CHAPTER 7

ENERGY DISSIPATION

7.5 Riprap Basin Design

7.5.1 Uses

One method to reduce the exit velocities from outlets is to install a riprap basin. A riprap outlet basin is a preshaped scour hole lined with riprap that functions as an energy dissipator by forming a hydraulic jump.

7.5.2 Basin Features

General details of the basin recommended in this chapter are shown on Figure 7.5.2-1. Principal features of the basin are:

7.5.2.1 The basin is preshaped and lined with riprap of median size (d_{50}).

7.5.2.2 The floor of the riprap basin is constructed at an elevation of h_s below the culvert invert. The dimension h_s is the approximate depth of scout that would occur in a thick pad of riprap of size d_{50} if subjected to design discharge. The ratio of h_s to d_{50} of the material should be between 2 and 4.

7.5.2.3 The length of the energy dissipating pool is 10 x h_s or 3 x W_O whichever is larger. The overall length of the basin is 15 x h_s or 4 x W_O whichever is larger.

7.5.3 Design Procedure

The following procedure should be used for the design of riprap basins.

1. Estimate the flow properties at the brink (outlet) of the culvert. Establish the outlet invert elevation such that $TW/y_o \leq 0.75$ for the design discharge.

2. For subcritical flow conditions (culvert set on mild or horizontal slope) utilize Figures 7.5.3-1 or 7.5.3-2 to obtain y_o/D, then obtain V_o by dividing Q by the wetted areas associated with y_o. D is the height of a box culvert. If the culvert is on a steep slope, V_O will be the normal velocity obtained by using the Manning equation for appropriate slope, section, and discharge.

3. For channel protection, compute the Froude number for brink conditions with $y_e = (A/2)^{1.5}$ Select d_{50}/y_e appropriate for locally available riprap (usually the most satisfactory results will be

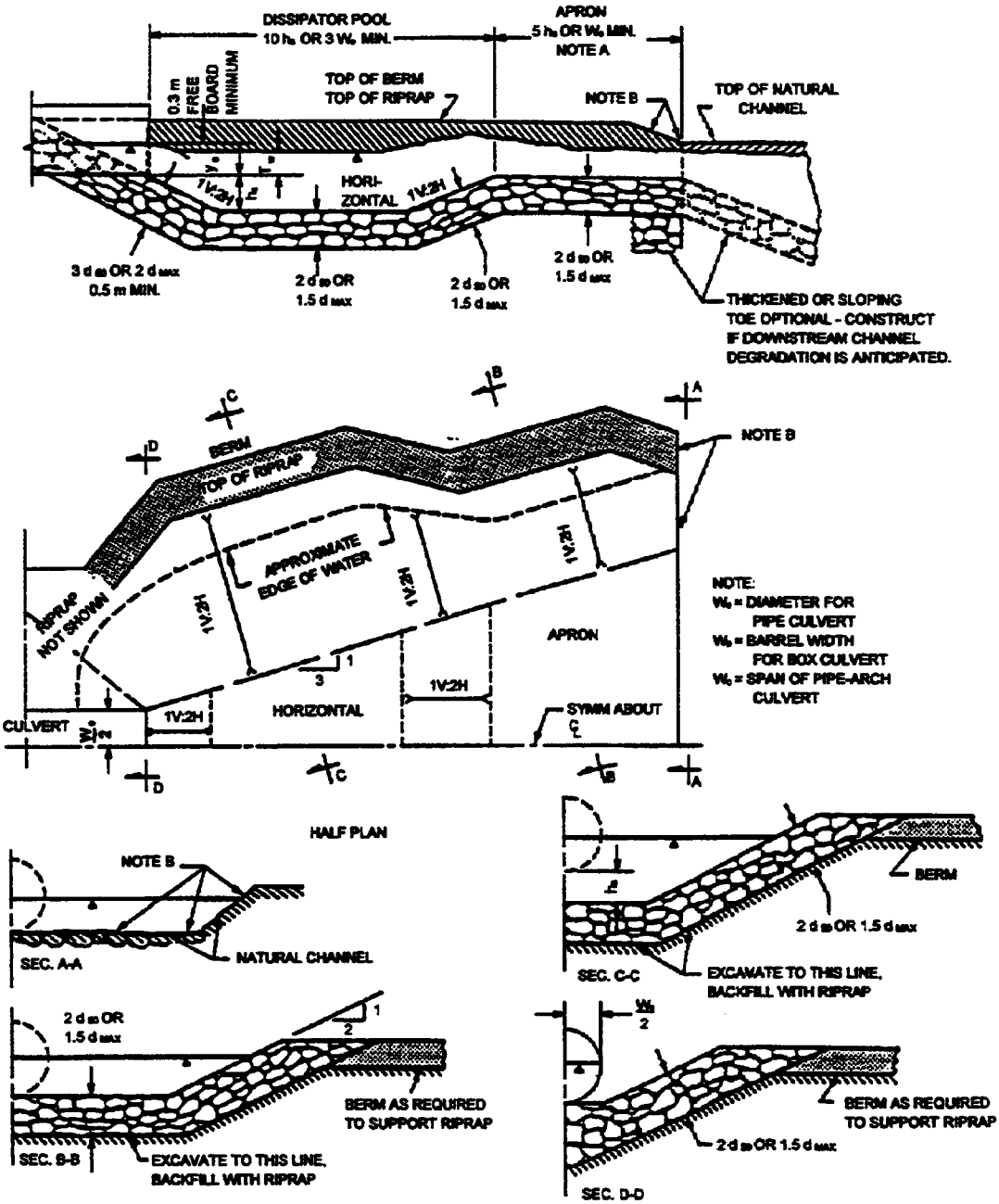
obtained if $0.25 < d_{50}/y_e < 0.45$). Obtain h_s/y_e from Figure 7.5.3-3, and check to see that $2 < h_s/d_{50} < 4$. Recycle computations if h_s/d_{50} falls out of this range.

