X. COMPREHENSIVE DESIGN EXAMPLE

10.1 General Description

Permanent diversion structures must be designed for conveying water around the spoil fill and across the reclaimed strip bench as shown in Figure 10.1. Four diversion channels must be designed. Channels A and B collect runoff from above the fill and convey it around the perimeter of the fill. The watershed above the fill is a reclaimed mountain top removal and the contributing drainage area to Channels A and B is 40 acres. Channel C is a reconstructed natural drainage extending from the toe of fill to the junction with a natural channel draining 16 acres. Diversion Channel D is a reconstructed channel passing over the reclaimed strip bench. All the channels are intermittent. The mine site is assumed to be located in southern West Virginia.

10.2 Hydrologic Design

The hydrologic design involves estimating the peak discharge rates for the two contributing areas, subwatersheds 1 and 2. For permanent diversions draining intermittent streams, Table 3.1 gives the required design event as the 100-year, 24-hour storm. Since the drainages involved in this design are relatively high in the watershed, there is no floodplain available to carry part of the design flows. Therefore, the channel must be capable of carrying the predicted peak discharges. Both the Rational Formula and the SCS TP-149 method will be used and the results compared to determine the design value.

10.2.1 Rational Formula

Subwatershed 1

Step 1: One C value is assumed adequate to represent the 40 acres existing within a reclaimed mountain top removal. From Table 3.3, the estimated C is 0.42 for a hilly pasture in a clay and silt loam.

Step 2: From topographic maps the maximum length of flow is estimated to be 2000 ft over an average slope of 30 percent. Using the formula given in Table 3.2,

$$t_c = 0.0078\ (2000)^{0.77}\ (0.30)^{-0.385}$$

$$t_c = 4.3 \text{ min}$$

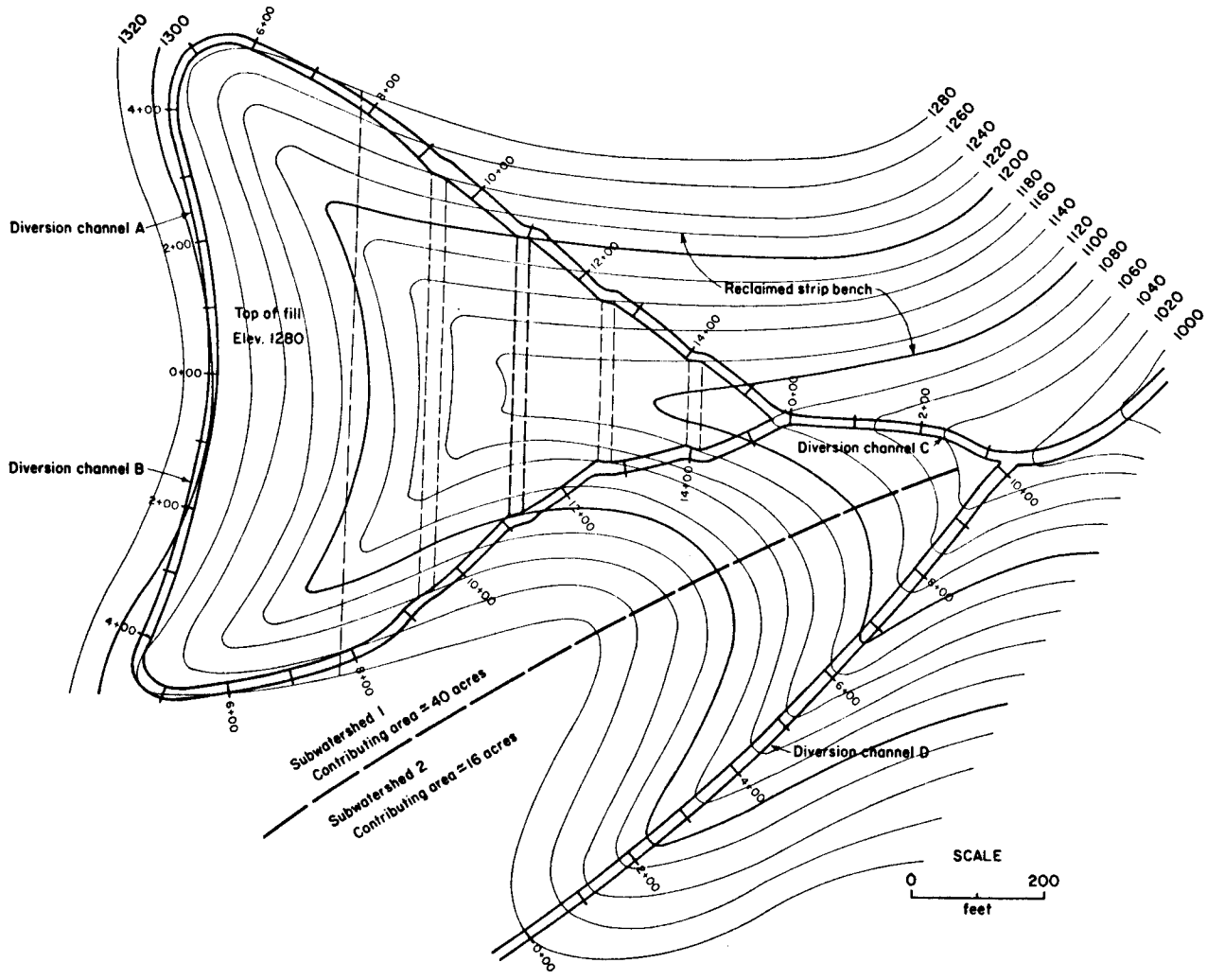

Figure 10.1. Topographic map of the design example.

Step 3: Since t_c is less than one hour, the 100-year, one-hour duration storm gives 3.0 inches of rain (Appendix A). From Figure 3.3 the required correction factor is 0.26, therefore

$$I_{4.3} = 3.0 \times 0.26 = 0.78 \text{ in}$$

$$\text{iph} = 0.78 \text{ in} \times \frac{1}{4.3 \text{ min}} \times \frac{60 \text{ min}}{\text{hour}} = 10.9 \text{ iph}$$

Step 4: From $Q = CiA$ (Equation 3.1),

$$= (0.42)\ (10.9)\ (40)$$

$$Q = 183 \text{ cfs}$$

Subwatershed 2

Step 1: Of the 16 contributing acres, about 5.0 acres represent the reclaimed strip bench. The remaining 11.0 acres exist as undisturbed woodland. For the reclaimed strip bench a C of 0.42 is again used. For the undisturbed area, a C of 0.50 is used. The composite C is then given by Equation 3.2 as

$$C = \frac{0.42\ (5) + 0.50\ (11)}{16} = 0.48$$

Step 2: From topographic maps the maximum length of flow is estimated to be 1200 feet for the average 30 percent slope. From the formula in Table 3.2,

$$t_c = 0.0078\ (1200)^{0.77}\ (0.30)^{-0.385}$$

$$t_c = 2.9 \text{ min}$$

Step 3: The 100-year, one-hour duration storm is again 3.0 inches. From Figure 3.3 the required correction factor is 0.20, therefore

$$I_{2.9} = 3.0 \times 0.2 = 0.60 \text{ in}$$

$$\text{iph} = 0.60 \times \frac{1}{2.9 \text{ min}} \times \frac{60 \text{ min}}{\text{hour}} = 12.4 \text{ iph}$$

Step 4: From $Q = CiA$ (Equation 3.1),

$$Q = (0.48)\ (12.4)\ (16)$$

$$Q = 95 \text{ cfs}$$

10.2.2 SCS TP-149 Method

Subwatershed 1

Step 1: From Table 3.5 the soil group for the sandy-clay loam soil is C. From Table 3.4 the CN for pasture in fair condition with no mechanical treatment is 79.

