Appendix 8E-1 Energy Dissipation

8E.1 Riprap Basin

Riprap basins are used for energy dissipation at the outlets of high velocity culverts.

Riprap basin design is based on laboratory data obtained from full-scale prototypical installations. The principal features of riprap basins are as follows:

1. Pre-shaping 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 would 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 $10(h_s)$ or $3(W_o)$, whichever is larger for a single barrel. The overall length of the basin is $15(h_s)$ or $4W_o$ whichever is larger.
5. Angular rock results are approximately the same as the results of rounded material.
6. Layout details and dimensions are shown on Figure 8E-1.

For high tailwater ($\frac{TW}{d_o} > 0.75$), 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 generally longer.
3. Riprap may be required for the channel downstream of the rock-lined basin.

8E.2 Design Procedures and Sample Problems

The procedure shown below should be used to determine the dimension for a riprap basin energy dissipator for culvert and pipe installations with pipe velocities greater than or equal to 19 feet per second as classified in Section 8.3.2.6. Maximum Outlet Velocity within the Chapter 8 text.

Step 1: *Determine input flow parameters: D_e or d_E, V_o, F_r at the culvert outlet*

Where:

d_E = Equivalent depth at the brink = $\sqrt{\frac{A}{2}}$

Note: $d_E = y_e$ in Figure 8E-2

Step 2: *Check TW*

Determine if $\frac{TW}{d_o} \leq 0.75$

Note: $d_o = d_E$ in Figure 8E-2 for rectangular sections

Step 3 *Determine d_{50}*

a. Use Figure 8E-2.
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 Froude number (F_r) and Figure 8E-2.
d. Check if $2<h_s/d_{50}<4$ and repeat until a d_{50} is found within the range.

Step 4: *Size basin*

a. As shown in Figure 8E-1.
b. Determine length of the dissipating pool, $L_s = 10h_s$ or $3W_o$ minimum.
c. Determine length of basin, $L_B = 15h_s$ or $4W_o$ minimum.

Thickness of riprap: Approach = $3d_{50}$ or $1.5d_{max}$
Remainder = $2W_o$ or $1.5d_{max}$

Step 5: Determine exit velocity at brink (V_B)

a. Basin exit depth, d_B = critical depth at basin exit

b. Basin exit velocity, $V_B = \frac{Q}{W_B d_B}$

c. Compare V_B with the average normal flow velocity in the natural channel (V_d)

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 from:

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

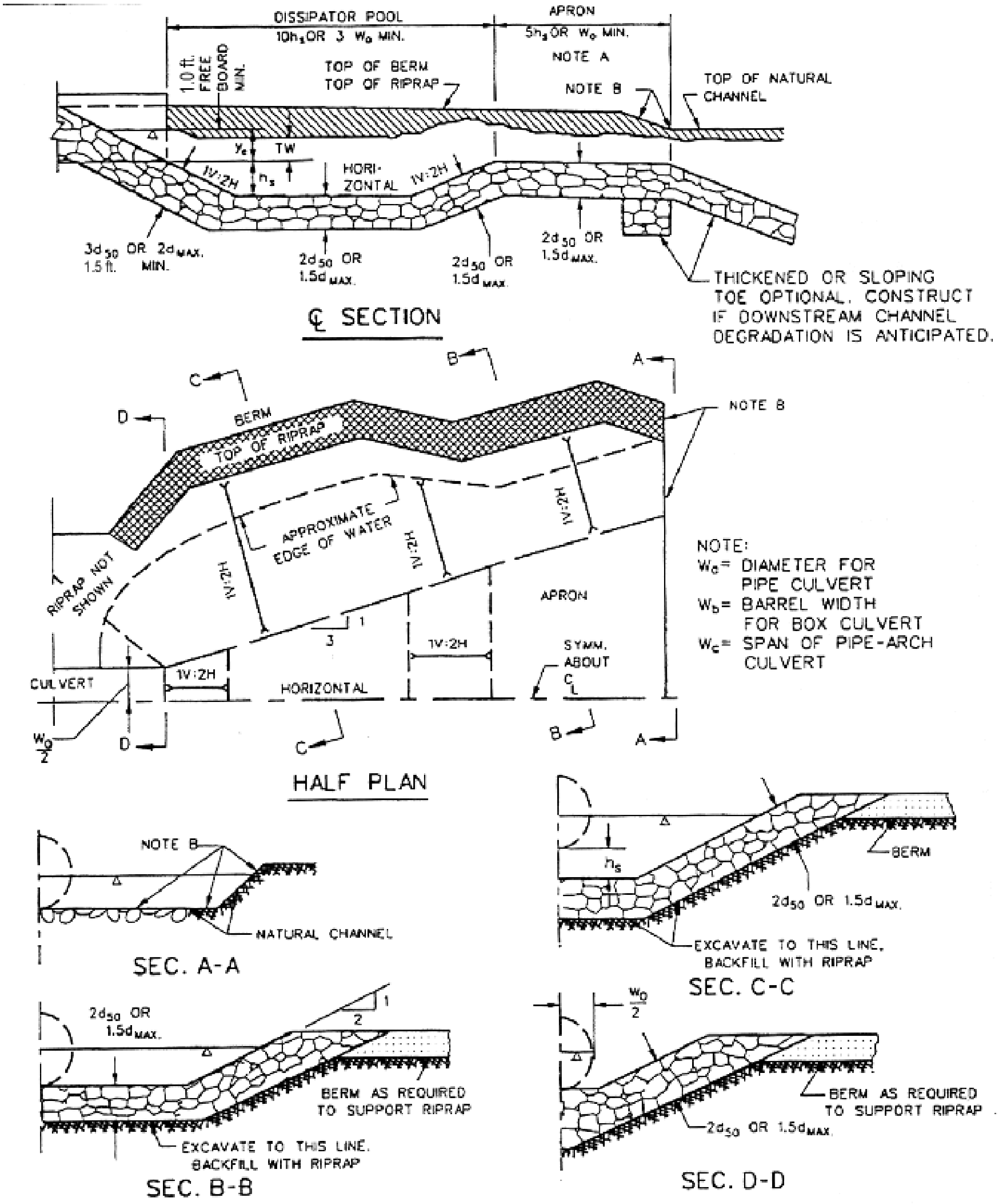
c. Estimate centerline velocity at a series of downstream cross sections using Figure 8E-4.

Size riprap using HEC -11 "Use of Riprap for Bank Protection."[1]

Step 7: Design Filter

The design filter is necessary unless the streambed material is sufficiently well graded. To deign a filter for riprap, use the procedures in Section 4.4 of HEC-11.

Dissipator geometry can also be computed using the "Energy Dissipator" module that is available in the microcomputer program HY8, Culvert Analysis.



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.