4. Size basin as shown in Figure 7.5.2-1-5.

5. Where allowable dissipator exit velocity is specified:

   5.1 Determine the average normal flow depth in the natural channel for the design discharge.

Figure 7.5.2-1
Details of Riprap Outlet Basin



NOTE A - IF EXIT VELOCITY OF BASIN IS SPECIFIED, EXTEND BASIN AS REQUIRED TO OBTAIN SUFFICIENT CROSS-SECTIONAL AREA AT SECTION A-A SUCH THAT Q/(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.

Figure 7.5.3-1
Dimensionless rating Curves for the Outlets of Rectangular culverts
On Horizontal and Mild Slope
Source: USDOT, FHWA, HEC-14 (1983)

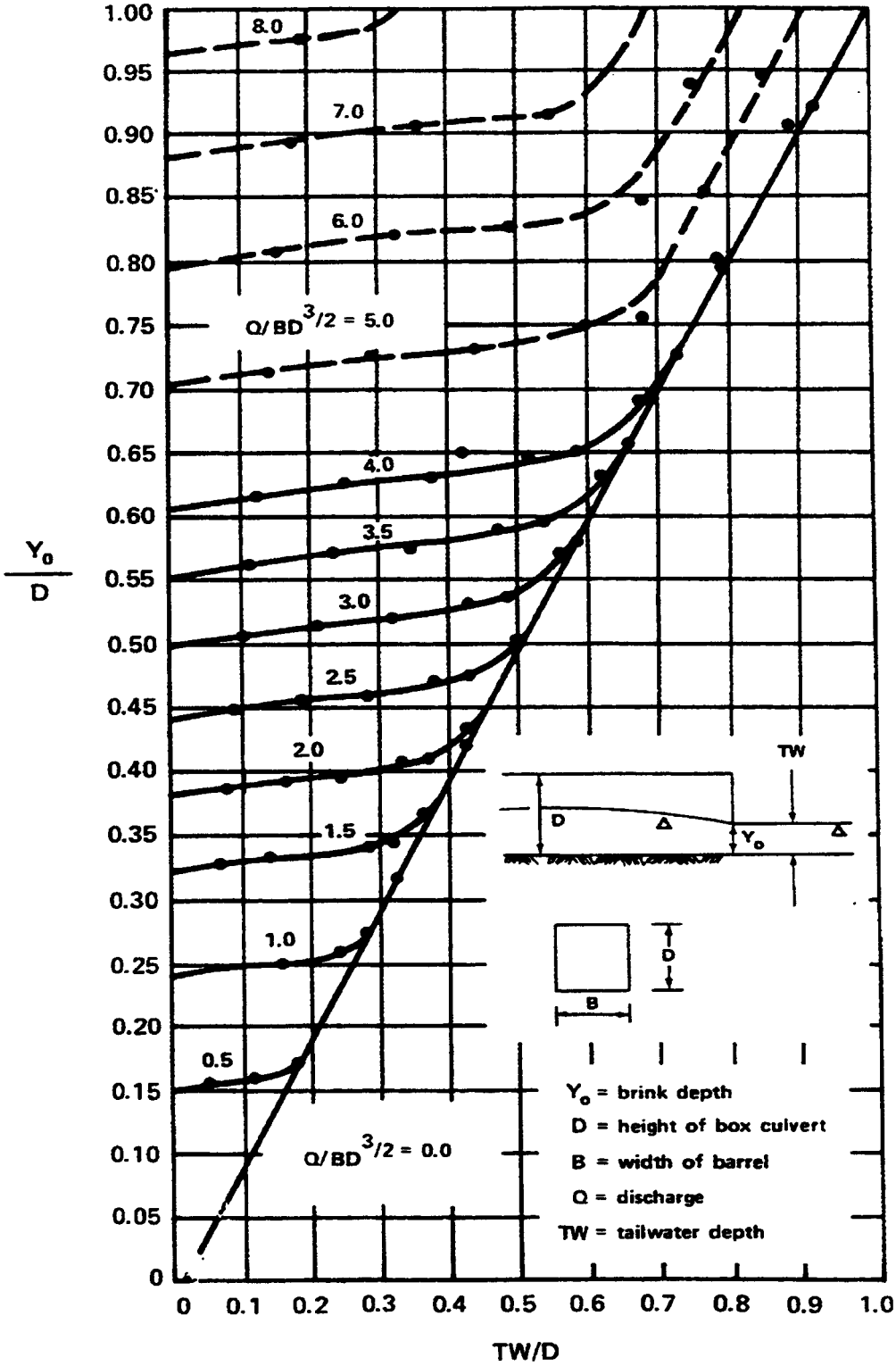


Figure 7.5.3-2
Dimensionless rating curve for the Outlets of Circular Culverts
On Horizontal and Mild Slope
Source: USDOT, FHWA, HEC-14 (1983)