Step 2: From the charts in Appendix A, the 100-year, 24-hour duration storm gives 5.7 inches of rain.

Step 3: From charts in Appendix B for steep terrain and curve numbers 75 and 80, the Q is, respectively,

$$Q = 140 \text{ cfs} \qquad \text{and} \qquad Q = 185 \text{ cfs}$$

Using linear interpolation, Q for a CN = 79 is

$$Q = 172 \text{ cfs}$$

Subwatershed 2

Step 1: An area weighted curve number is required for this drainage, similar to the area weighted C for the Rational Formula. Using a CN of 79 for the reclaimed strip bench and 73 for the undisturbed watershed (woods in fair condition), the composite CN is

$$CN = \frac{79\ (5) + 73\ (11)}{16}$$

$$CN = 75$$

Step 2: The 100-year, 24-hour event is again 5.7 inches.

Step 3: From charts in Appendix B for steep terrain and curve number 75, the Q is 62 cfs.

10.2.3 Design Values

Using an average (rounded to the nearest 5 cfs) of the estimates by the two methods, the recommended design discharges are given in Table 10.1.

10.3 Diversion Channel Designs

10.3.1 Channel A

The design flow for Channels A and B together is 180 cfs. Assuming the flow is equally divided between each channel, the design flow for each channel is 90 cfs. From the topographic map given in Figure 10.1, the longitudinal profile of the channel was evaluated (Figure 10.2). For stations 0+00 to 7+80

Table 10.1. Recommended Design Discharges.

Method	Subwatershed 1	Subwatershed 2
Rational Formula	183	95
SCS TP-149	172	62
Design Value	180	80

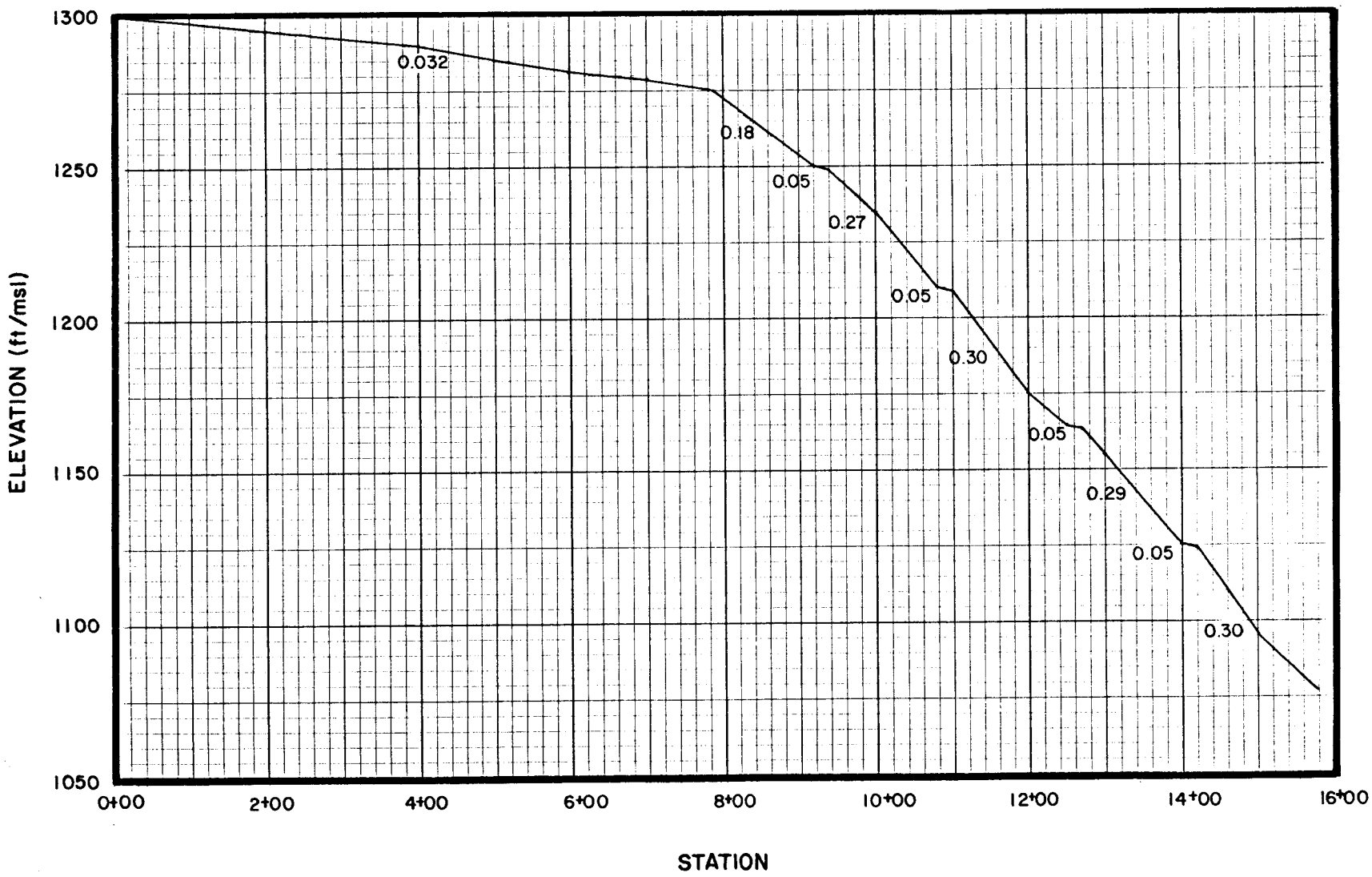

Figure 10.2. Longitudinal profile of diversion channel A.

the average slope is 0.032. As an initial assumption, assume the slope is mild. Since the channel is intermittent, a vegetative lining could be utilized. However, the material the channel will be constructed in cannot be considered erosion resistant, and a low permissible velocity would have to be used in design (Table 6.2). For the relatively large design discharge in this channel, this would result in a very wide, shallow cross section. Therefore, it is more practical to use rock riprap. The mild slope riprap design procedures can be used (Chapter VI).

For stations 7+80 to 15+80, the steep slopes require that only riprap be used for stabilization. The steep slope riprap design procedure given in Chapter V should be used.

Channel Design Station 0+00 to 7+80

1. Assume $K_m = 9$ in. From Equation 4.18,

$$n = 0.0395\ (0.75)^{1/6} = 0.038$$

2. From the charts in Appendix C for $Qn = 90\ (0.038) = 3.4$, a slope 0.032 and a bottom width of 6 ft,

$$Vn = 0.27 \text{ fps} \qquad V = Vn/n = 7.1 \text{ fps}$$

$$d = 1.5 \text{ ft, and}$$

$$R = \frac{A}{P} = \frac{6(1.5) + 2(1.5)^2}{6 + 2(1.5)(2^2+1)^{0.5}} = 1.06 \text{ ft}$$

3. $$\frac{V^2}{R^{0.33}} = \frac{6.8^2}{1.06^{0.33}} = 49$$

Therefore, from Table 6.4 the required riprap is Type L.

