Model studies were used to calibrate the equations and charts for scour-hole estimating and energy-dissipator design.

2. HEC 14 (revised version, 1995) is the base reference and includes a full explanation of all equations and procedures used herein, with the exception of those discussed in Section 34-4.03.

34-4.03 Culvert-Outlet Conditions

The culvert design establishes the outlet-flow conditions. However, these parameters may require closer analysis for energy-dissipator design.

1. Depth, d_o (m) The normal depth assumption should be reviewed, and a water-surface profile calculated if $L < 50d_o$. The brink depth (see HEC 14 for curves) should be used for a mild slope and low tailwater, not critical depth.

2. Area, A_o (m^2) The cross-sectional area of flow at the culvert outlet should be calculated using d_o.

3. Velocity, V_o (m/s) The culvert outlet velocity should be calculated as follows:

$$V_o = \frac{Q}{A_o} \qquad \text{(Equation 34-4.1)}$$

Where Q = discharge, m^3/s

4. Froude Number, Fr. The Froude number is a flow parameter that has been used to design an energy dissipater, and is calculated using the formula as follows:

$$Fr = \frac{V_o}{(gd_o)^{0.5}} \qquad \text{(Equation 34-4.2)}$$

Where g = acceleration due to gravity, 9.81 m/s^2

5. Equivalent Depth, $d_E = (A_o/2)^{0.5}$ (m) Equivalent depth is an artificial depth which is calculated for a culvert which is not rectangular, so that a reasonable Fr can be determined.

6. Discharge Intensity, DI_C. Discharge intensity is a flow parameter similar to Fr which is used for a circular culvert of diameter, D, which is flowing full, as follows:

$$DI_c = \frac{Q}{g^{0.5} D^{2.5}} \qquad \text{(Equation 34-4.3)}$$

7. Discharge Intensity Modified, DI. Modified discharge intensity, as described in HEC 14, Chapter V, (revised version, 1995), is as follows:

$$DI = \frac{Q}{g^{0.5} R_c^{2.5}} \qquad \text{(Equation 34-4.4)}$$

Where: Q = discharge, m^3/s
A_c = culvert area, m^2
P_c = culvert perimeter, m
R_c = A_c/P_c

34-4.04 Scour-Hole Estimation

HEC 14, Chapter V, (revised version, 1995) includes an estimating procedure for scour-hole geometry based on soil, flow data, and culvert geometry. This scour-prediction procedure is intended to serve together with the maintenance history and site reconnaissance information for determining energy-dissipator needs.

Only a scour hole on cohesionless material will be discussed herein. For a scour hole on cohesive soil, see HEC 14, Chapter V for details.

The results of tests by the U.S. Army Waterways Experiment Station, Vicksburg, Mississippi, indicate that scour-hole geometry varies with the tailwater conditions. The maximum scour-hole geometry occurs at a tailwater depth of less than half the culvert height. The maximum depth of scour, d_S, occurs at a location approximately $0.4L_S$ downstream of the culvert, where L_S is the length of the scour.

The following empirical equations defining the relationship between the culvert discharge intensity and time, and the length, width, depth, and volume of the scour hole, are provided for the maximum or extreme scour situation.

$$\left[\frac{d_s}{R_c}, \frac{W_s}{R_c}, \frac{L_s}{R_c}\right] = \left(\frac{C_s C_h \alpha}{\sigma^{0.33}}\right)\left(\frac{Q}{g^{0.5} R_c^{\ 2.5}}\right)^{\beta}\left(\frac{t}{316}\right)^{\theta} \qquad \text{(Equation 34-4.5)}$$

Where: d_S = maximum depth of scour hole, m
L_S = length scour hole, m
W_S = width of scour hole, m

$$d_S, W_S, \text{ or } L_S = R_c F_1 F_2 F_3 \qquad \text{(Equation 34-4.6)}$$

Where: $F_1 = \frac{C_s C_h \alpha}{\sigma^{0.33}}$ and $F_2 = \left(\frac{Q}{g^{0.5} R_c^{\ 2.5}}\right)^{\beta}$

t = 30 min or the time of concentration, if longer
R_c = hydraulic radius of drainage structure flowing full
σ = material standard deviation (σ = 2.10 for gravel, or 1.87 for sand)

ά, ß, θ, C_s, and C_h are coefficients as shown in Figure 34-4A, Coefficients for Scour-Hole Estimation

F_1, F_2 and F_3 are factors to aid the computation, as shown in Step 7B, Figure 34-5A, Energy Dissipator Checklist. An editable version of this form may also be found on the Department's website at www.in.gov/dot/div/contracts/design/dmforms/.

34-5.0 DESIGN PROCEDURE

The following design procedure is intended to provide a convenient and organized method for manually designing an energy dissipator. The designer should be familiar with all of the equations in Section 34-4.0 before using the procedure. Application of the following design method without an understanding of hydraulics can result in an inadequate, unsafe, or costly structure.

1. Step 1. Assemble Site Data And Project File.

   a. See culvert design file for site survey.
   b. Review Section 34-2.0 for applicable criteria.

2. Step 2. Determine Hydrology. See culvert design file.

3. Step 3. Select Design *Q*.

   a. See Section 34-2.03.
   b. See culvert design file.
   c. Select flood frequency.
   d. Determine *Q* from frequency plot (Step 2).

4. Step 4. Design Downstream Channel.

   a. See culvert design file.
   b. Determine channel slope, cross section, normal depth, and velocity.
   c. Check bed- and bank-materials stability.

5. Step 5. Design Culvert. See culvert design file and obtain design discharge, outlet flow conditions (velocity and depth), culvert type (size, shape, and roughness), culvert slope, and performance curve.

6. Step 6. Summarize Data On Design Form.

   a. Use Figure 34-5A, Energy Dissipator Checklist.

b. Enter data from Steps 1-5 into Figure 34-5A.

7. Step 7. Estimate Scour-Hole Size.

   a. Enter input for the scour equation shown in Figure 34-5A.
   b. Calculate d_S, W_S, L_S using Equation 34-4.5 or 34-4.6.

8. Step 8. Determine Need for Dissipator. An energy dissipator is needed if one or more conditions apply as follows:

   a. the estimated scour-hole dimensions, which exceed the allowable right of way, undermines the culvert cutoff wall or presents a safety or aesthetic problem;

   b. downstream property is threatened; or

   c. V_o is significantly greater than V_d.

9. Step 9. Select Design Alternative. See Section 34-2.04.

10. Step 10. Design Dissipator. Use the following design procedure and charts.

   a. Section 34-7.0 for SAF.
   b. Section 34-8.0 for riprap.
   c. Section 34-9.0 for USBR Type VI.

11. Step 11. Design Riprap Transition. A dissipator will likely require some protection adjacent to the basin exit. The length of protection can be judged based on the difference between V_o and V_d. The riprap should be designed using HEC 11.

12. Step 12. Review Results.

   a. If downstream channel conditions (velocity, depth, and stability) are exceeded, either design riprap for the channel (Step 4), or select another dissipator (Step 9).

   b. If the preferred energy dissipator type affects the culvert hydraulics, return to Step 5 and calculate culvert performance.

   c. If a debris-control structure is required upstream, see HEC 9.

   d. If a check Q was used for the culvert design, assess the dissipator performance with this discharge.

13. Step 13. Documentation.

    a. See Chapter Twenty-eight.
    b. Include computations in the culvert report or file.

34-6.0 DESIGN EXAMPLE

34-6.01 Design Example Steps

The following example problem uses the culvert data provided in Chapter Thirty-one.

1. Step 1. Assemble Site Data and Project File.

    a. Site survey. The culvert project file includes USGS, site, and location maps, roadway profile, and embankment cross sections. Site-visit notes indicate no sediment or debris problems and no nearby structures. See Figure 34-6.1 for site data.

    b. Studies by Other Agencies. None.

    c. Design Criteria.

        (1) 50-year frequency for design.
        (2) 100-year frequency for check.

2. Step 2. Determine Hydrology. USGS regression equations yield the following:

    a. Q_{50} = 11.33 m^3/s
    b. Q_{100} = 14.16 m^3/s

3. Step 3. Select Design Q. Use Q_{50} = 11.33 m^3/s, as requested by the design criteria.

4. Step 4. Design Downstream Channel.

    a. See Figure 34-6.2 for cross section of channel with slope = 0.05.

Point	Station, m	Elevation, m
1	3.7	54.86
2	6.7	53.34
3	9.8	53.19
4	10.4	52.58

5	11.9	52.58
6	12.5	53.19
7	15.5	53.34
8	18.6	54.86

b. Rating curve for channel. Calculating normal depth yields the following:

Q (m^3/s)	TW (m)	V (m/s)
2.83	0.43	3.40
5.66	0.63	4.20
8.50	0.77	4.86
11.33	0.86	5.35
14.16	*0.94*	*5.74*

c. At V_{50} = 5.35 m/s, the 75-mm gravel material which makes up the channel boundary is not stable and riprap is needed for a transition.

5. Step 5. Design Culvert. A reinforced-concrete box culvert, 2135 mm by 1830 mm, with a beveled entrance on a slope of 0.05 was the selected design. The FHWA HY8 program showed that this culvert is operating at inlet control and has the following properties.

Q (m^3/s)	HW_i (m)	V_o (m/s)
Q_{50} = 11.33	2.32	8.61
Q_{ot} = 13.00	2.59	8.88
Q_{100}= 14.16	2.62	8.90

6. Step 6. Summarize Data On Design Form. See Figure 34-5A.

7. Step 7. Size Scour Hole. The size of the scour hole is determined using Equations 34-4.5 and 34-4.6. For a channel with gravel bed, the standard deviation of the material, σ, is 2.10. Figure 34-4A shows that the value of C_s =1.00 and C_h = 1.08. See Figure 34-6A, Energy Dissipator Checklist (Example), for a summary of the computation.

8. Step 8. Determine Need For Dissipator. The scour-hole dimensions are excessive, and, since V_o = 8.61 m/s is much greater than V_d = 5.35 m/s, an energy dissipator is needed.

9. Step 9. Select Design Alternative. See Section 34-2.04.

10. Step 10. Design Dissipator. The design of an SAF stilling basin is as shown in Section 34-7.0.

11. Step 11. Design Riprap Transition. Protection is required (see HEC 11).

12. Step 12. Review Results. The downstream-channel conditions are matched by the dissipator.

13. Step 13. Documentation.

    a. See Chapter Twenty-eight.
    b. Include computations in the culvert report or file.

34-6.02 Computer Output

The scour-hole geometry can also be computed by using the FHWA microcomputer program HY-8, Culvert Analysis, Version 4.0 or later, Energy Dissipators module. A hardcopy of the module output is as shown as Figure 34-6B. The dimensions of the scour hole computed by the HY-8 program are reasonably close to the values calculated above.

34-7.0 STILLING BASIN

34-7.01 Overview

The St. Anthony Falls (SAF) stilling basin uses a forced hydraulic jump to dissipate energy and has the properties as follows:

1. is based on model studies conducted by the Natural Resources Conservation Service (NRCS) at the St. Anthony Falls (SAF) Hydraulic Laboratory of the University of Minnesota;

2. uses chute blocks, baffle blocks, and an end sill to force the hydraulic jump and reduce jump length by about 80%; and

3. is recommended where *Fr* ranges from 1.7 to 17.0.

34-7.02 Equations

1. Basin Width, W_B.

    a. for a box culvert, $W_B = B$ = culvert width (m)
    b. for a pipe, W_B = culvert diameter, D, (m) or

$$W_B = \frac{0.054Q}{D^{1.5}} \qquad \text{(Equation 34-7.1)}$$

whichever is larger.

Where Q = discharge, m^3/s

2. Flare (z:1). Flare is optional. If used, it should be flatter than 2:1.

3. Basin Length, L_B.

$$d_j = 0.5d_1\left[\left(1 + 8Fr_1^2\right)^{0.5} - 1\right] \qquad \text{(Equation 34-7.2)}$$

Where: d_1 = initial depth of water, m
d_j = sequent depth of jump, m
Fr_1 = Froude number entering basin, ≠ Fr

$$L_B = \frac{4.5d_j}{Fr_1^{0.76}} \qquad \text{(Equation 34-7.3)}$$

4. Basin Floor. The basin floor should be depressed below the streambed enough to obtain the depth, d_2, below the tailwater as follows:

a. For $1.7 \le Fr_1 < 5.5$,

$$d_2 = d_j\left[1.1 - \left(\frac{Fr_1^2}{120}\right)\right] \qquad \text{(Equation 34-7.4)}$$

b. For $5.5 \le Fr_1 < 11.0$,

$$d_2 = 0.85d_j \qquad \text{(Equation 34-7.5)}$$

c. For $11.0 \le Fr_1 < 17.0$,

$$d_2 = d_j\left[1.1 - \left(\frac{Fr_1^2}{800}\right)\right] \qquad \text{(Equation 34-7.6)}$$

5. Chute Blocks.

Height, $h_1 = d_1$
Width, W_1 = spacing, $W_1 = 0.75d_1$
Number of blocks, $N_c = W_B/2W_1$, rounded to a whole number
Adjusted $W_1 = W_2 = W_B/2N_c$
N_c includes the half-block at each wall

6. <u>Baffle Blocks</u>.