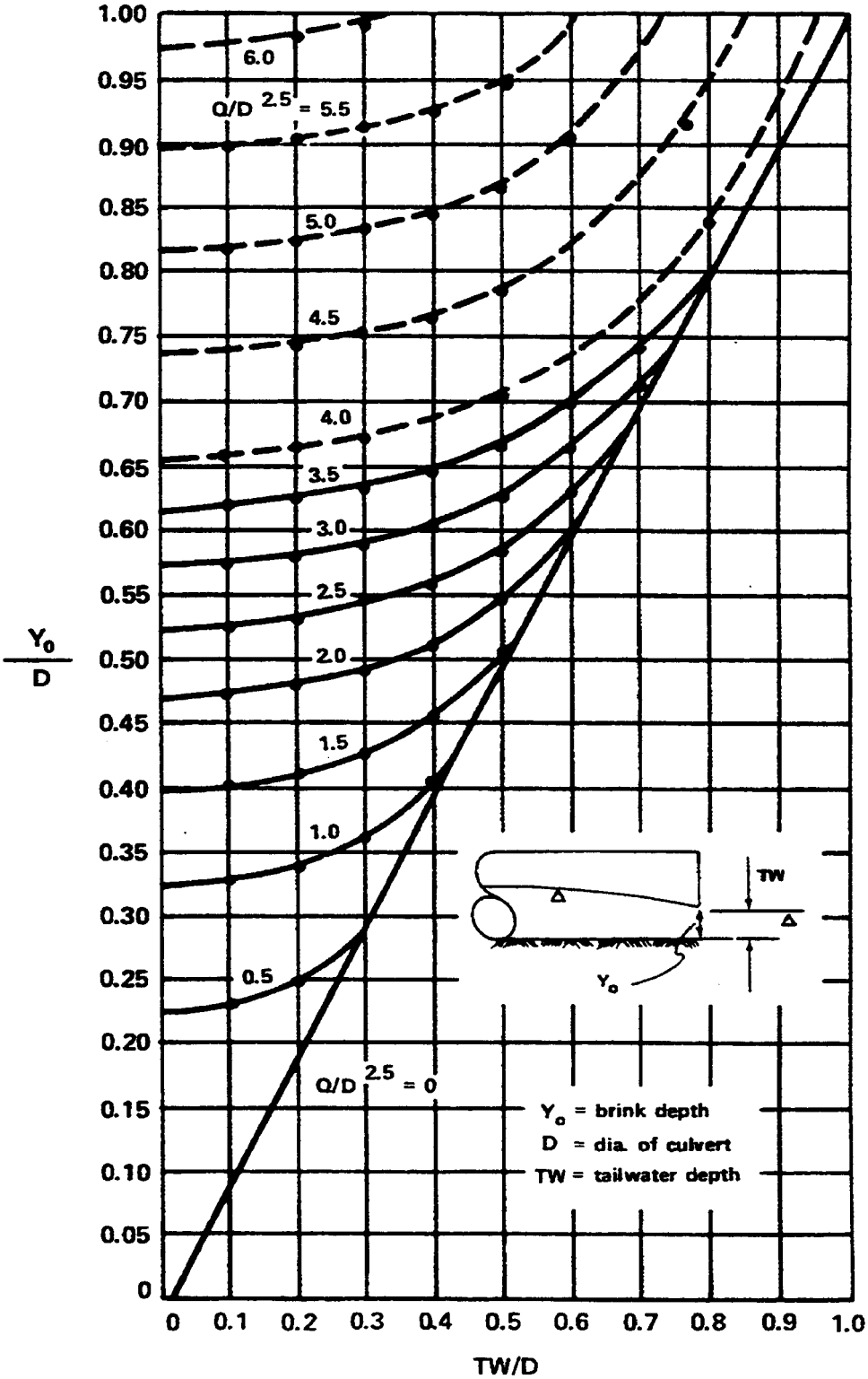