4. For Type L the K_m size is 9 in., therefore the initial assumption is OK.

5. No iteration is required.

6. $$F_r = \frac{7.1}{\sqrt{32.2\ (1.5)}} = 1.0$$

Since the Froude number is greater than 0.8, the mild slope assumption for a six-foot bottom width channel was not valid. Two options are now available. The bottom width can be increased to reduce the velocity, and consequently the Froude number, or the six-foot bottom width can be

retained and the steep slope design procedure used.

Try the steep slope procedure for a six-foot bottom width.

a. The design flow remains 90 cfs.

b. Bed slope = 0.032.

c. As discussed above, use a trapezoidal channel with six-foot bottom width and 2:1 side slopes.

d. From Figure 5.4 using 0.05 slope,

D_{50} = 0.95 ft use 1.0 ft.

d = 0.96 ft.

This D_{50} value compares favorably with the mild slope design result and substantiates the use of the steep slope procedure for Froude numbers greater than 0.8.

e. Gradation

$D_{max} = 1.25\ D_{50}$

$= 1.25$ ft.

$D_{10} = \frac{D_{50}}{3} = 0.33$ ft

Riprap thickness = $1.25\ D_{50} = 1.25$ ft.

7. Filter Evaluation

a. The assumed base material gradation is

D_{85} = 0.27 in.

D_{50} = 0.10 in.

D_{15} = 0.036 in.

The riprap charateristics are determined graphically by plotting the recommended gradation on semilog paper (Figure 10.3).

D_{85} = 14 in.

D_{50} = 12 in.

D_{15} = 4 in.

b. Using Army Corps of Engineers and U.S. Bureau of Reclamation filter design criteria (Equations 5.2 and 5.3):

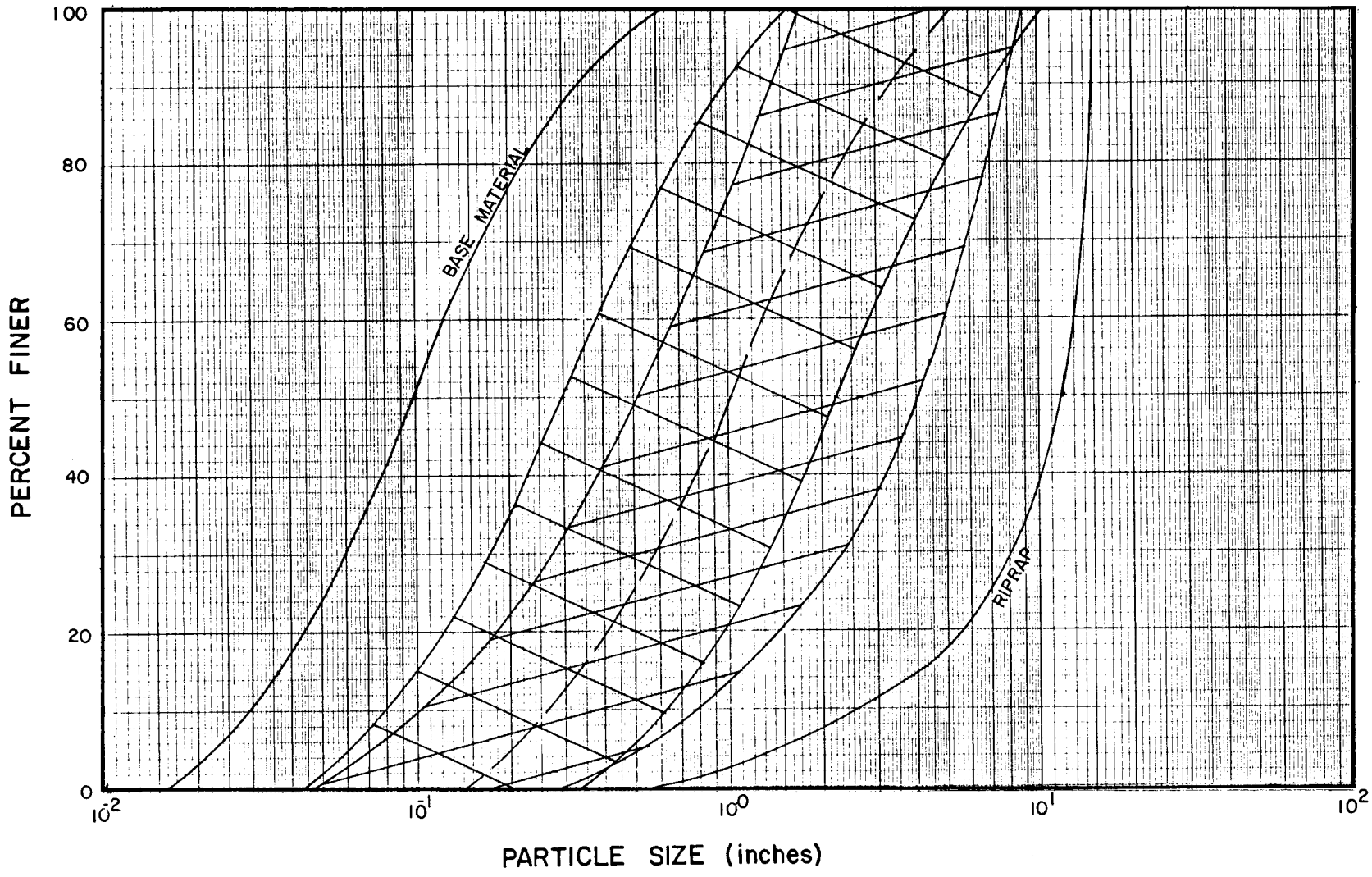

Figure 10.3. Particle size characteristic for diversion channel A from stations 0+00 to 7+80.

$$\frac{D_{15}\ \text{(riprap)}}{D_{85}\ \text{(base)}} = \frac{4}{0.27} = 15;\ 15 > 5$$

$$\frac{D_{15}\ \text{(riprap)}}{D_{15}\ \text{(base)}} = \frac{4}{0.036} = 111;\ 111 > 40$$

Therefore, a filter is necessary.

c. Properties of the filter relative to the base material:

$$\frac{D_{50}\ \text{(filter)}}{D_{50}\ \text{(base)}} < 40,\ \text{so}\ D_{50}\ \text{(filter)} < 40(0.10) = 4.0\ \text{in.}$$

$$\frac{D_{15}\ \text{(filter)}}{D_{15}\ \text{(base)}} < 40,\ \text{so}\ D_{15}\ \text{(filter)} < 40(0.036) = 1.4\ \text{in.}$$

$$\frac{D_{15}\ \text{(filter)}}{D_{85}\ \text{(base)}} < 5,\ \text{so}\ D_{15}\ \text{(filter)} < 4(0.27) = 1.1\ \text{in.}$$

$$\frac{D_{15}\ \text{(filter)}}{D_{15}\ \text{(base)}} > 5,\ \text{so}\ D_{15}\ \text{(filter)} > 4(0.036) = 0.14\ \text{in.}$$