Height, $h_3 = d_1$
Width, W_3 = spacing, $W_4 = 0.75d_1$
Basin width at baffle blocks, $W_{B2} = W_B + 2L_B/3z$
Number of blocks, $N_B = W_{B2}/2W_3$, rounded to a whole number
Adjusted $W_3 = W_4 = W_{B2}/2N_B$
Check total block width to ensure that 40% to 55% of W_{B2} is occupied by blocks
Staggered with chute blocks
Space at wall $\geq 0.38d_1$
Distance from chute blocks, $L_{1\text{-}3} = L_B/3$

7. <u>End Sill Height</u>. $h_4 = 0.07d_j$

8. <u>Sidewall Height</u>. $d_2 + 0.33d_j$

9. <u>Wingwall Flare</u>. 45 deg

34-7.03 Design Procedure

The design of a St. Anthony Falls (SAF) basin consists of the steps as follows.

1. <u>Step 1. Select Basin Type</u>.

   a. Rectangular or flared.
   b. Choose flare (if needed), z:1.
   c. Determine basin width, W_B.

2. <u>Step 2. Select Depression</u>.

   a. Choose depth d_2 to depress below the streambed, B_d.
   b. Assume $B_d = 0$ for first trial.

3. <u>Step 3. Determine Input Flow</u>.

a. d_1 and V_1, using energy equation.
b. Froude Number, Fr_1.

4. Step 4. Calculate Basin Dimensions.

a. d_j (Equation 34-7.2).
b. L_B (Equation 34-7.3).
c. d_2 (Equation 34-7.4, 34-7.5. or 34-7.6).
d. $L_S = (d_2 - TW)/S_S$
e. $L_T = B_d/S_T$ (see Figure 34-7A, St. Anthony Falls Basin Checklist). An editable version of this form may also be found on the Department's website at www.in.gov/dot/div/contracts/design/dmforms/.
f. $L = L_T + L_B + L_S$ (see Figure 34-7A).

5. Step 5. Review Results.

a. If $d_2 \neq (B_d - LS_o + TW)$, return to Step 2.
b. If approximately equal, continue.

6. Step 6. Size Elements.

a. Chute blocks, h_1, W_1, W_2, N_c.
b. Baffle blocks, h_3, W_3, W_4, N_B, $L_{1\text{-}3}$.
c. End sill, h_4.
d. Side wall height, $h_5 = d_2 + 0.33d_j$.

* * * * * * * *

34-7.04 Example 34-7.1

See Section 34-6.0 for input values. See Figure 34-7C, Energy Dissipator HY-8 Program Output, for completed computation form.

1. Step 1. Select Basin Type.

a. Use a rectangular basin.
b. No flare.
c. Basin width, $W_B = 2.13$ m

2. Step 2. Select Depression. Trial 1: $B_d = 1.83$ m, $S_S = S_T = 1$.

3. Step 3. Determine Input Flow, Trial 1.

   a. Energy equation, culvert to basin:
      Culvert outlet = $B_d + d_o + V_o^2/2g = 1.83 + 0.56 + (8.67)^2/2(9.81) = 6.22$ m
      Basin floor = $0 + d_1 + V_1^2/2g$
      Solve: $6.22 = d_1 + V_1^2/2g$

d_1	V_1	$d_1 + V_1^2/2$
0.49	10.86	6.49 > 6.23
0.50	10.64	6.27 ≠ 6.23, Use.

   b. $$Fr_1 = \left(\frac{10.64}{0.50}\right)(9.81)^{0.5} = 4.80$$

4. Step 4. Calculate Basin Dimensions, Trial 1.

   a. $d_j = 3.15$ m (Equation 34-7.2)
   b. $L_B = 4.30$ m (Equation 34-7.3)
   c. $d_2 = 2.86$ m (Equation 34-7.5)
   d. $L_S = (d_2 - TW)/S_S = (2.86 - 0.86)/1 = 2.00$ m
   e. $L_T = B_d/S_T = 1.83/1 = 1.83$ m
   f. $L = L_T + L_B + L_S = 1.83 + 4.30 + 2.00 = 8.13$ m

5. Step 5. Review Results, Trial 1.

   a. If d_2 does not equal $(B_d - LS_o + TW)$, adjust drop.
      $2.86 \neq [1.83 - 8.13(0.05) + 0.86] = 2.28$ m

   b. Add 2.86 – 2.28 = 0.58 more drop and return to Step 2.

6. Repeat Step 2. Select Depression. Trial 2: $B_d = 2.41$ m, $S_S = S_T = 1$.

7. Repeat Step 3. Determine Input Flow. Trial 2:

   a. Energy equation, culvert to basin:
      Culvert outlet = $B_d + d_o + V_o^2/2g = 2.41 + 0.62 + (8.61)^2/2g = 6.81$ m
      Basin floor = $0 + d_1 + V_1^2/2g$
      Solve: $6.60 = d_1 + V_1^2/2g$

d_1	V_1	$d_1 = V_1^2/2g$
0.48	11.08	6.74 ≠ 6.81, Use.

b. $$Fr_1 = \frac{11.08}{[(0.48)(0.91)]^{0.5}}$$

8. Repeat Step 4. Calculate Basin Dimensions. Trial 2:

a. d_j = 3.16 m (Equation 34-7.2)
b. L_B = 4.18 m (Equation 34-7.3)
c. d_2 = 2.82 m (Equation 34-7.5)
d. $L_S = (d_2 – TW)/S_S$ = 1.96 m
e. $L_T = B_d/S_T$ = 2.39/1 = 2.41 m
f. $L = L_T + L_B + L_S$ = 2.41 + 4.18 + 1.96 = 8.55 m

9. Repeat Step 5. Review Results. Trial 2:

d_2 = 2.82 ≠ [2.41 – 8.55(0.05) + 0.86] = 2.84 m.
Is approximately equal; continue.

10. Step 6. Size Elements. Trial 2:

a. Chute blocks, h_1, W_1, W_2, N_c
$h_1 = d_1$ = 0.48 m
$W_1 = 0.75d_1$ = 0.36 m
$N_c = W_B/2W_1$ = 2.13/2(0.36) = 2.96; use 3
Adjusted W_1 = 2.13/2(3) = 0.35 m = W_2
Use 2 full blocks, 3 spaces and a half-block at each wall.

b. Baffle blocks, h_3, W_3, W_4, N_B, L_{1-3}
$h_3 = d_1$ = 0.48 m
$W_3 = 0.75d_1$ = 0.36 m
Use 3 blocks, as above, $W_3 = W_4$ = 0.35 m
$L_{1-3} = L_B/3$ = 4.18/3 = 1.39 m

c. End sill, $h_4 = 0.07d_j$ = 0.07(3.16) = 0.22 m

d. Sidewall height, $h_5 = d_2 + 0.33d_j$ = 2.82 + 0.33(3.16) = 3.86 m
See Figure 34-7A(0) for block design.

34-7.05 Computer Output

The dissipator geometry can be computed using the HY-8 Culvert Analysis microcomputer program, Energy Dissipator module. The output of the culvert and channel input data, and computed geometry using this module are shown as Figure 34-7B, St. Anthony Falls Basin, Example.

34-8.0 RIPRAP BASIN

34-8.01 Overview

The riprap-basin design is based on laboratory data obtained from full-scale prototypical installations. The following are the principal features of the basin.

1. Preshaping and lining with riprap of median size, d_{50}.
2. Constructing the floor at a depth of h_S below the invert, where h_S is the depth of scour that will occur in a pad of riprap of size d_{50}.
3. Sizing d_{50} so that $2 < h_S/d_{50} < 4$.
4. Sizing the length of the dissipating pool to be $10h_S$ or $3W_o$, whichever is larger for a single barrel. The overall length of the basin is $15h_S$ or $4W_o$, whichever is larger.
5. Angular-rock results were approximately the same as the results for rounded material.
6. Layout details are shown on Figure 34-8A, Details of Riprap-Basin Energy Dissipator.

For high tailwater, $TW/d_o > 0.75$, the following applies.

1. The high-velocity core of water emerging from the culvert retains its jet-like character as it passes through the basin.
2. The scour hole is not as deep as with low tailwater and is longer.
3. Riprap may be required for the channel downstream of the rock-lined basin.

34-8.02 Design Procedure

An editable version of Figure 34-8C, Riprap Basin Design Checklist, may also be found on the Department's website at www.in.gov/dot/div/contracts/design/dmforms/.

1. Step 1. Determine Input Flow. d_o or d_E, V_o, Fr at the culvert outlet, and d_E, the equivalent depth at the brink = $(A/2)^{0.5}$.

2. Step 2. Check *TW*. Determine if $TW/d_o \leq 0.75$.

3. Step 3. Determine d_{50}.

   a. Use Figure 34-8B, Riprap Basin Depth of Scour.
   b. Select d_{50}/d_E. Satisfactory results will be obtained if $0.25 < d_{50}/d_E < 0.45$.
   c. Obtain h_S/d_E using *Fr* and Figure 34-8B.
   d. Check if $2 < h_S/d_{50} < 4$ and repeat until d_{50} is found to be within the range.

4. Step 4. Size basin as shown in Figure 34-8A, Details of Riprap Basin Energy Dissipator.

   a. Determine length of the dissipating pool, $L_S = 10h_S$ or $3W_o$ minimum.

   b. Determine length of basin, $L_B = 15h_S$ or $4W_o$ minimum.

   c. Thickness of riprap:
      (1) Approach, $3d_{50}$ or $1.5d_{max}$
      (2) Remainder, $2d_{50}$ or $1.5d_{max}$

5. Step 5. Determine V_B.

   a. Basin exit depth, d_B = critical depth at basin exit.
   b. Basin exit velocity, $V_B = Q/W_Bd_B$.
   c. Compare V_B with the average normal flow velocity in the natural channel, V_d.

6. Step 6. High Tailwater Design.

   a. Design a basin for low tailwater conditions, Steps 1-5.

   b. Compute equivalent circular diameter, D_E, for brink area as follows:

$$A = \frac{\pi D_E^{\ 2}}{4} = d_o W_o$$

   c. Estimate centerline velocity at a series of downstream cross sections using Figure 34-8D, Distribution of Centerline Velocity for Flow from Submerged Outlets.

   d. Size riprap using HEC 11, Use of Riprap For Bank Protection.

7. Step 7. Design Filter. This is necessary unless the streambed material is sufficiently well-graded. Follow the instructions shown in HEC 11, Section 4.4.

* * * * * * * *

34-8.03 Low Tailwater, Example 34-8.1

Given: Box culvert, 2440 mm by 1830 mm
Design discharge $Q = 22.65$ m^3/s
Supercritical flow in culvert
Normal flow depth, d_o = brink depth; $d_E = 1.22$ m
Tailwater depth, $TW = 0.85$ m

1. Step 1. Determine Input Flow.

   $d_o = d_E$ for rectangular section
   $d_o = d_E = 1.22$ m
   $V_o = Q/A = 22.65/(1.22)(2.44) = 7.61$ m/s
   $Fr = V/(gd_E)^{0.5} = 7.61/[(9.81)(1.22)]^{0.5} = 2.20 < 3.0$, therefore OK

2. Step 2. Check TW.

   Determine if $TW/d_o \leq 0.75$
   $TW/d_E = 0.85/1.22 = 0.7$
   $TW/d_E < 0.75$, therefore OK

3. Step 3. Determine d_{50}.

   a. Use Figure 34-8B.

   b. Select $d_{50}/d_E = 0.45$
   $d_{50} = 0.45(1.22) = 0.55$ m

   c. Obtain h_S/d_E using $Fr = 2.2$ and $0.41 \leq d_{50}/d_E \leq 0.5$
   $h_S/d_E = 1.6$

   d. Check if $2 < h_S/d_{50} < 4$:
   $h_S = 1.22(1.6) = 1.95$ m
   $h_S/d_{50} = 1.95/0.55 = 3.55$ m
   $2 < 3.55 < 4$, therefore OK

4. Step 4. Size basin as shown in Figure 34-8A, Details of Riprap Basin Energy Dissipator.

a. Determine length of dissipating pool, L_S.
$L_S = 10h_S = 10(1.95) = 19.5$ m
minimum = $3W_o = 3(2.44) = 7.32$ m
Therefore, use $L_S = 19.5$ m

b. Determine length of basin, L_B.
$L_B = 15h_S = 15(1.95) = 29.25$ m
minimum = $4W_o = 4(2.44) = 9.76$ m
Therefore, use $L_B = 29.25$ m

c. Determine the hickness of riprap.
Approach, $3d_{50} = 3(0.55) = 1.65$ m
Remainder, $2d_{50} = 2(0.55) = 1.10$ m

5. Step 5. Determine V_B.

a. d_B = critical depth at basin exit = 1.01 m, assuming a rectangular cross section with width $W_B = 7.32$ m

b. $V_B = Q/W_B d_B = 22.65/(7.32)\ (1.01) = 3.06$ m/s

c. $V_B = 3.06$ m/s $< V_d = 5.49$ m/s

* * * * * * * *

34-8.04 High Tailwater, Example 34-8.2

Given: Data for the channel and the culvert are the same as for Example 34-8.1, except that the tailwater depth, $TW = 1.28$ m.
$TW/d_o = 1.28/1.22 = 1.05 > 0.75$
Downstream channel can tolerate only 2.13 m/s.