Figure 8E- 1. Details of Riprap Basin Energy Dissipator

Appendix 8E-1 Energy Dissipation

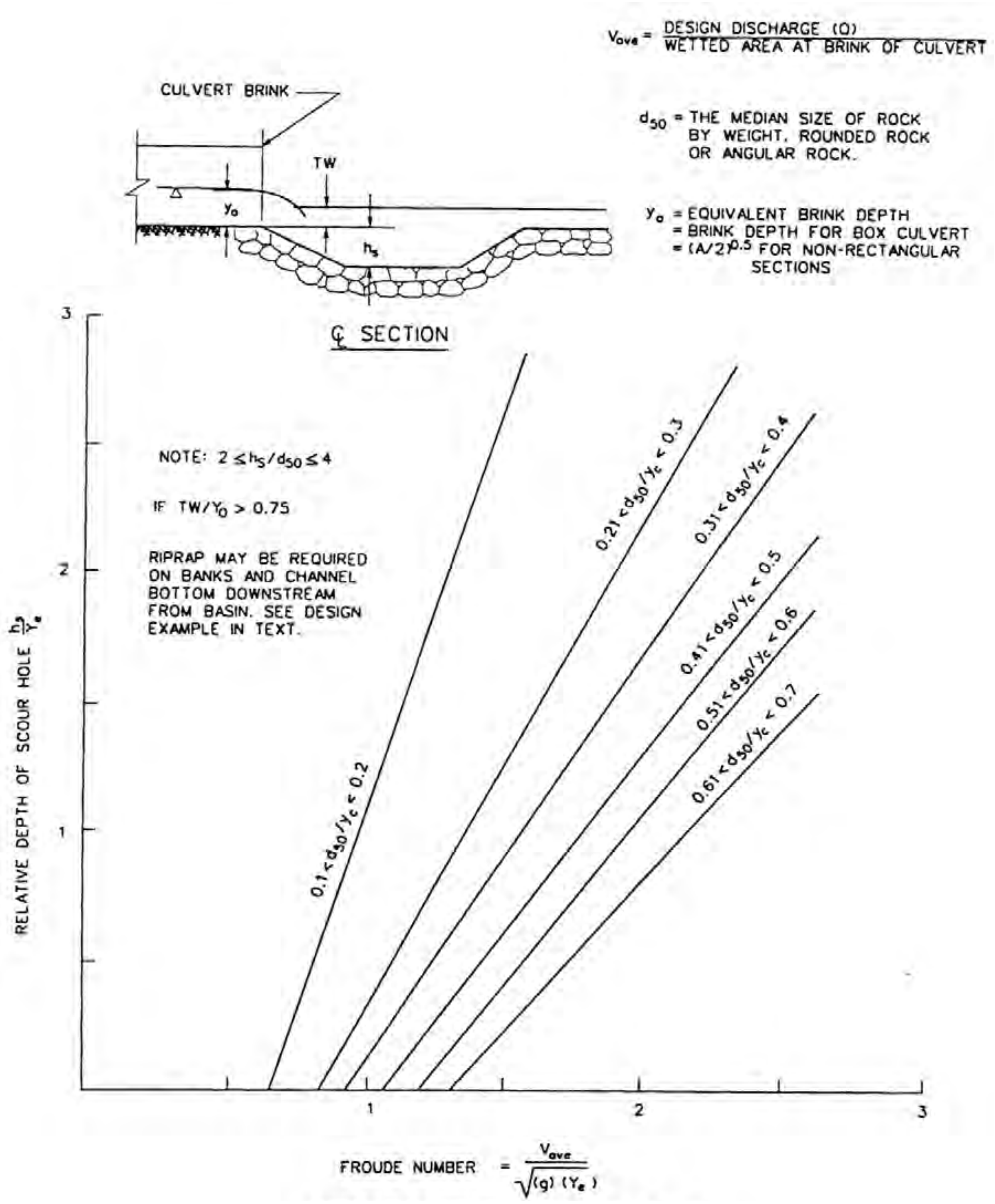


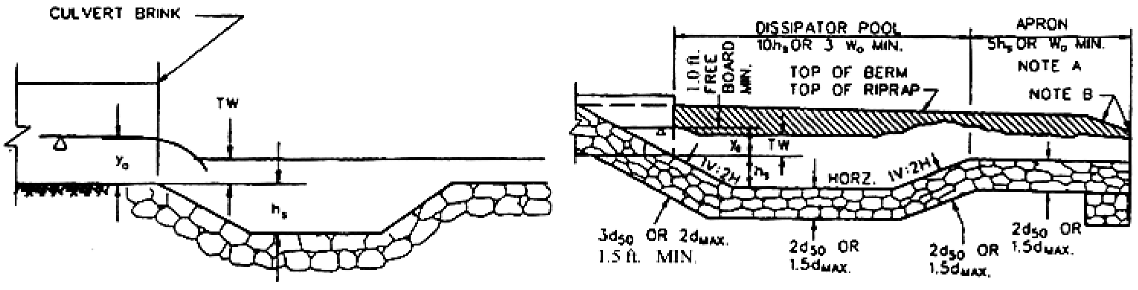
Figure 8E- 2. Riprap Basin Depth of Scour

RIPRAP BASIN

Project No. ______________________________

Designer ______________________ Date __________

Reviewer ______________________ Date __________



DESIGN VALUES (Figure 8E-2)	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 using Figure 8E-4	
$D_E = (4A_c/\pi)^{0.5}$	

DOWNSTREAM RIPRAP (Figure 8E-4)

L/D_E	L	V_L/V_o	V_L	D_{50}
10				
15				
20				
21				

Figure 8E- 3. Riprap Basin Design Checklist

8E.2.1 Riprap Design for Low Tailwater Condition-Sample Problem

Given:
Box culvert: 8.0 ft by 6.0 ft.
Design discharge Q = 800 cfs
Supercritical flow in culvert
Normal flow depth d_o = brink depth d_E = 4.0 ft
Tailwater depth, TW = 2.8 ft
Downstream channel velocity = 18 fps

Step 1: Determine input flow parameters: D_e or d_E, V_o, F_r at the culvert outlet

$d_o = d_E$ for rectangular section
$d_o = d_E = 4.0$ ft.

$$V_o = \frac{Q}{A} = \frac{800}{4.0(8.0)} = 25 \text{ fps}$$

$$F_r = \frac{V_o}{\sqrt{gd_E}} = \frac{25}{\sqrt{32.2(4.0)}} = 2.2 < 3.0$$

Step 2: Check TW:

Determine if $\frac{TW}{d_E} < 0.75$

$$\frac{2.8}{4.0} = 0.70 < 0.75$$

Therefore, $\frac{TW}{d_E} < 0.75$, O.K.