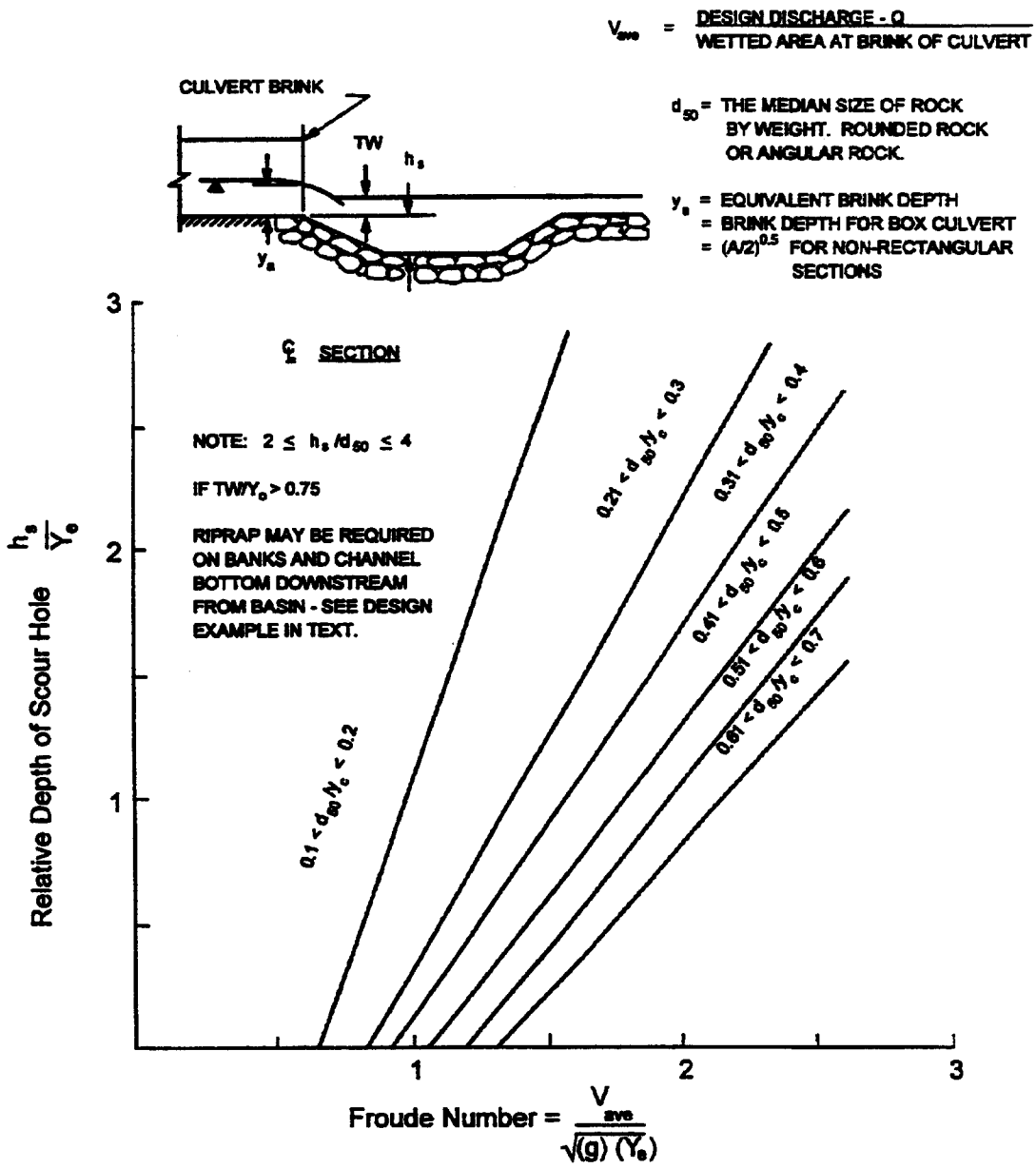