Therefore, with respect to the base material, the filter must satisfy

$$0.14\ \text{in.} < D_{15}\ \text{(filter)} < 1.1\ \text{in.}$$

$$D_{50}\ \text{(filter)} < 4.0\ \text{in.}$$

Considering the riprap and filter:

$$\frac{D_{50}\ \text{(riprap)}}{D_{50}\ \text{(filter)}} < 40,\ \text{so}\ D_{50}\ \text{(filter)} > \frac{12}{40} = 0.30\ \text{in.}$$

$$\frac{D_{15}\ \text{(riprap)}}{D_{15}\ \text{(filter)}} < 40,\ \text{so}\ D_{15}\ \text{(filter)} > \frac{4}{40} = 0.10\ \text{in.}$$

$$\frac{D_{15}\ \text{(riprap)}}{D_{85}\ \text{(filter)}} < 5,\ \text{so}\ D_{85}\ \text{(filter)} > \frac{4}{5} = 0.8\ \text{in.}$$

$$\frac{D_{15}\ \text{(riprap)}}{D_{15}\ \text{(filter)}} > 5,\ \text{so}\ D_{15}\ \text{(filter)} < \frac{4}{5} = 0.8\ \text{in.}$$

Therefore, with respect to the riprap layer, the filter must satisfy

$0.10 \text{ in.} < D_{15}$ (filter) < 0.8 in.

D_{50} (filter) > 0.30 in.

D_{85} (filter) > 0.8 in.

The limits of the filter material with respect to both the riprap and base material are shown on Figure 10.3. The selected size distribution of the filter is indicated by the dashed line. The filter thickness should be equal to D_{max} (filter) but not less than 6-9 in. Therefore, use 9 in. as thickness.

8. Freeboard

$$F.B. = c_{fb}d + \frac{1}{2}\Delta Z \qquad \text{(Equation 4.20)}$$

Since the channel has a relatively short bend between Station 4+00 and 6+00, superelevation must be included in the freeboard calculation. From the topographic map, the radius of curvature (r_c) is estimated as 80' and $r_o - r_c$ (equal to the top width of the channel) is 12.0 ft. Froude number

$$V = \frac{Q}{A} = \frac{90}{6(0.96) + 3(0.96^2)} = 10.5 \text{ fps}$$

$$F_r = 10.5/\sqrt{32.2\ (0.96)} = 1.9$$

The freeboard coefficient c_{fb} from Table 4.4 is 1.0.

$c_{fd}(d) = 1.0(0.96) = 0.96 \text{ ft} < 1.0 \text{ ft}$; use 1.0 ft

$$F.B. = 1.0 + \frac{1}{2g}\frac{10.5^2}{80}(12.0) = 1.25 \text{ ft} \qquad (4.20)$$

The final channel dimensions are b = 6 ft and channel depth = 2.2 ft. Figure 10.4 illustrates the channel dimensions and excavation amounts required to accommodate the riprap and filter layer.

<u>Channel Design for Station 7+80 to 15+80</u>

Steep Slope Riprap Design

1. The design flow, as determined above, is 90 cfs.

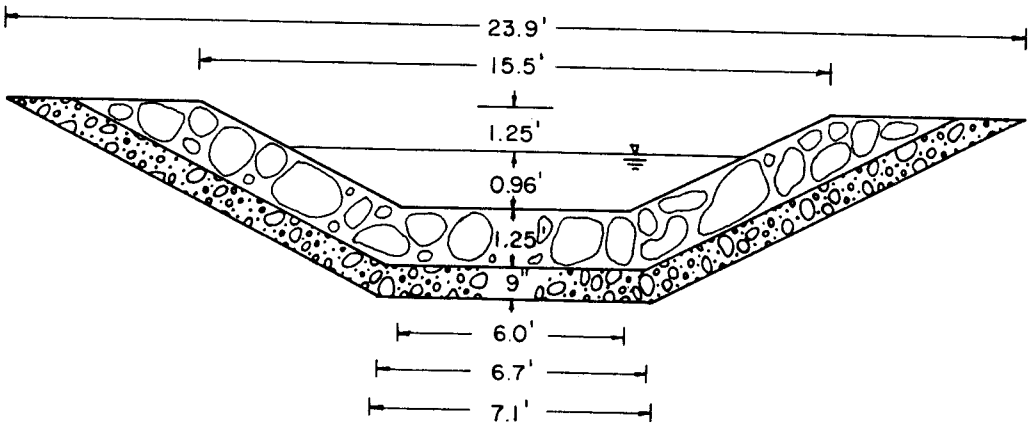

Figure 10.4. Diversion channel A dimensions from station 0+00 to 7+80.

2. The bed slope selected for design is based on an examination of Figure 10.2. The channel must collect runoff from each bench and therefore, must follow slope of fill. Using the steepest section, the bed slope is determined to be 0.30.

3. Channel size and shape. Try a trapezoidal channel with a 2:1 side slope and 6 foot base width.

4. From Figure 5.4, D_{50} = 2.1 ft, use D_{50} = 2.25 ft.

$$d = 0.4 \text{ ft.}$$

5. Gradation of riprap is

$$D_{max} = 1.25\ D_{50}$$

$$= 2.8 \text{ ft.}$$

$$D_{10} = \frac{D_{50}}{3} = 0.75 \text{ ft}$$

Riprap thickness = 1.25 D_{50} = 2.8 ft.

6. Granular filter design

a. The assumed base material gradation is

D_{85} = 0.27 in.

D_{50} = 0.10 in.

D_{15} = 0.036 in.

The riprap properties are determined by plotting the recommended gradation on semilog paper (Figure 10.5).

D_{85} = 33 in.

D_{50} = 27 in.

D_{15} = 12 in.

b. Using the Army Corps of Engineers and U.S. Bureau of Reclamation filter design criteria,

$$\frac{D_{15}\ \text{(riprap)}}{D_{85}\ \text{(base)}} = \frac{12}{0.27} = 44\ ;\ 44 > 5$$