1. Steps 1 through 5 are the same as in Example 34-8.1.

2. Step 6. High-Tailwater Design.

a. Design a basin for the low-tailwater condition, Steps 1-5 as above:

$d_{50} = 0.55$ m, $h_S = 1.95$ m
$L_S = 19.5$ m, $L_B = 29.25$ m

b. Compute equivalent circular diameter, D_E, for the brink area as follows:

$$A = \frac{\pi D_E^{\ 2}}{4} = d_o W_o = (1.22)(2.44) = 2.98\ m^2$$

$$D_E = \left[\frac{(2.98)(4)}{\pi}\right]^{0.5} = 1.95\ m$$

V_o = 7.62 m/s

c. Estimate centerline velocity at a series of downstream cross sections using Figure 34-8D, Distribution of Centerline Velocity for Flow from Submerged Outlets.

L/D_E [1]	L	V_L/V_o	V_L	d_{50} [2]
10	19.5	0.59	4.50	0.43
15 [3]	29.25	0.37	2.82	0.18
20	39.01	0.30	2.32	0.12
21	41.15	0.28	2.32	0.12

[1] Use $W_o = D_E$ in Figure 34-8D.
[2] from Figure 34-8E, Riprap Size Versus Exit Velocity (After HEC 14).
[3] is on a logarithmic scale, therefore, interpolations must be made logarithmically.

d. Size riprap using HEC 11. The channel can be lined with the same size rock used for the basin. Protection must extend at least 41 m downstream.

34-8.05 Computer Output

The dissipator geometry can be computed using the HY-8, Culvert Analysis microcomputer program, Energy Dissipator module. The output of the culvert and channel input data, and computed geometry using this module are shown as Figure 34-8G, Riprap Stilling Basin HY-8 Program Output.

34-9.0 IMPACT BASIN USBR TYPE VI

34-9.01 Overview

Figure 34-9A, USBR Type VI Impact Dissipator, was developed by the U.S. Bureau of Reclamation (USBR). The basin requirements are as follows:

1. it is referred to as the USBR Type VI basin, or hanging baffle;
2. it is contained in a relatively small boxlike structure;
3. it requires no tailwater for successful performance;
4. it also may be used for an open channel; and
5. it is not recommended where debris or ice buildup may cause substantial clogging.

The following applies to the USBR Type VI basin.

1. Hanging Baffle. Energy dissipation is initiated by flow striking the vertical hanging baffle and being deflected upstream by the horizontal portion of the baffle and by the floor, creating horizontal eddies.

2. Notches in Baffle. Notches are provided to aid in cleaning the basin. The notches provide concentrated jets of water for cleaning. The basin is designed to carry the full discharge over the top of the baffle if the space beneath the baffle becomes completely clogged.

3. Equivalent Depth. This depth must be calculated for a pipe or irregular shaped conduit. The cross-section flow area in the pipe is converted into an equivalent rectangular cross section in which the width is twice the depth of flow.

4. Limitations. A discharge of up to 11.33 m^3/s per barrel and a velocity as high as 15.24 m/s can be used without subjecting the structure to cavitation damage.

5. Tailwater. A moderate depth of tailwater will improve performance. For best performance, set the basin so that the maximum tailwater does not exceed $h_3 + (h_2/2)$.

6. Slope. If the culvert slope is greater than 15 deg, a horizontal section of at least four culvert widths should be provided upstream.

7. End Treatment. An end sill with a low-flow drainage slot, 45-deg wingwalls, and a cutoff wall should be provided at the end of the basin.

8. Riprap. Riprap should be placed downstream of the basin for a length of at least four conduit widths.

34-9.02 Design Procedure

1. Step 1. Calculate Equivalent Depth, d_E.

a. Rectangular section, $d_E = d_o = y_o$.

b. Other type of section, $d_E = (A/2)^{0.5}$.

2. Step 2. Determine Input Flow.

a. Froude number, $Fr = V_o/(gd_E)^{0.5}$.

b. Specific energy, $H_o = d_E + V_o^2/2g$.

3. Step 3. Determine Basin Width, W.

a. Use Figure 34-9B, Design Curve for USBR Type VI Dissipator.

b. Enter with Fr and read H_o/W.

4. Step 4. Size Basin.

a. Use Figure 34-9C, Dimensions of USBR Type VI Basin, and W.

b. Obtain the remaining dimensions.

5. Step 5. Energy Loss.

a. Use Figure 34-9D, Energy Loss for USBR Type VI Dissipator.

b. Enter with Fr and read H_L/H_o.

6. Step 6. Exit Velocity, V_B.

a. Exit energy, $H_E = H_o – H_L$.

b. $H_E = d_B + V_B^2/2g$.

c. $V_B = Q/Wd_B$.

* * * * * * * *

34-9.03 Example 34-9.1

An editable version of Figure 34-9E, Impact Basin Type VI Checklist, may also be found on the Department's website at www.in.gov/dot/div/contracts/design/dmforms/.

Given: D = 1200-mm dia. pipe, S_o = 0.15, n = 0.015
Q = 8.50 m^3/s, d_o = 0.7 m, V_o = 12.19 m/s

1. Step 1. Calculate Equivalent Depth, d_E.
Other type of section, $d_E = (A/2)^{0.5}$

$A = Q/V_o = 8.50/12.19 = 0.70\ \text{m}^2$
$d_E = (0.70/2)^{0.5} = 0.59$ m

2. <u>Step 2. Determine Input Flow</u>.

a. Froude number, $Fr_o = V_o/(gd_E)^{0.5}$
$Fr = 12.19/[9.81(0.59)]^{0.5} = 5.07$

b. Specific energy, $H_o = d_E + V_o^2/2g$
$H_o = 0.59 + (12.19)^2/(2)(9.81) = 8.16$ m

3. <u>Step 3. Determine Basin Width, *W*</u>.

a. Use Figure 34-9B, Design Curve for USBR Type VI Dissipator.
b. Enter with $Fr = 5.05$ and read $H_o/W = 1.68$
c. $W = 8.16/1.68 = 4.86$ m

4. <u>Step 4. Size Basin</u>.

a. Use Figure 34-9C, Dimensions of USBR Type VI Basin, and *W*.
b. Obtain the remaining dimensions.

5. <u>Step 5. Energy Loss</u>.

a. Use Figure 34-9D, Energy Loss for USBR Type VI Dissipator.
b. Enter with $Fr = 5.05$ and read $H_L/H_o = 0.67$
c. $H_L = 0.67(8.16) = 5.47$ m

6. <u>Step 6. Exit Velocity, V_B</u>.

a. Exit energy, $H_E = H_o - H_L = 8.16 - 5.47 = 2.69$ m
b. $H_E = d_B + V_B^2/2g = 2.69$ m
c. $V_B = Q/Wd_B = 8.50/4.86\text{d}_\text{B} = 1.75/\text{d}_\text{B}$

d_B	V_B	$d_B+V_B^2/2g = 2.69$
$0.7 = d_c$	2.50	1.02
0.3	5.83	2.03
0.2	8.75	4.10
0.26	6.73	2.57
0.27	6.48	2.41
0.25	7.00	2.75, approx. 2.69, use.

34-9.04 Computer Output

The dissipator geometry can be computed using the HY-8 Culvert Analysis, microcomputer program, Energy Dissipator module. The output of the culvert and channel input data, and computed geometry using this module are shown as Figure 34-9G, USBR Type 6 Dissipator HY-8 Program Output.

34-10.0 REFERENCES

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2. G.K. Young, J.S. Krolak, HYDRAIN *Integrated Drainage Design Computer System*, Volumes 1-6, FHWA, RD-88-120, 1987.

Symbol	Definition	Unit
A	Cross-sectional area	m^2
A_o	Area of flow at culvert outlet	m^2
D	Height of culvert	mm
d_{50}	Mean diameter of riprap	mm
d_E	Equivalent depth at brink	m
d_o	Normal flow depth at brink	m
DI	Discharge Intensity Modified	(none)
Fr	Froude number	(none)
h_S	Depth of dissipator pool	m
L	Length of culvert	m
L_B	Overall length of basin	m
L_S	Length of dissipator pool	m
Q	Rate of discharge	m^3/s
S_o	Slope of streambed	m/m
TW	Tailwater depth	m
V_d	Velocity downstream	m/s
V_L	Velocity at L from brink	m/s
V_o	Normal velocity at brink	m/s
W_o	Diameter or width of culvert	mm
W_S	Width of scour hole	m

SYMBOLS, DEFINITIONS, AND UNITS

Figure 34-1A

A. Coefficient for Culvert-Outlet Scour, Cohesionless Materials

Property	α	β	θ
Depth, d_S	2.27	0.39	0.06
Width, W_S	6.94	0.53	0.08
Length, L_S	17.10	0.47	0.10
Volume, V_S	127.08	1.24	0.18

B. Coefficient C_S for Outlet Above the Bed

H_S	Depth	Width	Length	Volume
0	1.00	1.00	1.00	1.00
1	1.22	1.51	0.73	1.28
2	1.26	1.54	0.73	1.47
4	1.34	1.66	0.73	1.55
H_S is the height above bed in pipe diameters, m.				

C. Coefficient C_h for Culvert Slope

Slope %	Depth	Width	Length	Volume
0	1.00	1.00	1.00	1.00
2	1.03	1.28	1.17	1.30
5	1.08	1.28	1.17	1.30
> 7	1.12	1.28	1.17	1.30

COEFFICIENTS FOR SCOUR-HOLE ESTIMATION

Figure 34-4A

ENERGY DISSIPATOR CHECKLIST

Route Des No. Project No.
Designer: Date:
Reviewer: Date:

SCOUR EQUATIONS

$$\frac{d_s}{R_c}, \frac{W_s}{R_c}, \frac{L_s}{R_c} = C_{sCk}\left(\frac{a}{\sigma^{1/3}}\right)\left(\frac{Q}{g^{0.5}R_c^{\ 2.5}}\right)^{\beta}\left(\frac{t}{316}\right)^{\theta}$$

$$d_s, W_s, L_s = \left(\frac{C_s C_h \alpha}{\sigma^{1/3}}\right)(DI)^{\beta}\left(\frac{t}{316}\right)^{\theta}(R_c)$$

$$d_s, W_s, L_s = (F_1)(F_2)(F_3)(R_c)$$

STEP 6 – DATA SUMMARY

Parameters	Culvert	Channel
Station		
Control		
Type		
Height, *D*		
Width, *B*		
Length, *L*		
Material		
Manning's *n*		
Side Slope		
Discharge, *Q*		
Depth, *d*		
Velocity, *V*		
$Fr = V/(gd)^{0.5}$		
Flow Area, *A*		
Slope		