Step 3: Determine d_{50}:

a. Use Figure 8E-2

b. Try $d_{50}/d_E = 0.45$

$$d_{50} = \left(\frac{d_{50}}{d_E}\right) d_E = 0.45(4.0) = 1.8 \text{ ft.}$$

c. Obtain h_S/d_E using $F_r = 2.2$ and line $0.41 \le d_{50}/d_E \le 0.50$

$h_S/d_E = 1.6$

d. Check if $2<h_S/d_{50}<4$:

$$h_s = \left(\frac{h_s}{d_E}\right) d_E = 1.6(4.0) = 6.4 \text{ ft.}$$

$$\frac{h_s}{d_{50}} = \frac{6.4}{1.8} = 3.55 \text{ ft.}$$

2 <3.55<4, O.K.

Step 4: Size the basin:

a. As shown in Figure 8E-1

b. Determine length of dissipating pool, L_S:
$L_S = 10h_S = 10(6.4) = 64$ ft.
L_S min.= $3W_o = 3(8) = 24$ ft
Therefore, use $L_S = 64$ ft

c. Determine length of basin, L_B:
$L_B = 15h_S = 15(6.4) = 96$ ft

L_B min. = $4W_o = 4(8) = 32$ ft

Therefore, use $L_B = 96$ ft

d. Thickness of riprap:
Approach = $3d_{50} = 3(1.80) = 5.4$ ft
Remainder = $2d_{50} = 2(1.80) = 3.6$ ft

Step 5: Determine V_B:

a. d_B = Critical depth at basin exit = 3.30 ft. (assuming a rectangular cross section with width W_B = 24 ft.)

b. $V_B = \dfrac{Q}{W_B d_B} = \dfrac{800}{24(3.3)} = 10$ fps

c. V_B =10 fps $< V_d$ = 18 fps

8E.2.2 Riprap Design for High Tailwater Condition-Sample Problem

Given: Data on the channel and the culvert are the same as Sample Problem 1, except that the new tailwater depth,

TW = 4.2 ft.

$$\frac{TW}{d_o} = \frac{4.2}{4.0} = 1.05 > 0.75$$

Downstream channel can tolerate only 7.0 fps

Steps 1 through 5 are the same as Sample Problem 8E.2.1.

Step 6: High tailwater design:

a. Design a basin for low tailwater conditions, Steps 1-5 as above:
D_{50} = 1.8 ft, h_S = 6.4 ft
L_S = 64 ft, L_B = 96 ft

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

$$A = \frac{\pi D_E{}^2}{4} = d_o(W_o) = 4.0(8.0) = 32\ \text{ft}^2$$

$$D_E = \sqrt{\frac{4A}{\pi}} = \sqrt{\frac{4(32)}{\pi}} = 6.4\ \text{ft.}$$

V_o = 25 fps (Sample Problem 8E.2.1).

c. Estimate centerline velocity at a series of downstream cross sections using Figure 8E-5.

$\frac{L}{D_E}$ [1]	L	$\frac{V_L}{V_O}$	V_L	D_{50} [2]
10	64	0.59	14.7	1.4
15[3]	96	0.36	9.0	0.6
20	128	0.30	7.5	0.4
21	135	0.28	7.0	0.4

[1] Use W_o = D_E in Figure 8E- 5.
[2] From Figure 8E- 6.
[3] Is on a logarithmic scale so interpolations must be performed logarithmically.

d. Size riprap using HEC 11. The channel can be lined with the same size rock used for the basin. Protection should extend at least 135 ft downstream.