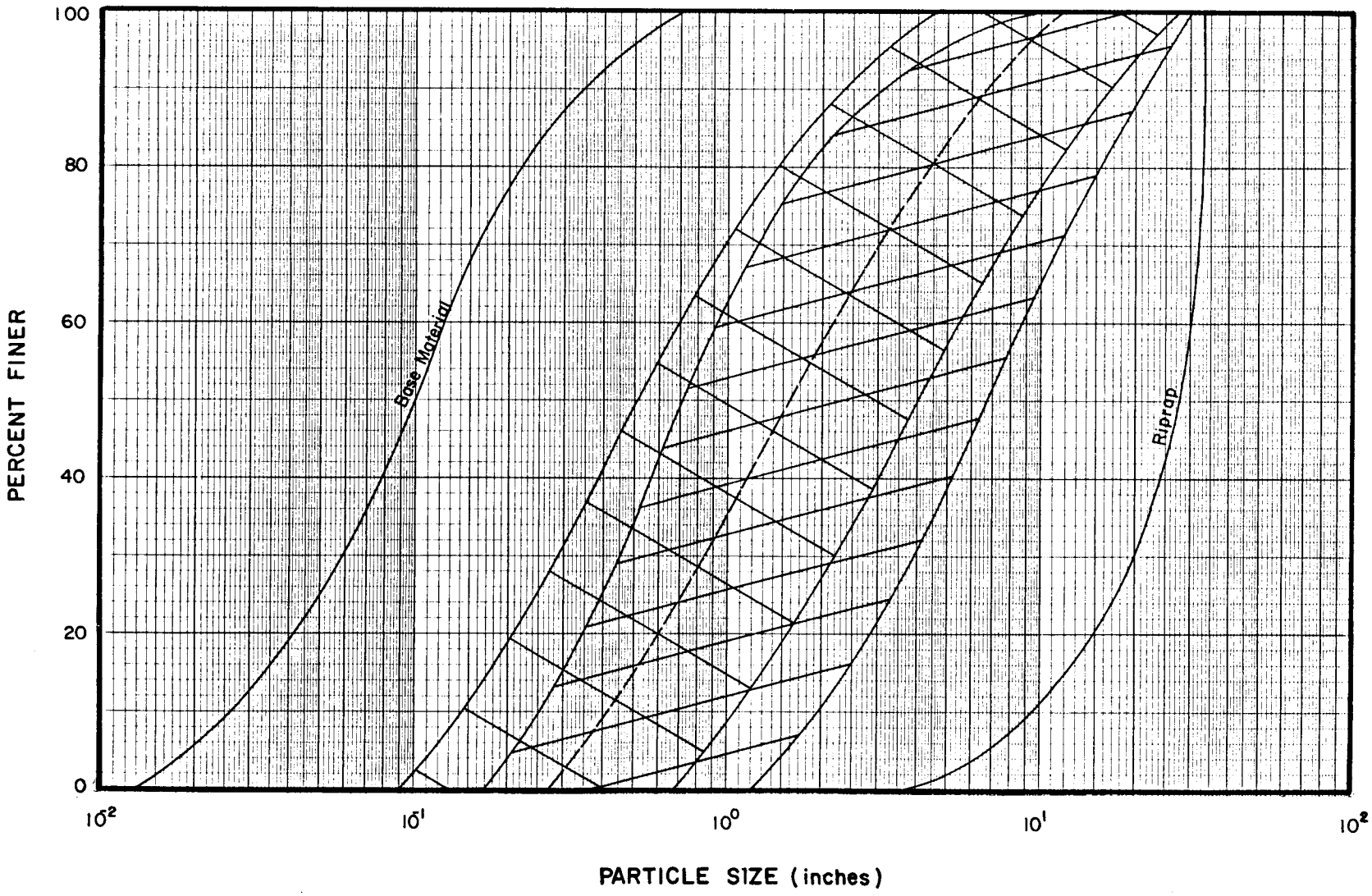

Figure 10.5. Particle size characteristics for diversion channel A stations 7+80 to 15+80.

$$\frac{D_{15}\ \text{(riprap)}}{D_{15}\ \text{(base)}} = \frac{12}{0.036} = 333\ ;\ 333 > 40$$

Therefore, a filter layer is necessary.

c. Properties of the filter relative to the base material are:

$$\frac{D_{50}\ \text{(filter)}}{D_{50}\ \text{(base)}} < 40,\ \text{so}\ D_{50}\ \text{(filter)} < 40(0.1) = 4.0\ \text{in.}$$

$$\frac{D_{15}\ \text{(filter)}}{D_{15}\ \text{(base)}} < 40,\ \text{so}\ D_{15}\ \text{(filter)} < 40(0.036) = 1.4\ \text{in.}$$

$$\frac{D_{15}\ \text{(filter)}}{D_{85}\ \text{(base)}} < 5,\ \text{so}\ D_{15}\ \text{(filter)} < 5(0.27) = 1.3\ \text{in.}$$

$$\frac{D_{15}\ \text{(filter)}}{D_{15}\ \text{(base)}} > 5,\ \text{so}\ D_{15}\ \text{(filter)} > 5(0.036) = 0.18\ \text{in.}$$

With respect to the base material, the filter must satisfy

$0.18\ \text{in.} < D_{15}\ \text{(filter)} < 1.3\ \text{in.}$

$D_{50}\ \text{(filter)} < 4.0\ \text{in.}$

Considering the riprap and filter material

$$\frac{D_{50}\ \text{(riprap)}}{D_{50}\ \text{(filter)}} < 40,\ \text{so}\ D_{50}\ \text{(filter)} > \frac{27}{40} = 0.6\ \text{in.}$$

$$\frac{D_{15}\ \text{(riprap)}}{D_{15}\ \text{(filter)}} < 40,\ \text{so}\ D_{15}\ \text{(filter)} > \frac{12}{40} = 0.30\ \text{in.}$$

$$\frac{D_{15}\ \text{(riprap)}}{D_{85}\ \text{(filter)}} < 5,\ \text{so}\ D_{85}\ \text{(filter)} > \frac{12}{5} = 2.4\ \text{in.}$$

$$\frac{D_{15}\ \text{(riprap)}}{D_{15}\ \text{(filter)}} > 5,\ \text{so}\ D_{15}\ \text{(filter)} < \frac{12}{5} = 2.4\ \text{in.}$$

With respect to the riprap layer, the filter must satisfy

$0.30\ \text{in} < D_{15}\ \text{(filter)} < 2.4\ \text{in.}$

D_{50} (filter) > 0.68 in.

D_{85} (filter) > 2.4 in.

The limits of the filter material with respect to both the riprap and base material are shown in Figure 10.5. The selected size distribution of the filter material is indicated by the dashed line. Thickness of the filter material is equal to the maximum size of the filter material if more than nine inches. In this case, thickness is equal to eleven inches.

7. Freeboard

The riprap size necessary for stability is determined by considering the steepest reach of the channel. However, in the steepest channel reach the flow depth will be a minimum relative to the milder-sloped reaches. To ensure adequate freeboard and overall channel depth, the depth of flow must be evaluated for the mildest-sloped reach. For the steep channel design between stations 7+80 and 15+80, neglecting the short bench sections of channel, the mildest slope is 15%.

From Figure 5.4

$d = 0.7$ ft.

$c_{fb} = 1.0$ (Table 4.4)

$c_{fb}(d) = 1.0(0.7) = 0.7 < 1.0$; use 1.0 ft.

$F.B. = c_{fb}(d) + \frac{1}{2}\Delta Z = 1.0 + 0 = 1.0$ ft. (Equation 4.20)

The constructed channel section dimensions are therefore $b = 6$ ft. and total channel depth = F.B. + d = 1.7 ft. Figure 10.6 illustrates the final channel dimensions.

10.3.2 Diversion Channel B

As determined above, the design flow for Channel B is 90 cfs. From the topographic map (Figure 10.1), the longitudinal profile was evaluated and plotted in Figure 10.7. For stations 0+00 to 7+80 the average slope is 0.044 and from 7+80 to 15+60, the maximum slope is 33 percent. Therefore, based on the results of Diversion Channel A, assume both slopes are steep.