Figure 7.5.3-3
Relative Depth of Scourhole Versus Froude Number at Brink of Culvert
With Relative Size of Riprap as a Third Variable
Source: USDOT, FHWA, HEC-14 (1983)



5.2 Extend the length of the energy basin (if necessary) so that the width of the energy basin at section A-A, Figure 7.5.2-1, times the average normal flow depth in the natural channel is approximately equal to the design discharge divided by the specified exit velocity.

6. In the exit region of the basin, the walls and apron of the basin should be warped (or transitioned) so that the cross section of the basin at the exit conforms to the cross section of the natural channel. Abrupt transition of surfaces should be avoided to minimize separation zones and resultant eddies.

7. If high tailwater is a possibility and erosion protection in necessary for the downstream channel, the following design procedure is suggested:

   - Design a conventional basin for low tailwater conditions in accordance with the instructions above.

   - Estimate centerline velocity at a series of downstream cross sections using the information shown in Figure 7.5.3-4.

   - Shape downstream channel and size riprap using Figure 7.2.2-1 and the stream velocities obtained above.

   Material, construction techniques, and design details for riprap should be in accordance with specifications in the Federal Highway Administration publication HEC No. 11 entitled Use of Riprap For Bank Protection.

7.5.4 Design Considerations

Riprap basin design should include consideration of the following:

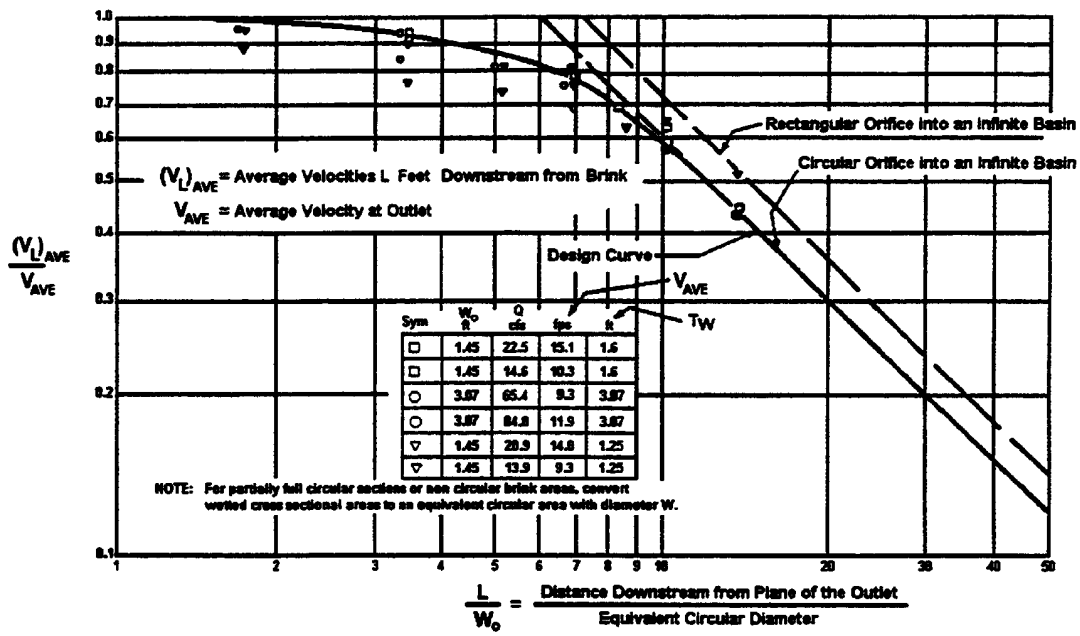
7.5.4.1 The dimensions of a scour hole in a basin constructed with angular rock can be approximately the same as the dimensions of a scour hole in a basin constructed of rounded material when rock size and other variables are similar.

7.5.4.2 When the ratio of tailwater depth to brink depth, TW/y_o, is less than 0.75 and the ratio of scour depth to size of riprap, h_s/d_{50}, is greater than 2.0, the scour hole should function very efficiently as an energy dissipator. The concentrated flow at the culvert brink plunges into the hole, a jump forms against the downstream extremity of the scour hole, and flow is generally well dispersed as it leaves the basin.

7.5.4.3 The mound of material formed on the bed downstream of the scour hole contributes to the dissipation of energy and reduces the size of the scour hole; that is, if the mound from a stable scoured basin is removed and the basin is again subjected to design flow, the scour hole will enlarge.

7.5.4.4 For high tailwater basins (TW/y_o greater than 0.75), the high velocity core of water emerging from the culvert retains its jet-like character as it passes through the basin and diffuses similarly to a concentrated jet diffusing in a large body of water. As a result, the scour hole is much shallower and generally longer. Consequently, riprap may be required for the channel downstream of the rock-lined basin.

Figure 7.5.3-4
Distribution of Centerline Velocity for flow from Submerged Outlets to Be Used for Predicting Channel Velocities Downstream from Culvert Outlet Where High Tailwater Prevails
Source: USDOT, FHWA, HEC-14 (1983)



7.5.4.5 It should be recognized that there is a potential for limited degradation to the floor of the dissipator pool for rate event discharges. With the protection afforded by the $2(d_{50})$ thickness of riprap, the heavy layer of riprap adjacent to the roadway prism, and the apron riprap in the downstream portion of the basin, such damage should be superficial.

7.5.4.6 See Standards in the in HEC No.11 for details on riprap materials and use of filter fabric.

7.5.4.7 Stability of the surface at the outlet of a basin should be considered using the methods for open channel flow as

outlined in the Open Channel Hydrology chapter of this manual.