STEP 7A – EQUATION INPUT DATA

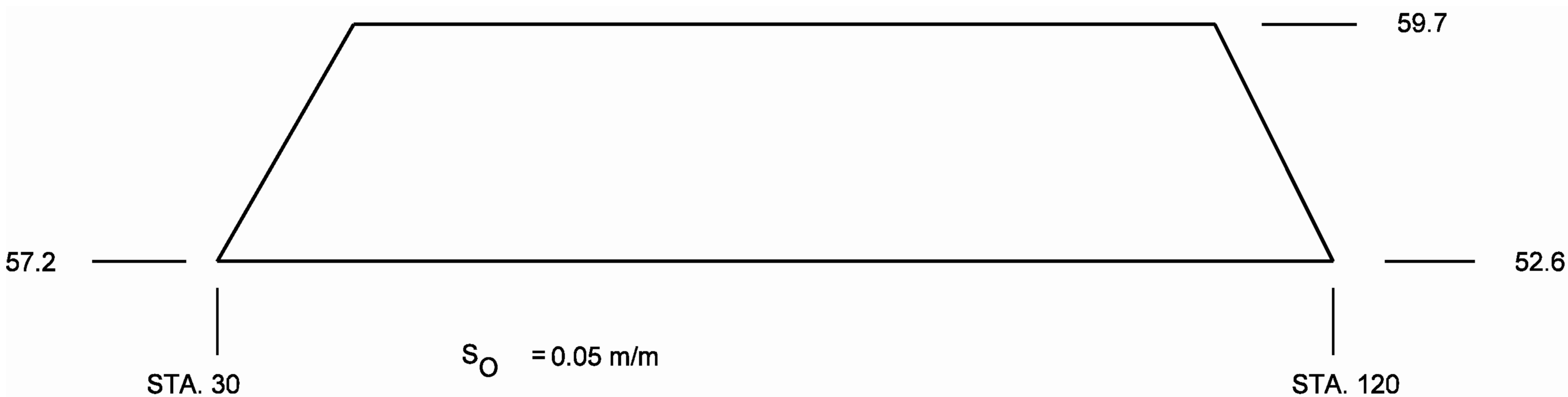
FACTOR	Value
Q = Discharge, m^3/s	
A_c = Culvert area, m^2	
P_c = Perimeter, m	
$R_c = A_c / P_c$	
DI = Discharge Intensity	
t = time of concentration	

STEP 7B – SCOUR COMPUTATION

Factor	Depth, m	Width, m	Length, m
α	2.27	6.94	17.10
β	0.39	0.53	0.47
θ	0.06	0.08	0.10
F_1			
F_2			
F_3			
$(F_1)(F_2)(F_3)(R_c)$			
Allowable			

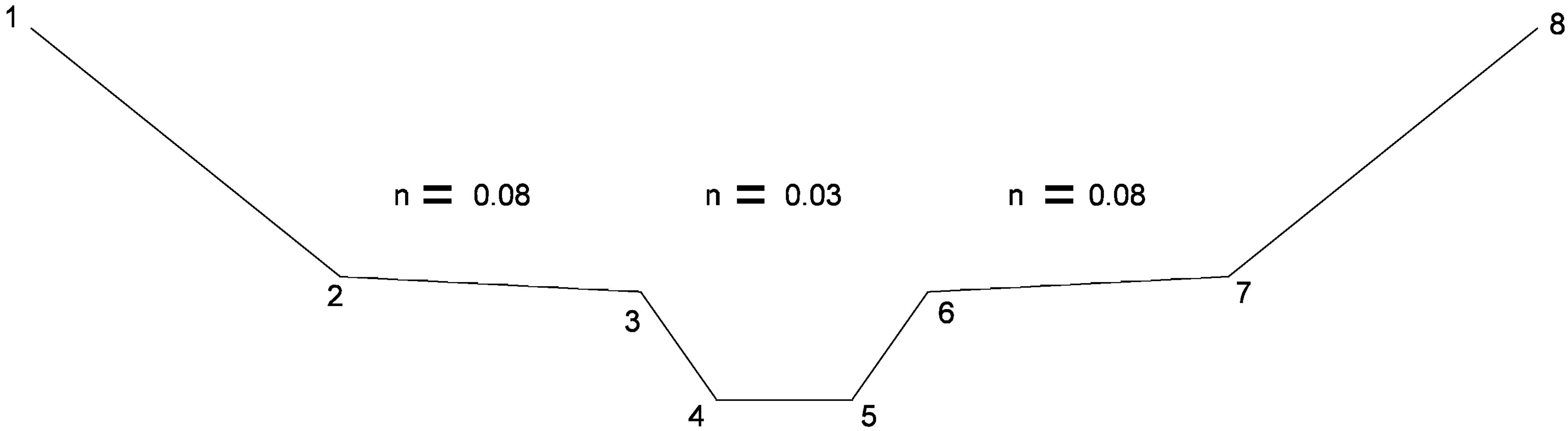
If calculated scour > allowable scour, and:

1. $Fr > 3$, design a SAF basin
2. $Fr \leq 3$, design a riprap basin
3. $Fr \leq 3$, design a USBR Type VI



Energy Dissipator Design Example - Site Data

Figure 34-6.1



ENERGY DISSIPATOR DESIGN EXAMPLE - DOWNSTREAM CHANNEL SECTION

Figure 34-6.2

ENERGY DISSIPATOR CHECKLIST

Project No.	I-31(88) over Example Creek		
Designer	PLT	Date	8/26/88
Reviewer	Te Anh Ngo, OK. DOT	Date	6/2/97

SCOUR EQUATIONS

$$\frac{d_S}{R_C}, \frac{W_S}{R_C}, \frac{L_S}{R_C} = C_S C_h \left[\frac{\alpha}{\sigma^{1/3}}\right] \left[\frac{Q}{g^{.5} R_C^{2.5}}\right]^{\beta} \left[\frac{t}{316}\right]^{\theta}$$

$d_S, W_S, L_S = [C_S C_h \alpha/\sigma^{1/3}][DI]^{\beta}[t/316]^{\theta} R_c$

$d_S, W_S, L_S = [F_1]\ [F_2]\ [F_3]\ R_c$

STEP 6 - DATA SUMMARY

Parameters	Culvert	Channel
Station	30 + 48	121 + 92
Control	Inlet	Super.
Type	RCB	Natural
Height, D	1830 mm	2.29 m
Width, B	2135 mm	8.84 m
Length, L	91.45 m	-----
Material	Concrete	Gravel
Manning's n	0.012	0.03 & 0.08
Side Slope	---	1V:1H
Discharge, Q	11.33 m^3/s	11.33 m^3/s
Depth, d	0.56 m	0.86 m
Velocity, V	8.61 m/s	5.35 m/s
$Fr = V/(gd)^{0.5}$	3.54	2.01
Flow Area, A	1.30 m^2	2.12 m^2
Slope	0.05 m/m	0.05 m/m

STEP 7A - EQUATION INPUT DATA

FACTOR	VALUE
Q = Discharge, m^3/s	11.33 m^3/s
A_c = Culvert area, m^2	3.9 m^2
P_c = Perimeter, m	7.92 m
$R_c = A_c / P_c$	0.49
DI= Discharge Intensity	21.1
t = time of concentration	30 minutes

STEP 7B - SCOUR COMPUTATION

Factor	Depth	Width	Length
α	2.27	6.94	17.10
β	0.39	0.53	0.47
θ	0.06	0.08	0.10
F_1	1.92	5.85	14.42
F_2	3.28	5.03	4.19
F_3	0.87	0.83	0.79
$[F_1][F_2][F_3]R_c$	2.68	11.92	23.39
Allowable	2.13*	8.84*	18.39*

If calculated scour > Allowable and:
1. Fr > 3, design a SAF basin
2. Fr < 3, design a riprap basin
3. Fr < 3, design a USBR Type VI

* These values are not standards. They may vary, depending on design criteria. In this case, calculated scour > Allowable and Fr>3: Recommend a SAF Basin.

Figure 34-6A

FHWA CULVERT ANALYSIS, HY-8, VERSION 6.0

CURRENT DATE	CURRENT TIME	FILE NAME	FILE DATE
06-04-2003	10:56:51	CHPTR11A	06-04-2003

CULVERT AND CHANNEL DATA

CULVERT NO. 1
CULVERT TYPE: 2135 mm x 1830 mm BOX
CULVERT LENGTH = 91.554 m
NO. OF BARRELS = 1.0
FLOW PER BARREL = 11.330 m^3/s
INVERT ELEVATION = 52.580 m
OUTLET VELOCITY = 8.745 m/s
OUTLET DEPTH = 0.616 m

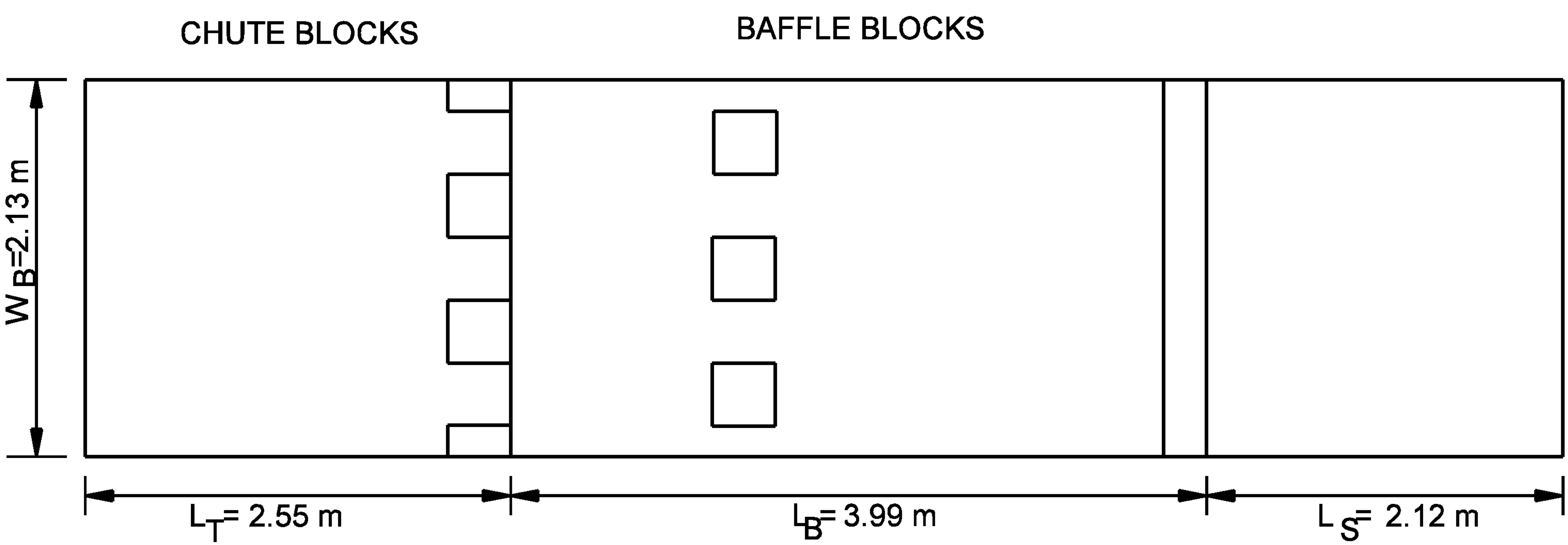
DOWNSTREAM CHANNEL
CHANNEL TYPE : IRREGULAR
BOTTOM WIDTH = 2.100 m
TAILWATER DEPTH = 0.860 m
TOTAL DESIGN FLOW = 11.330 m^3/s
BOTTOM ELEVATION = 52.581 m
NORMAL VELOCITY = 5.354 m/s

SCOUR HOLE GEOMETRY AND SOIL DATA

LENGTH = 28.686 m
WIDTH = 16.076 m
DEPTH = 3.015 m
VOLUME = 499.995 m^3
MAXIMUM SCOUR OCCURS 11.474 m DOWNSTREAM OF CULVERT
SOIL TYPE: NONCOHESIVE
SAND SIZES:
D16 = 8 mm
D50 = 14 mm
D84 = 18 mm

SCOUR HOLE GEOMETRY HY-8 PROGRAM OUTPUT

Figure 34-6B



ST. ANTHONY FALLS BASIN EXAMPLE - BLOCK DESIGN

Figure 34-7.1

ST. ANTHONY FALLS (SAF) BASIN CHECKLIST

Route Project No.