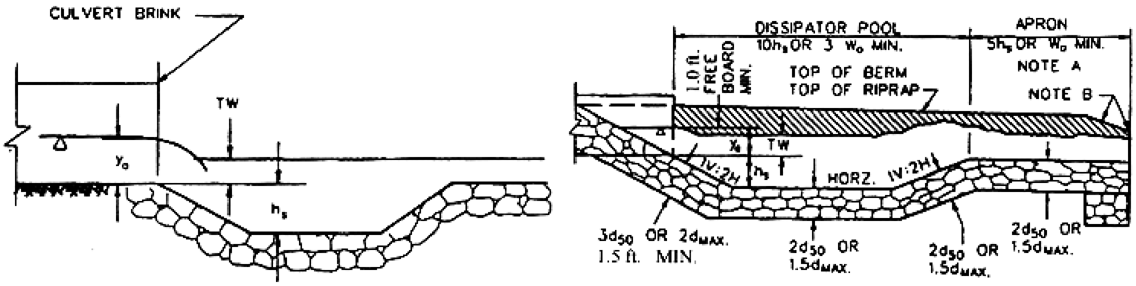
This information is summarized in the worksheet for riprap basin design, Figure 8E- 4.

RIPRAP BASIN

Project No. ____________________

Designer ____________________ Date __________

Reviewer ____________________ Date __________



DESIGN VALUES (Figure 8E-2)	TRIAL 1	FINAL TRIAL
Equi. Depth, d_E	4.0 ft.	4.0 ft.
D_{50}/d_E	0.45	0.45
D_{50}	1.80 ft.	1.80 ft.
Froude No., Fr	2.20	2.20
h_s/d_E	1.60	1.60
h_s	6.40 ft.	6.40 ft.
h_s/D_{50}	3.55	3.55
$2 < h_s/D_{50} < 4$	OK	OK

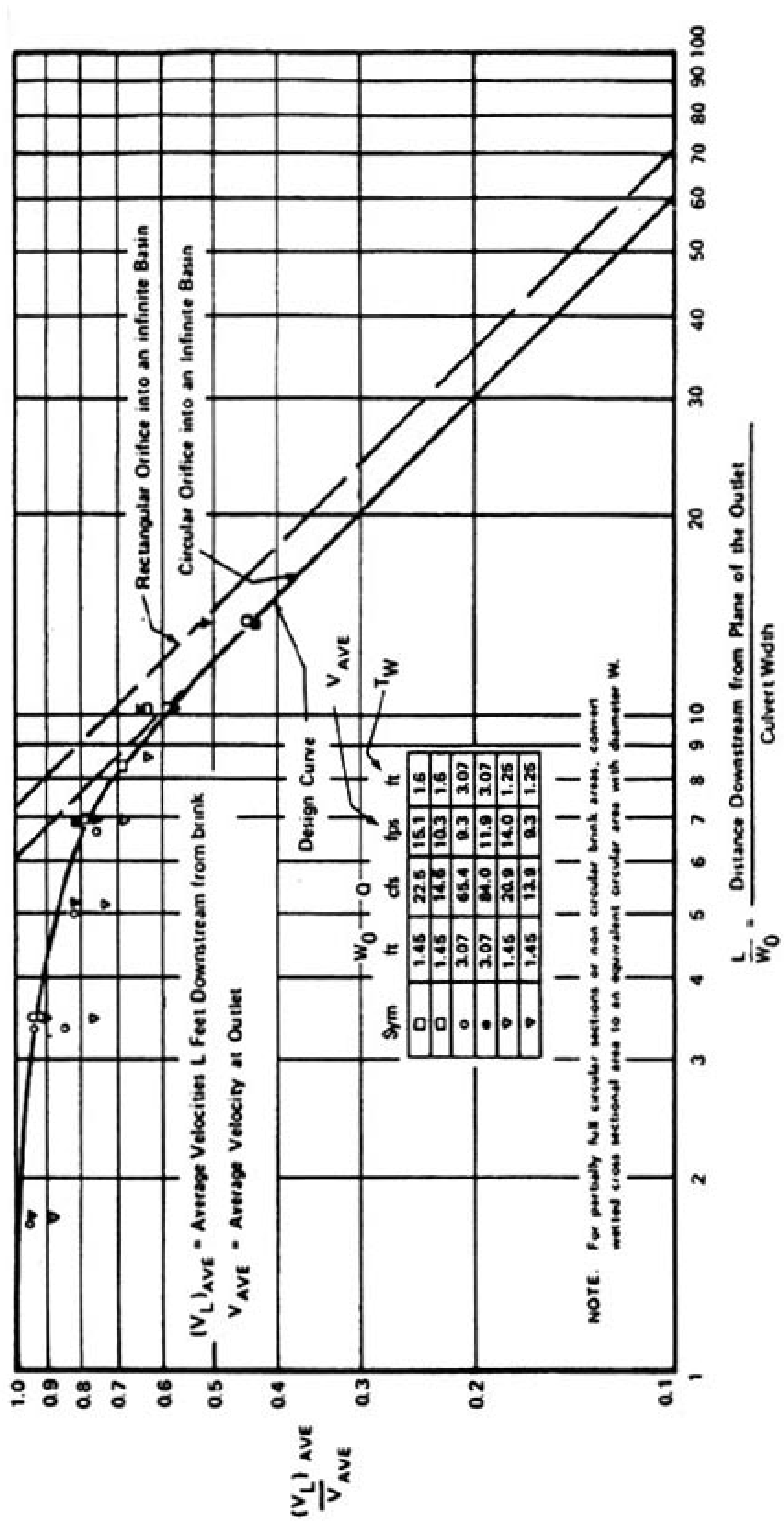
BASIN DIMENSIONS		FEET	
Pool length is the larger of:	$10h_s$	64	64
	$3W_o$	24	
Basin length is the larger of:	$15h_s$	96	96
	$4W_o$	32	
Approach Thickness	$3D_{50}$	5.4	
Basin Thickness	$2D_{50}$	3.6	