7.5.5 Example Designs

Following are some example problems to illustrate the design procedure outlined above.

Example No. 1

Given: Box culvert – 8 ft by 6 ft Design Discharge Q = 800 cfs
Supercritical flow in culvert Normal flow depth = brink depth
Y_o = 4 ft Tailwater depth TW = 2.8 ft

Find: Riprap basin dimensions for these conditions:

Solution: Definition of terms in steps 1-5 can be found in Figures 7.5.2-1 and 7.5.3-3.

1. $y_o = y_e$ for rectangular section, therefore with y_o given as 4 ft, y_e = 4 ft.

2. $V_o = Q/A = 800/(4 \times 8) = 25$ ft/s

3. Froude Number + Fr + $V/(g \times y_e)^{0.5}$ ($g = 32.3$ ft/s^2)
   $Fr = 25/(32.2 \times 4)^{0.5} = 2.20 < 2.5$ O.K.

4. $TW/y_e = 2.8/4.0 = 0.7$ Therefore $TW/y_e < 0/75$ O.K.

5. Try $d_{50}/y_e = 0.45$, $d_{50} = 0.45 \times 4 = 1.80$ ft
   From Figure 7-8, $h_s/y_e = 1.6$, $h_s = 4 \times 1.6 = 6.4$ ft
   $h_s/d_{50} = 6.4/1.8 = 3.6$ ft, $2 < h_s/d_{50} < 4$ O.K.

6. $L_s = 10 \times h_s = 10 \times 6.4 = 64$ ft (L_s = length of energy dissipator pool)
   L_s min = $3 \times W_o = 3 \times 8 = 24$ ft, therefore use $L_s = 64$ ft
   $L_B = 15 \times h_s = 15 \times 6.4 = 96$ ft (L_B = overall length of riprap basin)
   L_B min = $4 \times W_o = 4 \times 8 = 32$ ft, therefore use $L_B = 96$ ft

7. Thickness of riprap:
   On the approach = $3 \times d_{50} = 3 \times 1.8 = 5.4$ ft
   Remainder = $2 \times d_{50} = 2 \times 1.8 = 3.6$ ft
   Other basin dimensions designed according to details shown in figure 7.5.2-1.

Example No. 2

Given: Same design data as Example 1 except:

Tailwater depth TW = 4.2 ft
Downstream channel can tolerate only 7 ft/s discharge

Find: Riprap basin dimensions for these conditions

Solutions: Note – High tailwater depth, $TW/y_o = 4.2/4 = 1.05 > 0.75$

1. Use the riprap basin designed in Example 1 with: $d_{50} = 1.8$ ft, $h_s = 6.4$ ft, $L_s = 64$ ft, $L_B = 96$ ft.

2. Design riprap for downstream channel. Utilize Figure 7.5.3-4 for estimating average velocity along the channel. Compute equivalent circular diameter D_e for brink area from:
$A = 3.14D_e^2/4 = y_o \times W_o = 4 \times 8 = 32\ ft^2$
$D_e = ((32 \times 4)/3.14)^{0.5} = 6.4$ ft
$V_o = 25$ ft/s (From Example 1)

3. Set up the following table:

L/D_e (Assume) ($D_e = W_o$)	L (Compute) ft	V_1/V_o (Fig. 7-9)	v_1 ft/sec	Rock Size d_{50}(ft) (Fig. 7-1)
10	64	0.59	14.7	1.4
15*	96	0.37	9.0	0.6
20	128	0.30	7.5	0.4
21	135	0.28	7.0	0.4

* L/W_o is on a logarithmic scale so interpolations must be logarithmically.

Riprap should be at least the size shown but can be larger. As a practical consideration, the channel can be lined with the same size rock used for the basin. Protection must extend at least 135 ft downstream from the culvert brink. Channel should be shaped and riprap should be installed in accordance with details shown in the HRC No. 11 publication.