Designer Date

Reviewer Date

SAF BASIN DESIGN VALUES	TRIAL 1	FINAL TRIAL
Type		
Flare (z:1)		
Width, W_B		
Depression, B_d		
$S_S = S_T$		
Depth, d_o		
Velocity, V_o		
$B_o = d_o + V_o^2/2g$		
Depth, d_1		
Velocity, V_1		
Fr_1		
d_j		
L_B		
d_2		
L_S		
$L_T = B_d / S_T$		
$L = L_B + L_S + L_T$		
$B_d = LS_o + TW$		

DIMENSIONS OF ELEMENTS	TRIAL 1	FINAL TRIAL	DIMENSIONS OF ELEMENTS	TRIAL 1	FINAL TRIAL
CHUTE BLOCK			BAFFLE BLOCK		
Height, h_1			Height, h_3		
Width, W_1			Width, W_3		
Spacing, W_2			Spacing, W_4		
Block No., N_C			Block No., N_B		
END SILL			SIDE WALL		
Height, h_4			Height, h_5		

ST. ANTHONY FALLS (SAF) BASIN

Project No. Example Problem
Designer ______ Date ______
Reviewer Te Anh Ngo Date 9/19/96

SAF BASIN DESIGN VALUES	TRIAL 1	FINAL TRIAL
Type	Rect.	Rect.
Flare (Z:1)	1:1	1:1
Width, W_B	2.13	2.13
Depression, B_d	1.83	2.21
$S_S = S_T$	1:1	1:1
Depth, d_o	0.62	0.62
Velocity, V_o	8.61	8.61
$B_o = d_o + V_o^2/2g$	6.23	6.81
Depth, d_1	0.50	0.48
Velocity, V_1	10.64	11.08
Fr_1	4.76	5.11
d_j	3.15	3.16
L_B	4.30	4.18
d_2	2.86	2.82
L_S	2.00	1.96
$L_T = B_d / S_T$	1.83	2.41
$L = L_B + L_S + L_T$	8.13	8.55
$B_d - LS_o + TW$	2.28	2.84

DIMENSIONS OF ELEMENTS	TRIAL 1	FINAL TRIAL	DIMENSIONS OF ELEMENTS	TRIAL 1	FINAL TRIAL
CHUTE BLOCK			BAFFLE BLOCK		
Height, h_1	0.48	0.48	Height, h_3	0.48	0.48
Width, W_1	0.35	0.35	Width, W_3	0.35	0.35
Spacing, W_2	0.35	0.35	Spacing, W_4	0.35	0.35
Block No., N_C	3	3	Block No., N_B	3	3
END SILL			SIDE WALL		
Height, h_4	0.22	0.22	Height, h_5	3.86	3.86

ST. ANTHONY FALLS BASIN
(Example Problem)
Figure 34-7B

FHWA CULVERT ANALYSIS, HY-8, VERSION 6.0

CURRENT DATE	CURRENT TIME	FILE NAME	FILE DATE
09-19-2003	15:26:05	CHPTR11A	09-19-2003

CULVERT AND CHANNEL DATA

CULVERT NO. 1	DOWNSTREAM CHANNEL
CULVERT TYPE: 2135 mm x 1830 mm BOX	CHANNEL TYPE: IRREGULAR
CULVERT LENGTH = 91.554 m	BOTTOM WIDTH = 2.135 m
NO. OF BARRELS = 1.0	TAILWATER DEPTH = 0.860 m
FLOW PER BARREL = 11.330 m^3/s	TOTAL DESIGN FLOW = 11.330 m^3/s
INVERT ELEVATION = 52.580 m	BOTTOM ELEVATION = 52.581 m
OUTLET VELOCITY = 8.611 m/s	NORMAL VELOCITY = 5.354 m/s
OUTLET DEPTH = 0.616 m	

ST. ANTHONY FALLS BASIN -- FINAL DESIGN

LB = 4.220 m	LS = 4.163 m	LT = 5.557 m
L = 13.940 m	Y1 = 0.461 m	Y2 = 2.896 m
Z1 = 49.802 m	Z2 = 49.802 mm	Z3 = 51.883 m
WB = 2.135 m	WB3 = 2.135 m	

------------------------------ CHUTE BLOCKS ------------------------------

H1 = 0.461 m	W1 = 0.356 m	W2 = 0.356 m	NC = 3.000

------------------------------ BAFFLE BLOCKS -----------------------------

W3 = 0.356 m	W4 = 0.356 m	NB = 3.000
H3 = 0.461 m		LCB = 1.407 m

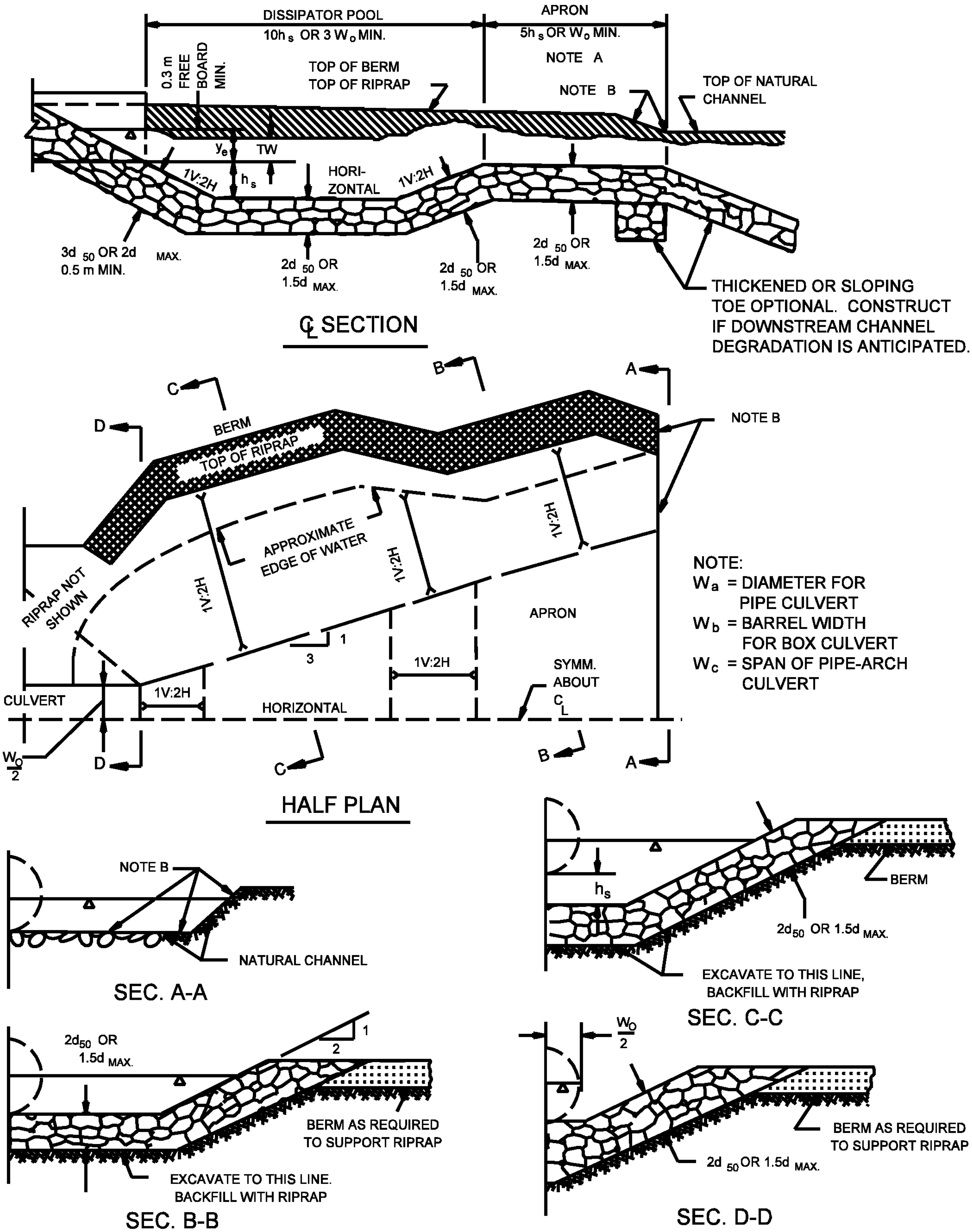
------------------------------ END SILL ----------------------------

H4 = 0.237 m

BASIN OUTLET VELOCITY = 5.354 m/s

ENERGY DISSIPATOR HY-8 PROGRAM OUTPUT

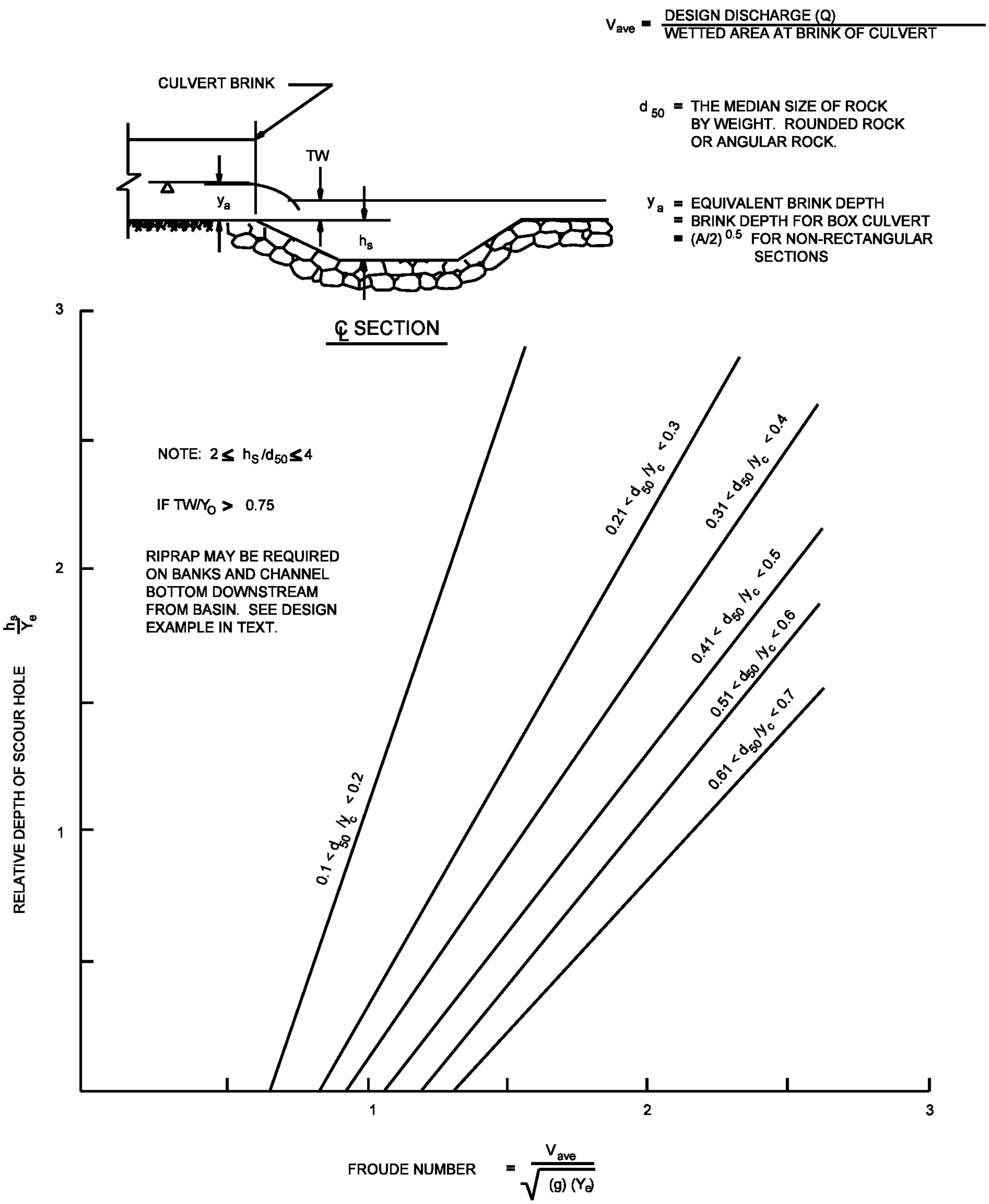
Figure 34-7C



NOTE A - IF EXIT VELOCITY OF BASIN IS SPECIFIED, EXTEND BASIN AS REQURIED TO OBTAIN SUFFICIENT CROSS-SECTIONAL AREA AT SECTION A-A SUCH THAT Q_{des}/(CROSS SECTION AREA AT SEC. A-A) = SPECIFIED EXIT VELOCITY.

NOTE B - WARP BASIN TO CONFORM TO NATURAL STREAM CHANNEL. TOP OF RIPRAP IN FLOOR OF BASIN SHOULD BE AT THE SAME ELEVATION OR LOWER THAN NATURAL CHANNEL BOTTOM AT SEC. A-A.