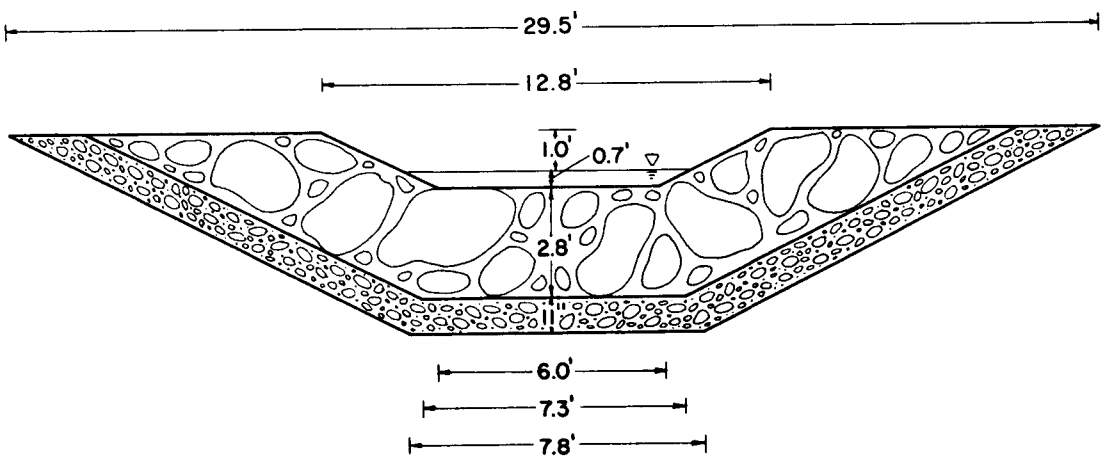

Figure 10.6. Diversion channel A dimensions from station 7+80 to 15+80.

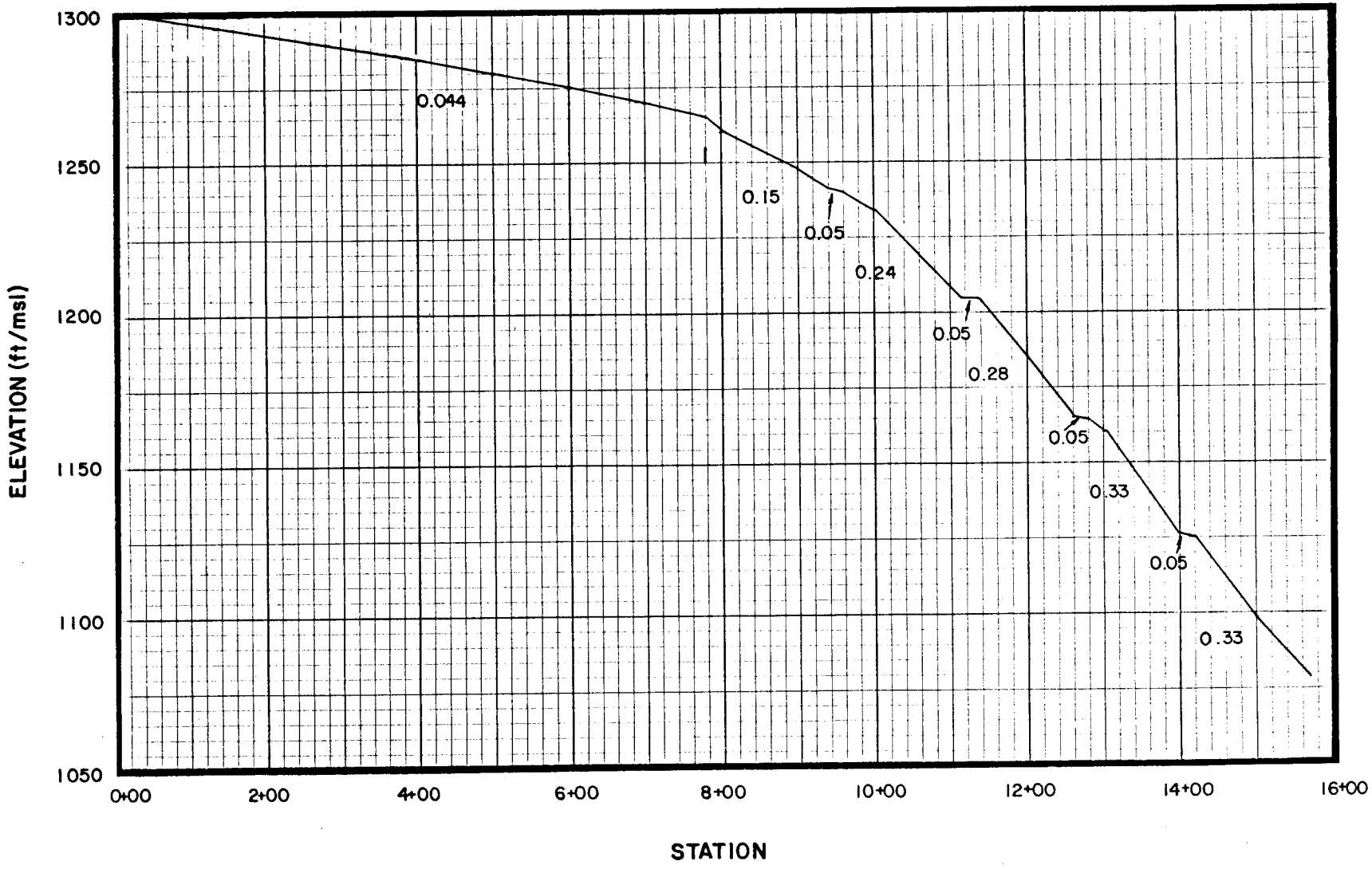

Figure 10.7. Longitudinal profile for diversion channel B.

Station 0+00 to 7+80

Since the design discharge is the same as Channel A and the 0.05 slope line will again be used on Figure 5.4, the riprap design will be identical to Channel A station 0+00 to 7+80. Also due to the similarity in alignment, the freeboard is nearly the same. It is adequate to use the same cross section for Channel B, station 0+00 to 7+80 as Channel A, station 0+00 to 7+80 (Figure 10.4).

Channel Design for Station 7+80 to 15+60

Steep Slope Riprap Design

1. The design flow is 90 cfs.
2. The bed slope selected for design is based on an examination of Figure 10.7. Using the steepest section, the bed slope is determined to be 0.33.
3. Channel size and slope. Try a trapezoidal channel with 2:1 side slope and 6 foot base width.
4. From Figure 5.4, D_{50} = 2.2 ft; use D_{50} = 2.25 ft.

   d = 0.3 ft.
5. Gradation of riprap is

   $D_{max} = 1.25\ D_{50} = 2.8$ ft.

   $D_{10} = \frac{D_{50}}{3} = 0.75$ ft

   Riprap thickness = $1.25\ D_{50} = 2.8$ ft.
6. Granular filter design. Since the base material and riprap are the same for the steep sections of both Channel A and Channel B, the granular filter remains the same. The limits of the filter material with respect to the riprap and base material are shown on Figure 10.5. The selected size distribution of the filter material is indicated by the dashed line. Thickness of the filter material is eleven inches.
7. Freeboard

   $C_{fb} = 1.0$ (Table 4.4)

   $C_{fb}(d) = 1.0(0.3) = 0.3 < 1.0$; use 1.0 ft.

$$F.B. = C_{fb}(d) + \frac{1}{2}\Delta Z = 1 + 0 = 1.0 \text{ ft.}$$

The channel design will be b = 6 ft and channel depth = 1.3 ft. Comparing this with the steep slope design of Channel A reveals a difference of 0.10 feet in design depth. This small difference in depth does not justify a new channel design. Therefore use the same channel as previously illustrated in Figure 10.6.