TAILWATER CHECK	
Tailwater, TW	4.2
Equivalent depth, d_E	4.0
TW/d_E	1.05
IF $TW/d_E > 0.75$, calculate riprap downstream using Figure 8E-4	
$D_E = (4A_c/\pi)^{0.5}$	

DOWNSTREAM RIPRAP (Figure 8E-4)				
L/D_E	L	V_L/V_o	V_L	D_{50}
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

Figure 8E- 4. Riprap Basin Design Worksheet, Sample Problem

Appendix 8E-1 Energy Dissipation



Sym	ft	cfs	fps	ft
□	1.45	22.5	15.1	1.6
□	1.45	14.6	10.3	1.6
○	3.07	65.4	9.3	3.07
●	3.07	84.0	11.9	3.07
▽	1.45	20.9	14.0	1.25
▼	1.45	13.9	9.3	1.25

Figure XI - 3 Distribution of Centerline Velocity for Flow from Submerged Outlets from Reference XI - 2 to be used for Predicting Channel Velocities Downstream from Culvert Outlet where High Tailwater prevails. Velocities obtained from the use of this Chart can be used with Figure 2 of HEC No. 11 for sizing riprap (DO not use Figure 1 HEC No. 11, use Mean Velocity Values)

Figure 8E- 5*.* Distribution of Centerline Velocity for Flow from Submerged Outlets