DETAILS OF RIPRAP BASIN ENERGY DISSIPATOR
Figure 34-8A



RIPRAP BASIN DEPTH OF SCOUR

Figure 34-8B

RIPRAP BASIN CHECKLIST

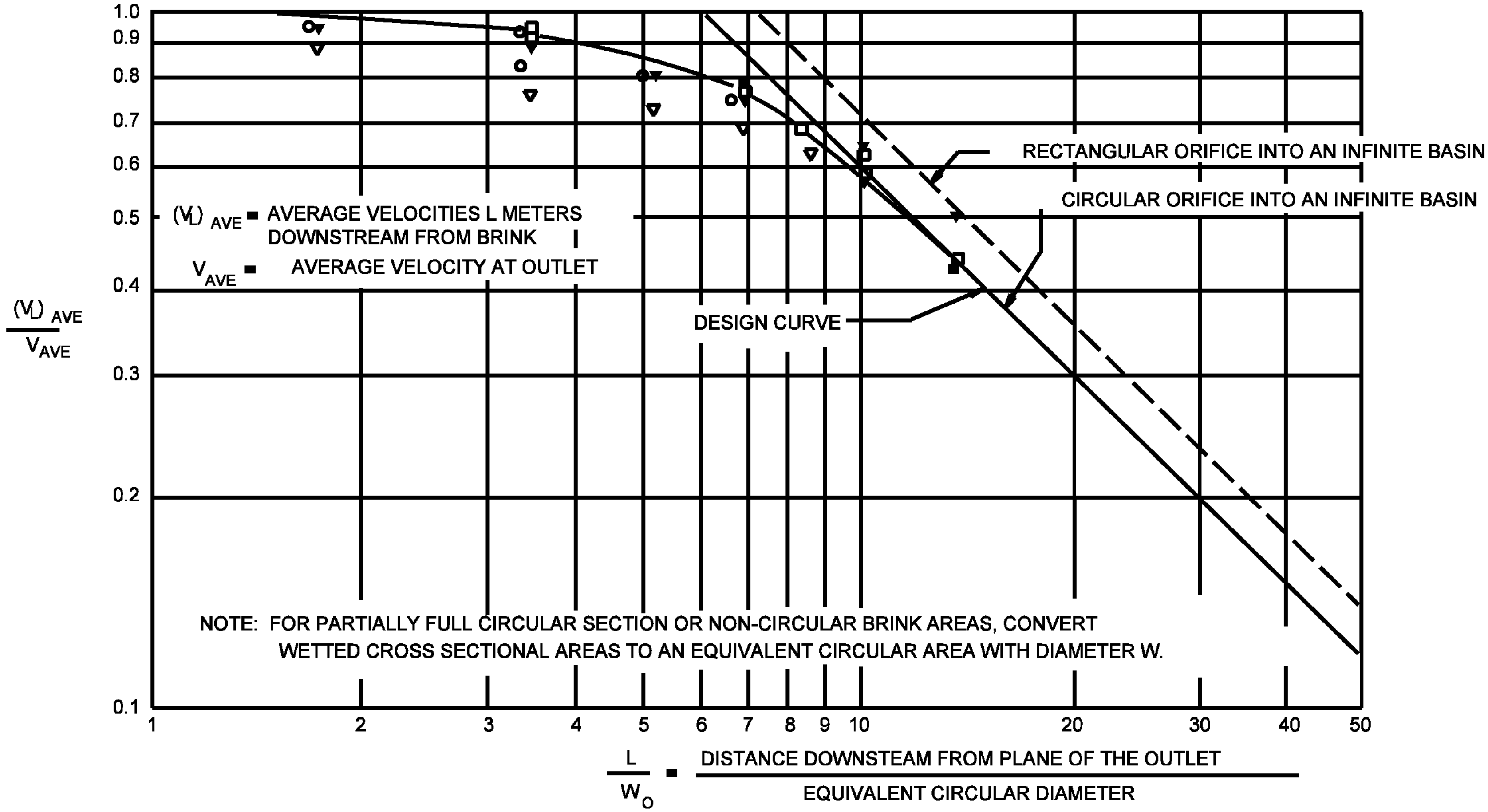
Route	Project No.
Designer	Date
Reviewer	Date

DESIGN VALUES (*IDM* Figure 34-8B)	TRIAL 1	FINAL TRIAL
Equivalent Depth, d_E		
D_{50}/d_E		
D_{50}		
Froude No., Fr		
h_S/d_E		
h_S		
h_S/D_{50}		
$2 < h_S/D_{50} < 4$		

BASIN DIMENSIONS		METERS
Pool length is the larger of:	$10h_S$	
	$3W_o$	
Basin length is the larger of:	$15h_S$	
	$4W_o$	
Approach Thickness	$3D_{50}$	
Basin Thickness	$2D_{50}$	

TAILWATER CHECK	
Tailwater, TW	
Equivalent depth, d_E	
TW/d_E	
IF $TW/d_E > 0.75$, calculate riprap downstream using *IDM* Figure 34-8D	
$D_E = (4A_c/\pi)^{0.5}$	

DOWNSTREAM RIPRAP (*IDM* Figure 34-8D)				
L/D_E	L	V_L/V_o	V_L	D_{50}

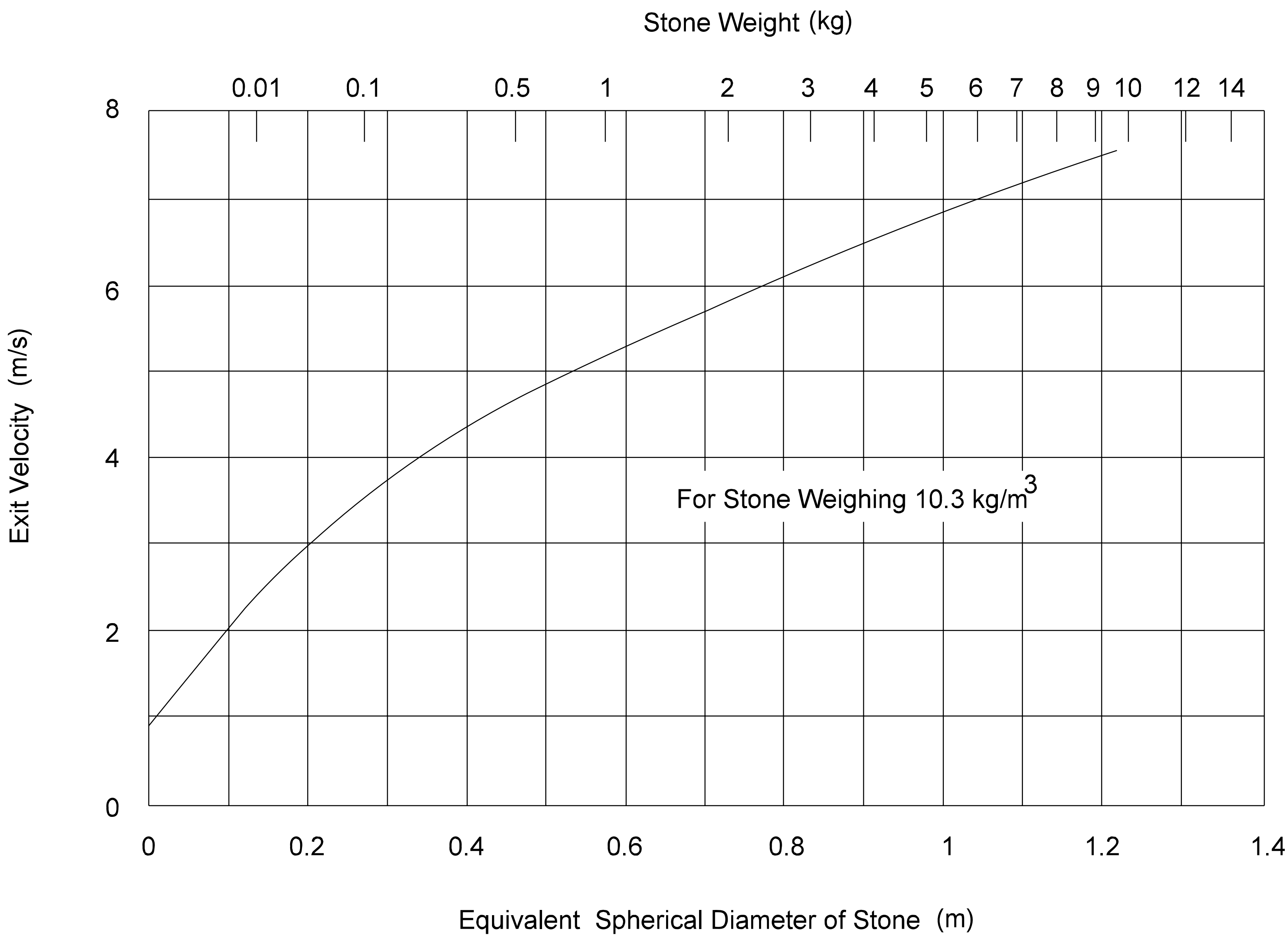


SYM	W_O (m)	Q (m^3/s)	V_{AVE} (m/s)	TW (m)
□	0.44	0.64	4.60	0.49
□	0.44	0.41	3.14	0.49
○	0.94	1.85	2.83	0.94
●	0.94	2.38	3.63	0.94
▽	0.44	0.59	4.27	0.38
▽	0.44	0.39	2.83	0.38

Note: To be used for predicting channel velocities downstream from culvert outlets where hihg tailwater prevails. Velocities obtained from te uf this figure can be used with Figure 2 of HEC 11 for sizing rip rap. (Do not us Fig of HEC 11: use Mean Velocity Values.)

DISTRIBUTION OF CENTERLINE VELOCITY FLOW FROM SUBMERGED OUTLETS

Figure 34-8D



RIPRAP SIZES VERSUS EXIT VELOCITY (AFTER HEC 14)

Figure 34-8E

RIPRAP BASIN CHECKLIST

Project No. ______________________________

Designer ________________________ Date __________

Reviewer ________________________ Date __________

DESIGN VALUES (*IDM* Figure 34-8B)	TRIAL1	FINAL TRIAL
Equivalent Depth, d_E	1.22 m	1.22 m
D_{50}/d_E	0.45	0.45
D_{50}	0.55 m	0.55 m
Froude No., Fr	2.20	2.20
h_S/d_E	1.60	1.60
h_S	1.95	1.95
h_S/D_{50}	3.55	3.55
$2 < h_S/D_{50} < 4$	OK	

BASIN DIMENSIONS		METERS	
Pool length is the larger of:	$10h_S$	19.5	19.5
	$3W_o$	7.32	
Basin length is the larger of:	$15h_S$	29.2	29.2
	$4W_o$	9.76	
Approach Thickness	$3D_{50}$	1.65	
Basin Thickness	$2D_{50}$	1.10	

TAILWATER CHECK	
Tailwater, TW	1.28 m
Equivalent depth, d_E	1.22 m
TW/d_E	1.05
IF $TW/d_E > 0.75$, calculate riprap downstream using *IDM* Figure 34-8D	
$D_E = (4A_c/\pi)^{0.5}$	

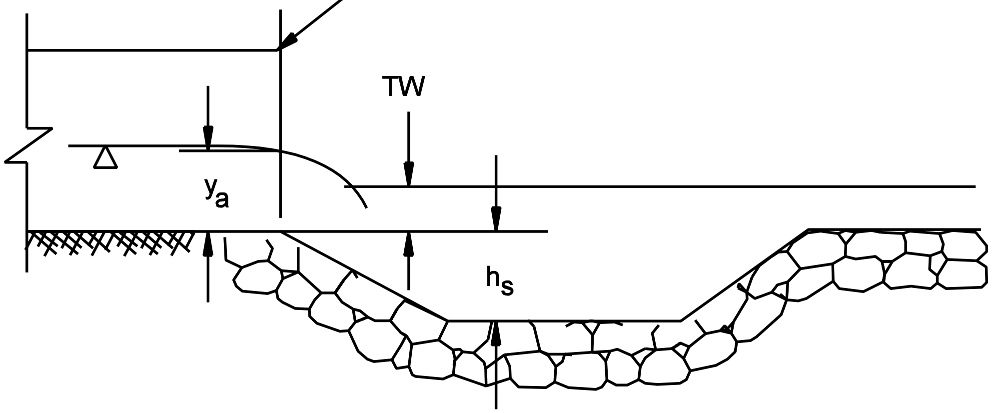
DOWNSTREAM RIPRAP (*IDM* Figure 34-8D)				
L/D_E	L	V_L/V_o	V_L	D_{50}
10	19.5	0.59	4.5	0.43
15	29.25	0.37	2.82	0.18
20	39.01	0.30	2.32	0.12
21	41.15	0.28	2.32	0.12