10.3.3 Diversion Channel C

Diversion Channel C collects runoff from both Channels A and B and therefore must be designed for 180 cfs. From the topographic map (Figure 10.1) the longitudinal profile was determined (Figure 10.8). The slope conditions require the steep slope design procedure.

1. The design flow is 180 cfs, as determined above.
2. The bed slope selected for design is based on examination of Figure 10.8. The amount of excavation required to design a uniform slope channel is prohibitive. Therefore, for ease in construction, a single channel cross section will be designed that is adequate for each section. Designing for riprap stability using the steepest section, the bed slope is determined to be 0.18, therefore use steep slope procedure.
3. The bottom widths of Channels A and B were equal to 6 ft. Therefore, try a bottom width of 10 ft for Channel C. Use 2:1 side slopes.
4. From Figure 5.5, D_{50} = 1.65 ft, use 1.75 ft.

   d = 0.8 ft

5. Gradation of the riprap is

   D_{max} = 1.25(1.75) = 2.2 ft

   D_{10} = 1.75/3 = 0.6 ft

   riprap thickness 1.25 (D_{max}) = 2.2 ft

6. Filter gradation design.
   a. The assumed base material gradation is

   D_{85} = 0.27 in.

   D_{50} = 0.10 in.

   D_{15} = 0.036 in.

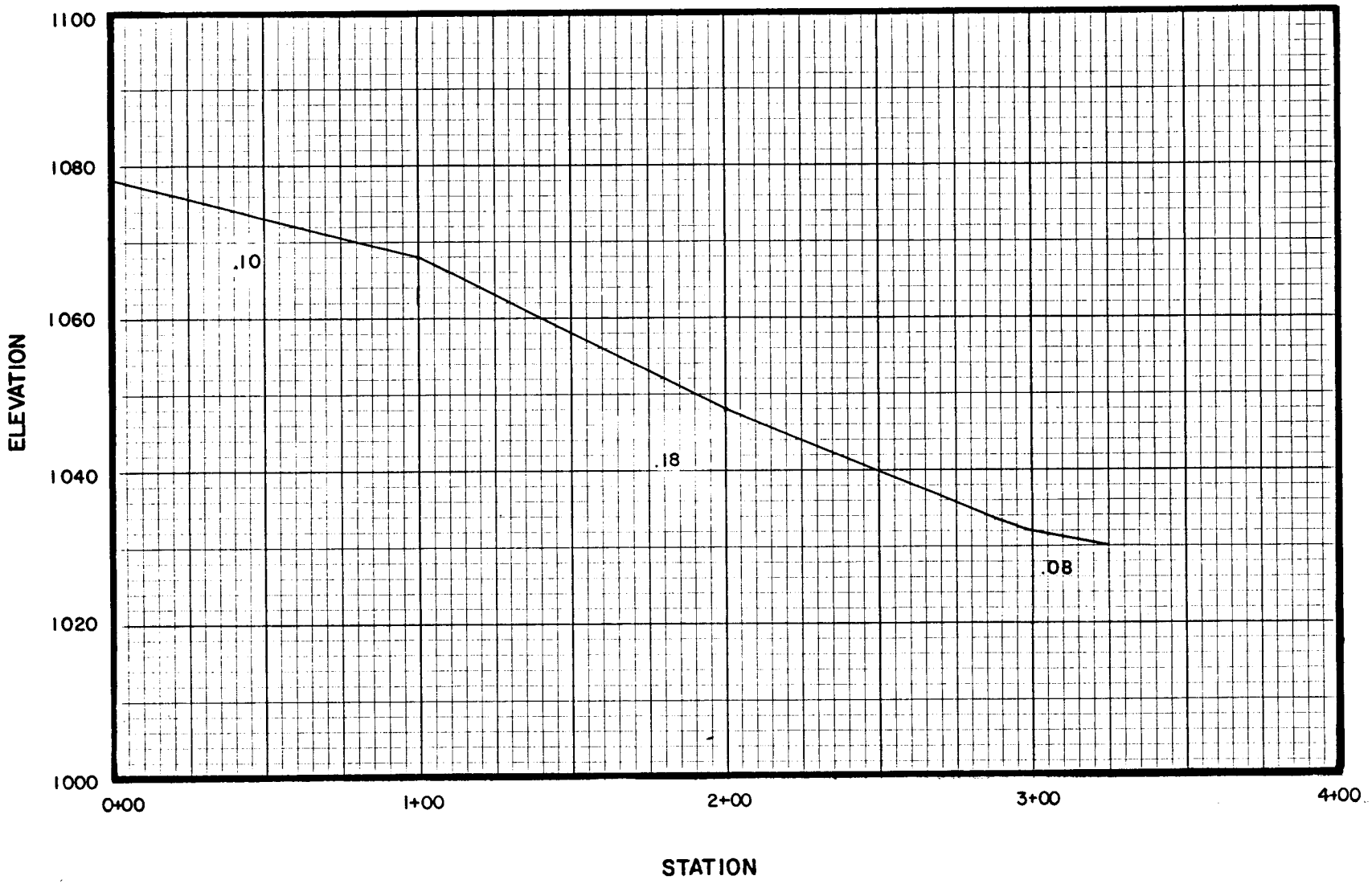

Figure 10.8. Longitudinal profile of diversion channel C.

The riprap characteristics are determined graphically by plotting the recommended gradation on semi-log paper (Figure 10.9).

D_{85} = 26.0 in.

D_{50} = 21 in.

D_{15} = 8.5 in.

b. Using the Army Corps of Engineers and U.S. Bureau of Reclamation filter design criteria (Equations 5.2 and 5.3)

$$\frac{D_{15}(\text{riprap})}{D_{85}(\text{base})} = \frac{8.5}{0.27} = 31 \; ; \; 31 > 5$$

$$\frac{D_{15}(\text{riprap})}{D_{15}(\text{base})} = \frac{8.5}{0.036} = 236 \; ; \; 236 > 40$$

Therefore, a filter is necessary.

c. Properties of the filter relative to the base material are:

$$\frac{D_{50}(\text{filter})}{D_{50}(\text{base})} < 40 \text{ , so } D_{50}(\text{filter}) < 40(0.1) = 4.0 \text{ in.}$$

$$\frac{D_{15}(\text{filter})}{D_{15}(\text{base})} < 40 \text{ , so } D_{15}(\text{filter}) < 40(0.036) = 1.4 \text{ in.}$$

$$\frac{D_{15}(\text{filter})}{D_{85}(\text{base})} < 5 \text{ , so } D_{15}(\text{filter}) < 5(0.27) = 1.3 \text{ in.}$$

$$\frac{D_{15}(\text{filter})}{D_{15}(\text{base})} > 5 \text{ , so } D_{15}(\text{filter}) < 5(0.030) = 0.18 \text{ in.}$$

With respect to the base material, the filter must satisfy

$0.18 < D_{15}(\text{filter}) < 1.3$ in.

$D_{50}(\text{filter}) < 4.0$ in.