Example No. 3

Given: 6 ft diameter CMC
Design discharge Q = 135 cfs
Slope channel $S_o = 0.004$
Manning's n = 0.024
Normal depth in pipe for Q = 135 cfs is 4.5 ft
Normal velocity is 5.9 ft/s
Flow is subcritical
Tailwater depth TW = 2.0 ft

Find: Riprap basin dimensions for these conditions:

Solution:

1. Determine y_o and V_o
From Figure 7-7, $y_o/D = 0.45$
$Q/D^{2.5} = 135/6^{2.5} = 1.53$
$TW/D = 2.0/6 = 0.33$
$Y_o = .45 \times 6 = 2.7$ ft
$TW/y_o = 2.0/2.7 = 0.74$ $TW/y_o < 0.75$ O. K.

Determine Brink Area (A) for $y_o/D = 0.45$

From Uniform Flow in Circular Sections Table (from Design of Culverts chapter)
For $y_o/D = d/D = 0.45$
$A/D^2 = 0.3428$, therefore $A = 0.3428 \times 6^2 = 12.3$ ft^2
$V_o = Q/A = 135/12.3 = 11.0$ ft/s

2. For Froude number calculations at brink conditions.
$Y_e = (A/2)^{1/2} = (12.3/2)^{1/2} = 2.48$ ft

3. Froude number = $Fr = V_o/(32.2 \times y_e)^{1/2} = 11(32.2 \times 2.48)^{1/2} = 1.23 < 2.5$ O. K.

4. For most satisfactory results – $0.25 < d_{50}/y_e < 0.45$
Try $d_{50}/y_e = 0.25$
$d_{50} = 0.25 \times 2.48 = 0.62$ ft
From Figure 7.5.3-3, $h_s/y_e = 0.75$, therefore $h_s = 0.75 \times 2.48 = 1.86$ ft

Uniform Flow in circular Sections Flowing Partly Full (from Design of Culverts chapter)

Check: $h_s/d_{50} = 1.86/0.62 = 3$, $2 < h_s/d_{50} < 4$ O. K.

5. $L_s = 10 \times h_s = 10 \times 1.86 = 18.6$ ft or $L_s = 3 \times W_o = 3 \times 6 = 18$ ft, therefore use $L_s = 18.6$ ft
$L_B = 15 \times h_s = 15 \times 1.86 = 27.9$ ft or $L_B = 4 \times W_o = 4 \times 6 = 24$ ft, therefore use $L_B = 27.9$ ft

$d_{50} = 0.62$ ft or use $d_{50} = 8$ in

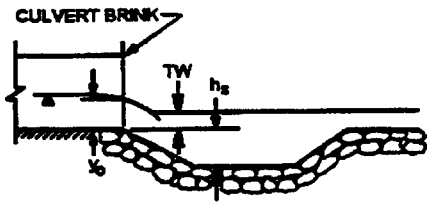
Other basin dimensions should be designed in accordance with details shown on Figure 7.5.2-1. Figure 7.5.5-1 is provided as a convenient form to organize and present the results of riprap basin designs.

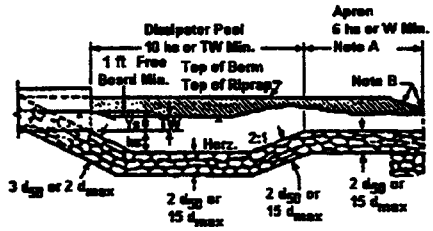
When using the design procedure outlined in this chapter, it is recognized that there is some chance of limited degradation of the floor of the

dissipator pool for rare event discharges. With the protection afforded by the 3 x d_{50} thickness of riprap on the approach and the 2 x d_{50} thickness of riprap on the basin floor and the apron in the downstream portion of the basin, the damage should be superficial.

Figure 7.5.5-1
Riprap Basins
Source: USDOT, FHWA, HEC-14 (1983)

Project No. _____
Designer _____ Date _____
Reviewer _____ Date _____





DESIGN VALUES	TRIAL 1	FINAL TRIAL
Equi. 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		FEET	
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	
$D_E=(4A_o/\pi)^{0.5}$	

DOWNSTREAM RIPRAP				
L/D_E	L	V_L/V_o	V_L	D_{50}

END OF SECTION 7.5