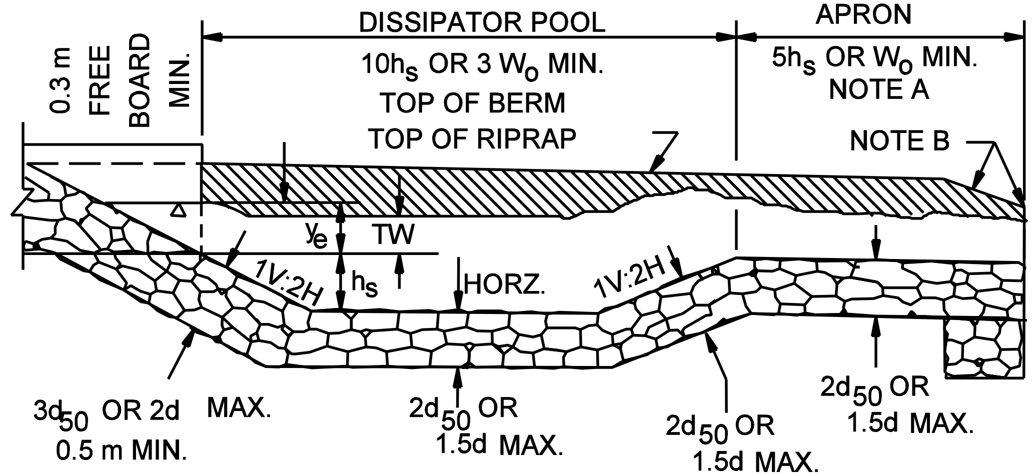
Click When Done

Clear Data

Riprap Basin Design Example Details

Back To Design Example





RIPRAP BASIN DESIGN EXAMPLE DETAILS

FHWA CULVERT ANALYSIS, HY-8, VERSION 6.0

CURRENT DATE	CURRENT TIME	FILE NAME	FILE DATE
06-02-2003	15:23:59	ENERGY3	06-02-2003

CULVERT AND CHANNEL DATA

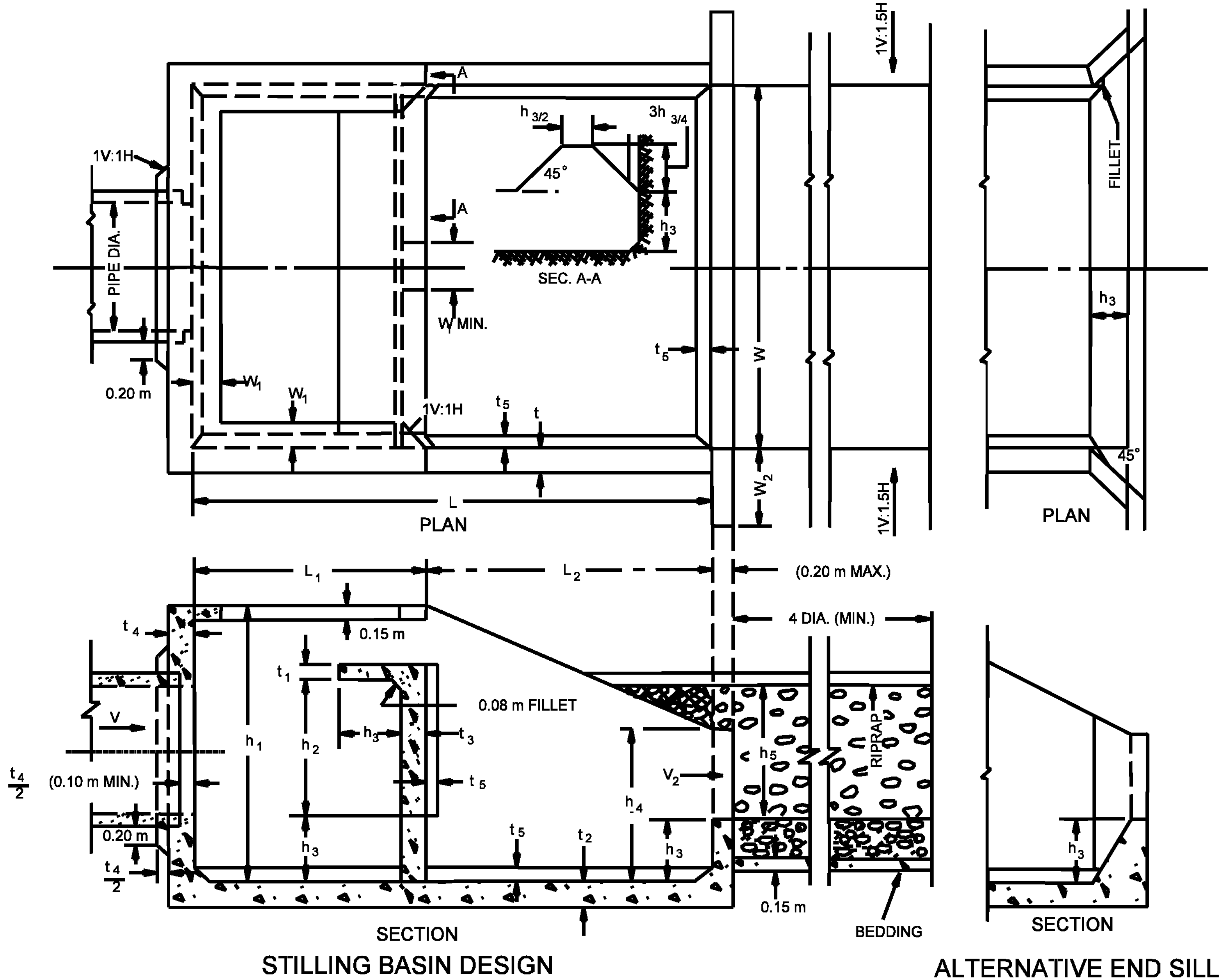
CULVERT NO. 1	DOWNSTREAM CHANNEL
CULVERT TYPE: 2400 mm x 1830 mm BOX	CHANNEL TYPE: IRREGULAR
CULVERT LENGTH = 91.453 m	BOTTOM WIDTH = 2.400
NO. OF BARRELS = 1.0	TAILWATER DEPTH = 0.851 m
FLOW PER BARREL = 22.653 m^3/s	TOTAL DESIGN FLOW = 22.653 m^3/s
INVERT ELEVATION = 52.578 m	BOTTOM ELEVATION = 52.581 m
OUTLET VELOCITY = 7.745 m/s	NORMAL VELOCITY = 9.644 m/s
OUTLET DEPTH = 1.219 m	

RIPRAP STILLING BASIN -- FINAL DESIGN

THE LENGTH OF THE BASIN	= 29.352 m
THE LENGTH OF THE POOL	= 19.568 m
THE LENGTH OF THE APRON	= 9.784 m
THE WIDTH OF THE BASIN AT THE OUTLET	= 2.400 m
THE DEPTH OF POOL BELOW CULVERT INVERT	= 1.957 m
THE THICKNESS OF THE RIPRAP ON THE APRON	= 2.000 m
THE THICKNESS OF THE RIPRAP ON THE REST OF THE BASIN	= 1.500 m
THE BASIN OUTLET VELOCITY	= 5.246 m/s
THE DEPTH OF FLOW AT BASIN OUTLET	= 1.799 m

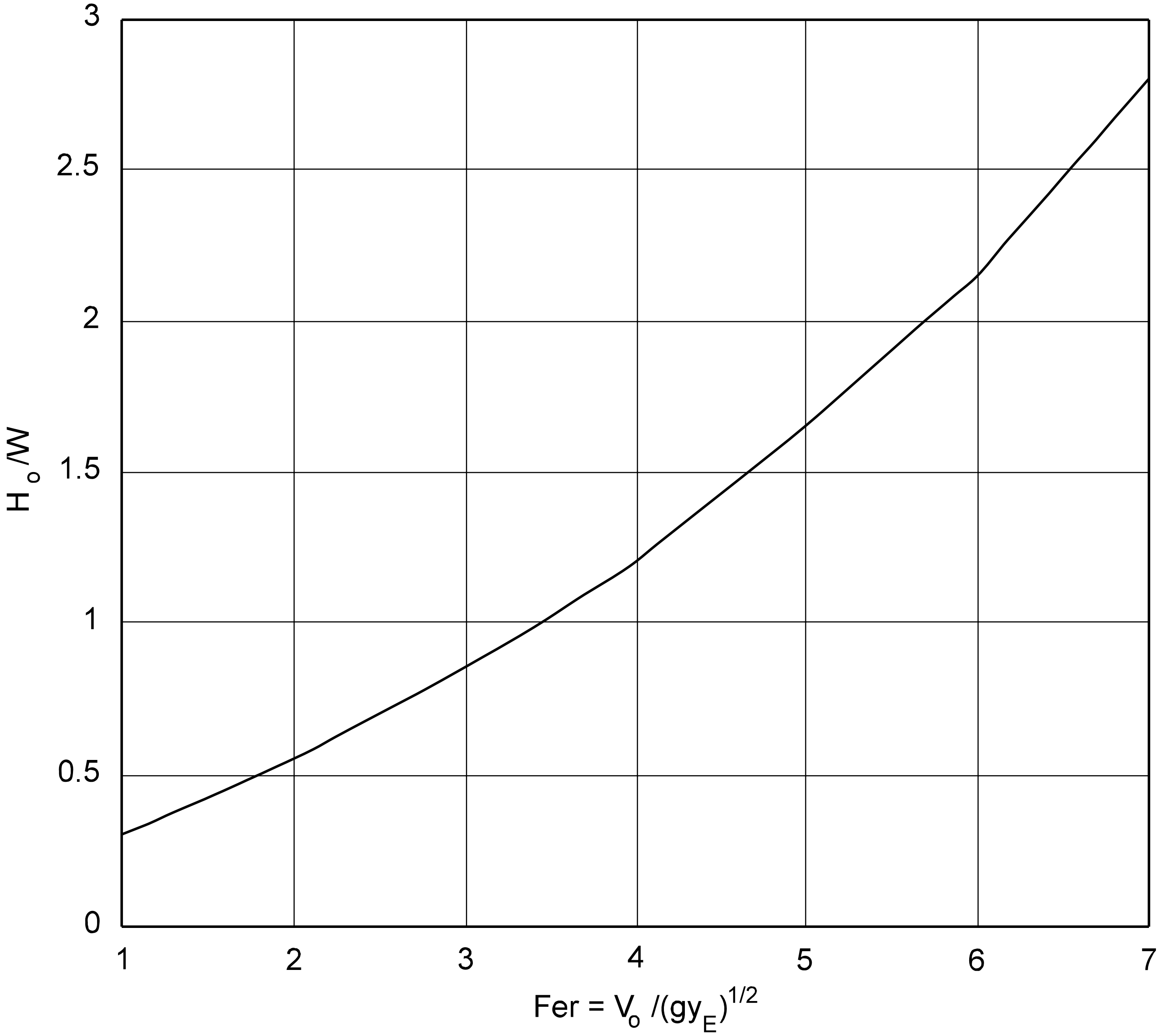
RIPRAP STILLING BASIN HY-8 PROGRAM OUTPUT