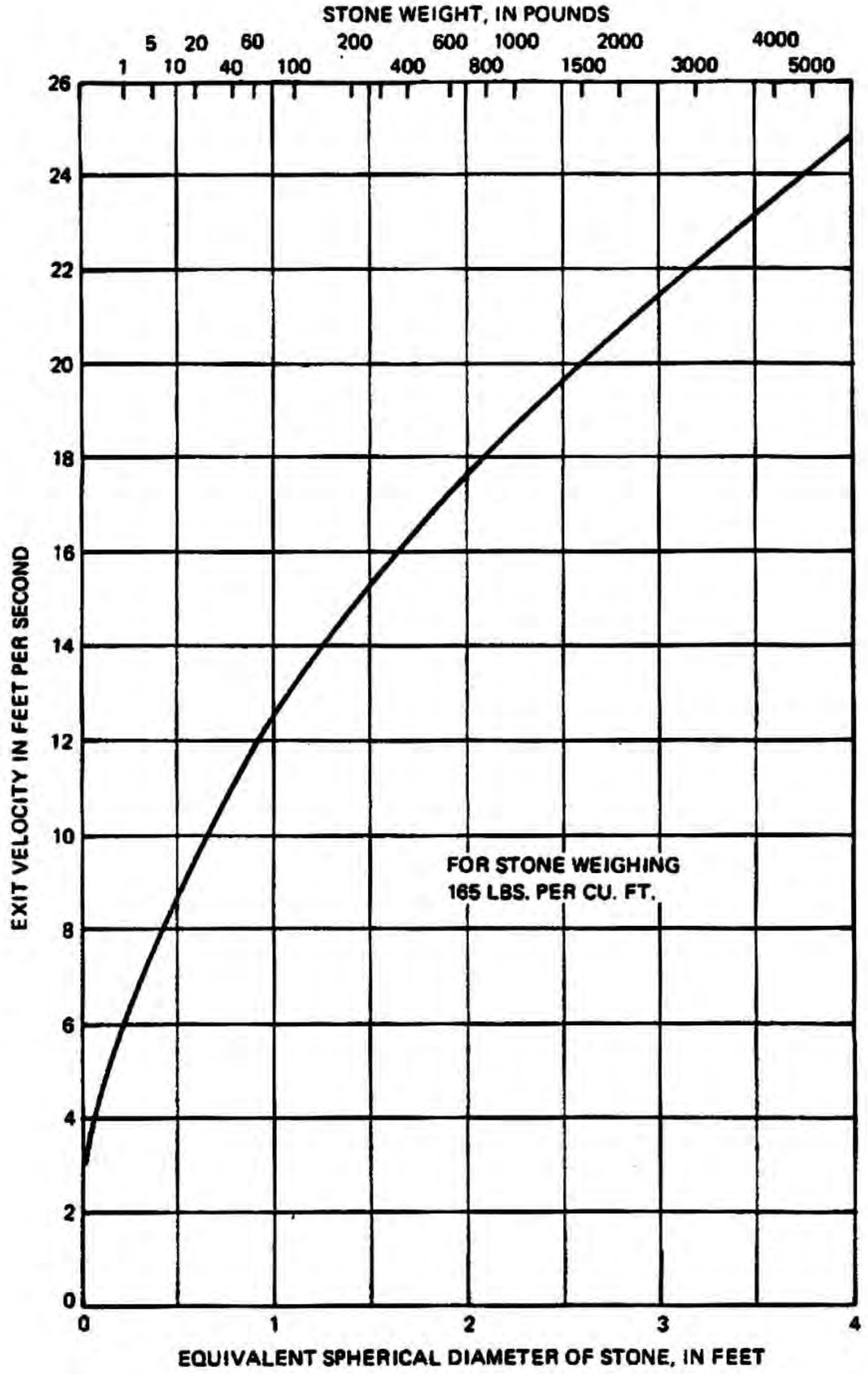


Figure 8E- 6. Riprap Size Versus Exit Velocity

8E.2.3 Computer Output

The dissipator geometry can be computed using the “Energy Dissipator” module, which is available in FHWA’s HY8, Culvert Analysis microcomputer program. The output of the culvert data, channel input data, and computed geometry using this module are shown below.

```
                    FHWA CULVERT ANALYSIS, HY-8, VERSION 6.0

    CURRENT DATE      CURRENT TIME      FILE NAME      FILE DATE
    06-02-1997        15:23:59          ENERGY3        06-02-1997
--------------------------------------------------------------------------
                         CULVERT AND CHANNEL DATA
--------------------------------------------------------------------------
CULVERT NO. 1                            DOWNSTREAM CHANNEL
CULVERT TYPE:  8.0 ft X 6.0 ft,  BOX     CHANNEL TYPE: IRREGULAR
CULVERT LENGTH = 300 ft                  BOTTOM WIDTH = 8.0 ft
NO. OF BARRELS = 1.0                     TAILWATER DEPTH = 2.8 ft
FLOW PER BARREL= 400 cfs                 TOTAL DESIGN FLOW = 400 cfs
INVERT ELEVATION = 172.5 ft              BOTTOM ELEVATION = 172.5 ft
OUTLET VELOCITY = 25 fps                 NORMAL VELOCITY = 32 fps
OUTLET DEPTH = 4.0 ft

--------------------------------------------------------------------------
                    RIPRAP STILLING BASIN – FINAL DESIGN
--------------------------------------------------------------------------

    THE LENGTH OF THE BASIN                                  = 96.3 ft
    THE LENGTH OF THE POOL                                   = 64.2 ft
    THE LENGTH OF THE APRON                                  = 32 ft
    THE WIDTH OF THE BASIN AT THE OUTLET                     = 8.0 ft
    THE DEPTH OF POOL BELOW CULVERT INVERT                   = 6.4 ft
    THE THICKNESS OF THE RIPRAP ON THE APRON                 = 6.6 ft
    THE THICKNESS OF THE RIPRAP ON THE REST OF THE BASIN     = 5.0 ft
    THE BASIN OUTLET VELOCITY                                = 17 fps
    THE DEPTH OF FLOW AT BASIN OUTLET                        = 6.0 ft
```