Figure 34-8G



USBR TYPE VI (IMPACT) DISSIPATOR

Figure 34-9A



DESIGN CURVE FOR USBR TYPE VI DISSIPATOR

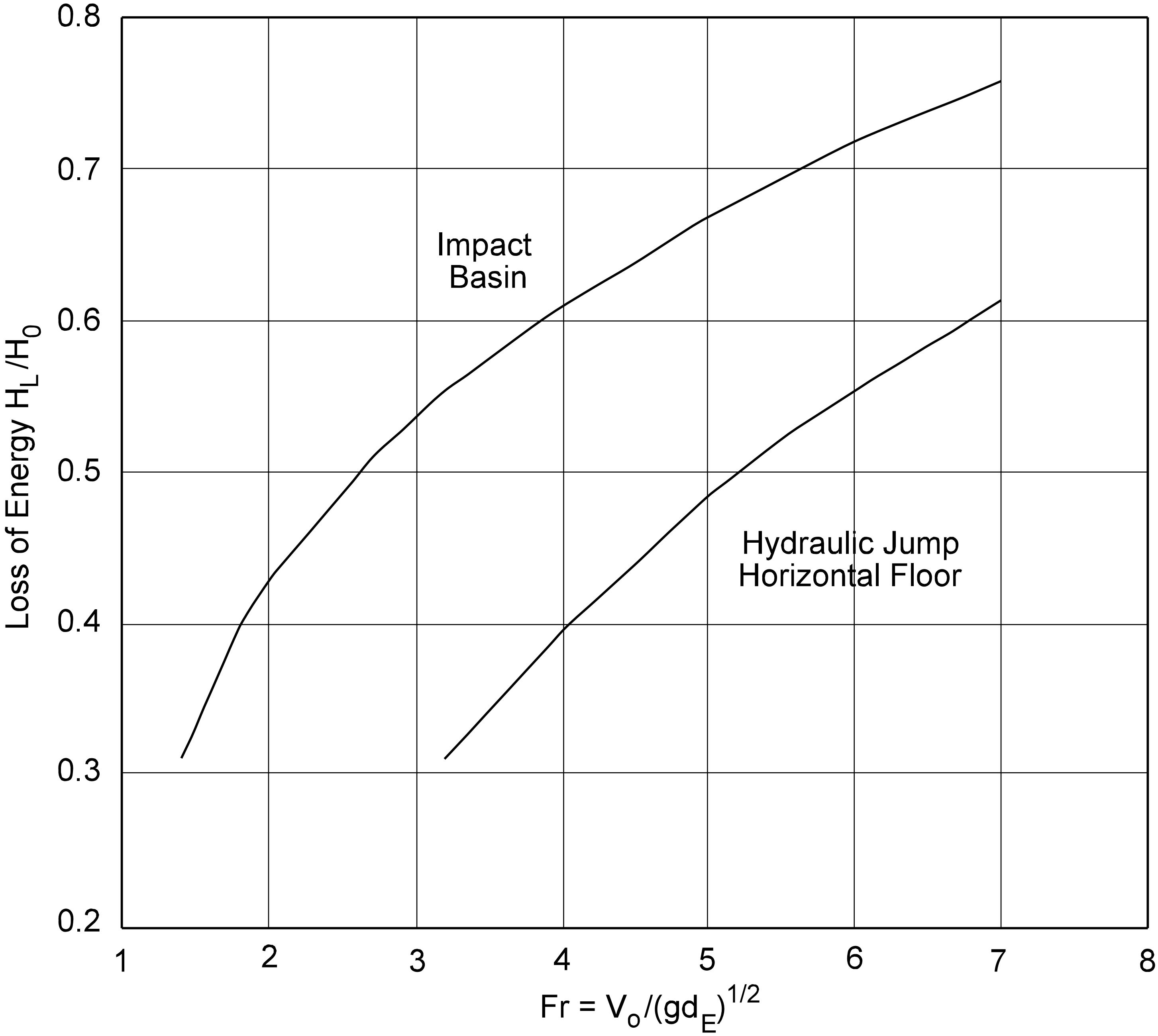
Figure 34-9B

W	h_1	h_2	h_3	h_4	*L*	L_1	L_2
1.0	0.79	0.38	0.17	0.43	1.40	0.59	0.79
1.5	1.16	0.57	0.25	0.62	2.00	0.88	1.16
2.0	1.54	0.75	0.33	0.83	2.68	1.14	1.54
2.5	1.93	0.94	0.42	1.04	3.33	1.43	1.93
3.0	2.30	1.12	0.50	1.25	4.02	1.72	2.30
3.5	2.68	1.32	0.58	1.46	4.65	2.00	2.68
4.0	3.12	1.51	0.67	1.67	5.33	2.28	3.08
4.5	3.46	1.68	0.75	1.88	6.00	2.56	3.46
5.0	3.82	1.87	0.83	2.08	6.52	2.84	3.82
5.5	4.19	2.03	0.91	2.29	7.29	3.12	4.19
6.0	4.60	2.25	1.00	2.50	7.98	3.42	4.60
W	W_1	W_2	t_1	t_2	t_3	t_4	t_5
1.0	0.08	0.26	0.15	0.15	0.15	0.15	0.08
1.5	0.13	0.42	0.15	0.15	0.15	0.15	0.08
2.0	0.15	0.55	0.15	0.15	0.15	0.15	0.08
2.5	0.18	0.68	0.16	0.18	0.18	0.16	0.08
3.0	0.22	0.83	0.20	0.20	0.22	0.20	0.08
3.5	0.26	0.91	0.20	0.23	0.23	0.21	0.10
4.0	0.30	0.91	0.20	0.28	0.25	0.25	0.10
4.5	0.36	0.91	0.20	0.30	0.30	0.30	0.13
5.0	0.39	0.91	0.22	0.31	0.30	0.30	0.15
5.5	0.41	0.91	0.22	0.33	0.33	0.33	0.18
6.0	0.45	0.91	0.25	0.36	0.35	0.35	0.19

Note: The h, L, *and* W *values in are in meters. The* t *values are in seconds.*

DIMENSIONS OF USBR TYPE VI BASIN

Figure 34-9C



ENERGY LOSS FOR USBR TYPE VI DISSIPATOR

Figure 34-9D

USBR TYPE VI BASIN CHECKLIST

Route	Project No.
Designer	Date
Reviewer	Date

DETERMINE BASIN WIDTH, *W* (*IDM* Figure 34-9B)	TRIAL 1	FINAL TRIAL	CHECK OUTLET VELOCITY, V_o			
Equivalent Depth, d_E			H_L/H_o (*IDM* Figure 34-9D)			
V_o (ft/s)			$H_L = (H_L/H_o)H_o$			
$H_o = d_E + V_o^2/2g$			$H_e = H_o - H_L$			
Froude No, *Fr*			d_B			
H_o/W			$V_B = (Q/W)/d_B$			
$W = H_o/(H_o/W)$			$(H_e)_T = d_B + V_B^2/2g$			

BASIN DIMENSIONS (m) FROM *IDM* FIGURE 34-9C

W	h_1	h_2	h_3	h_4	L	L_1	L_2
W	W_1	W_2	t_1	t_2	t_3	t_4	t_5

USBR TYPE VI BASIN CHECKLIST

Project No. ______________________________

Designer _______________________ Date ___________

Reviewer _______________________ Date ___________

DETERMINE BASIN WIDTH, W (*IDM* Figure 34-9B)	TRIAL 1	FINAL TRIAL
Equivalent Depth, d_E	1.22 m	3.55
V_o (m/s)	0.45	OK
$H_o = d_E + V_o^2/2g$	0.55 m	1.22 m
Froude No, Fr	2.20	0.45
H_o/W	1.60	0.55 m
$W = H_o/(H_o/W)$	1.95	2.20

CHECK OUTLET VELOCITY, V_o			
H_L/H_o (*IDM* Figure 34-9D)	1.60		
$H_L = (H_L/H_o)H_o$	1.95		
$H_e = H_o - H_L$	3.55		
d_B		19.5	7.32
$V_B = (Q/W)/d_B$	19.5	29.25	9.76
$(H_e)_T = d_B + V_B^2/2g$	29.2	1.65	

BASIN DIMENSIONS (METERS) FROM *IDM* FIGURE 34-9C

W	h_1	h_2	h_3	h_4	L	L_1	L_2
1.10		1.28 m	1.22 m	1.05		10	19.5

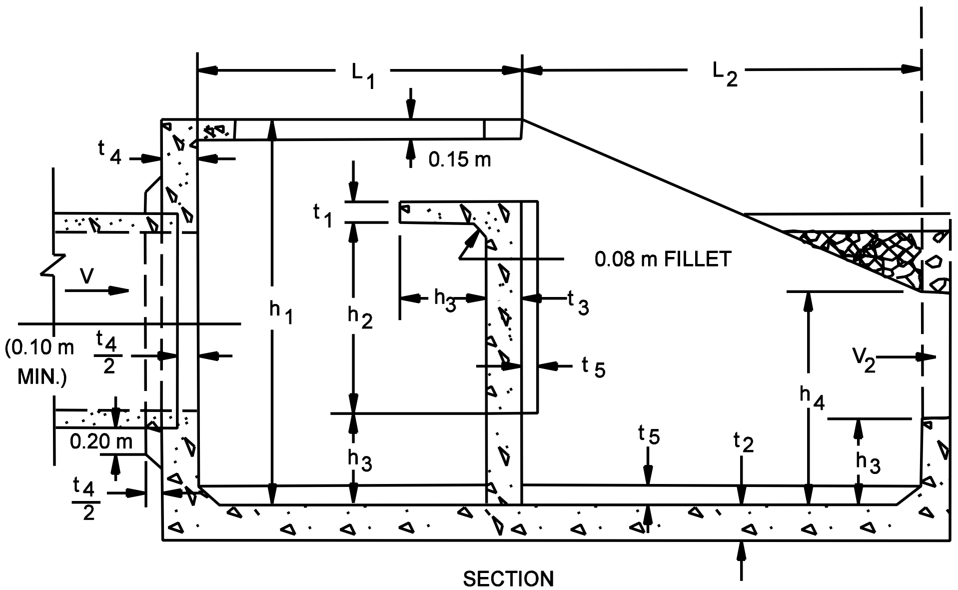
W	W_1	W_2	t_1	t_2	t_3	t_4	t_5
0.59	4.5	0.43	15	29.25	0.37	2.82	0.18

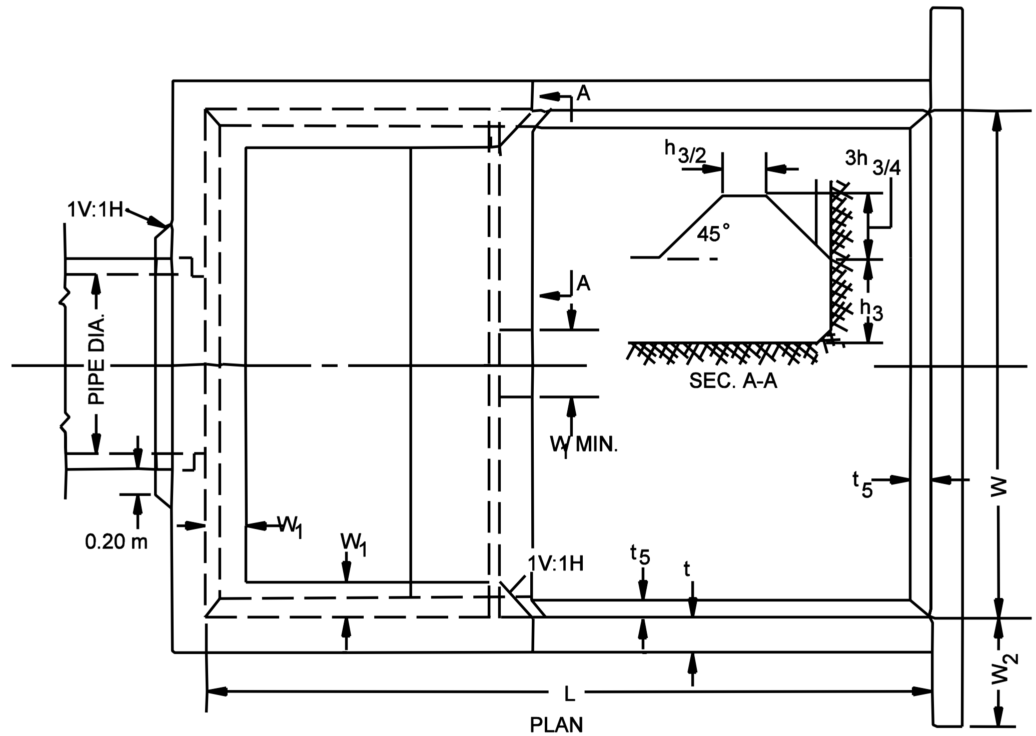
Click When Done

Clear Data

USBR Basin Type VI Details (Design Example)

Back To Design Example





USBR BASIN TYPE VI DETAILS
(Design Example)

FHWA CULVERT ANALYSIS, HY-8, VERSION 6.0

CURRENT DATE	CURRENT TIME	FILE NAME	FILE DATE
06-02-2003	16:13:53	ENERGY4	06-02-2003

CULVERT AND CHANNEL DATA

CULVERT NO. 1	DOWNSTREAM CHANNEL
CULVERT TYPE: 1200 mm CIRCULAR	CHANNEL TYPE: IRREGULAR
CULVERT LENGTH = 92.464 m	BOTTOM WIDTH = 1.500 m
NO. OF BARRELS = 1.0	TAILWATER DEPTH = 0.768 m
FLOW PER BARREL = 8.500 m^3/s	TOTAL DESIGN FLOW = 8.500 m^3/s
INVERT ELEVATION = 52.570 m	BOTTOM ELEVATION = 52.581 m
OUTLET VELOCITY = 7.516 m/s	NORMAL VELOCITY = 4.876 m/s
OUTLET DEPTH = 1.201 m	

USBR TYPE 6 DISSIPATOR - FINAL DESIGN

BASIN OUTLET VELOCITY = 0.992 m/s

W = 4.877 m	W1 = 0.381 m	W2 = 0.914 m
L = 6.502 m	L1 = 2.769 m	L2 = 3.734 m
H1 = 3.734 m	H2 = 1.829 m	H3 = 0.813 m
H4 = 2.032 m	T1 = 0.229 m	T2 = 0.305 m
T3 = 0.305 m	T4 = 0.305 m	T5 = 0.152 m

USBR TYPE 6 DISSIPATOR HY-8 PROGRAM OUTPUT

Figure 34-9G