Considering the riprap and filter material

$$\frac{D_{50}(\text{riprap})}{D_{50}(\text{filter})} < 40 \text{ , so } D_{50}(\text{filter}) > \frac{21}{40} = 0.52 \text{ in.}$$

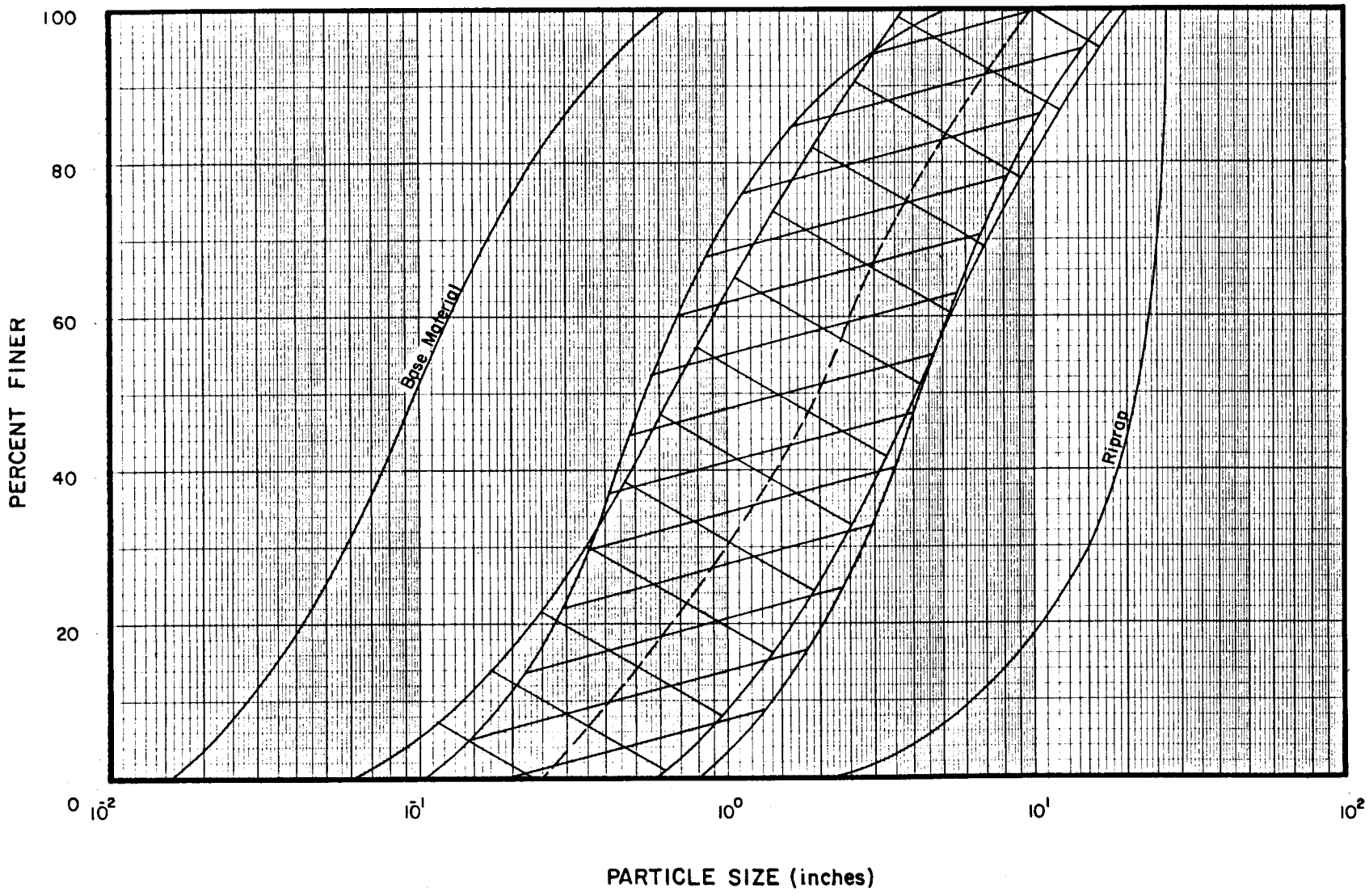

Figure 10.9. Particle size characteristics for diversion channel C.

$$\frac{D_{15}(\text{riprap})}{D_{15}(\text{filter})} < 40 \text{ , so } D_{15}(\text{filter}) > \frac{8.5}{40} = 0.21 \text{ in.}$$

$$\frac{D_{15}(\text{riprap})}{D_{85}(\text{filter})} < 5 \text{ , so } D_{85}(\text{filter}) > \frac{8.5}{5} = 1.7 \text{ in.}$$

$$\frac{D_{15}(\text{riprap})}{D_{15}(\text{filter})} < 5 \text{ , so } D_{15}(\text{filter}) < \frac{8.5}{5} = 1.7 \text{ in.}$$

With respect to the riprap layer, the filter must satisfy

$0.21 \text{ in.} < D_{15}(\text{filter}) < 1.7 \text{ in.}$

$D_{50}(\text{filter}) > 0.52 \text{ in.}$

$D_{85}(\text{filter}) > 1.7 \text{ in.}$

The limits of the filter material with respect to both the riprap and base material are shown in Figure 10.9. The selected size distribution of the filter material is indicated by the dashed line. The thickness of the filter material is equal to the maximum size of the filter, is more than nine inches. In this case, thickness is equal to 10 inches.

7. Freeboard.

The riprap size was determined in Step 4 by considering the critical flow conditions occurring in the steepest (S = 0.18) reach of Channel C. To evaluate freeboard and total channel depth required, the milder sloping reach from Station 0+00 to 1+00 with a slope of 10 percent is considered. The 8 percent channel reach starting at Station 3+00 is neglected because it is only 25 ft long.

Using $S = 0.10$

$Q = 180 \text{ cfs}$

Figure 5.5 indicates

$d = 1.1 \text{ ft.}$

From Table 4.4 $C_{fb} = 1.0$

$C_{fb}(d) = 1.0(1.1) = 1.1 > 1.0 \text{ ft. ; use } 1.1 \text{ ft.}$

$$F.B. = C_{fb}(d) + \frac{1}{2}\Delta Z = 1.1 + 0 = 1.1 \text{ ft.}$$

The final channel dimensions as shown in Figure 10.10 are b = 10 ft., total channel depth = 2.2 ft.

10.3.4 Diversion Channel D

Diversion Channel D is a reconstructed channel over a reclaimed strip bench. From the topographic map the channel extends from Stations 1+85 to 6+70. The profile of the waterway is shown in Figure 10.11. The slope conditions require utilizing the steep slope riprap design procedure.

1. The design flow as determined in Section 10.2 is 80 cfs.
2. From Figure 10.11 the bed slope is 0.24.
3. From consideration of upstream and downstream natural waterways, a channel bottom width of 6 ft is selected with a 2:1 side slope.
4. From Figure 5.1, $D_{50} = 1.75$ ft.

   $d = 0.46$ ft.
5. Gradation of riprap is

   $D_{max} = 1.25(1.75) = 2.2$ ft

   $D_{10} = 1.75/3 = 0.60$ ft.

   Riprap thickness $1.25\ D_{50} = 2.2$ ft.
6. Filter design. The riprap has the same particle size as Channel C. The particle size of the base material is also assumed nearly the same. Therefore, the filter requirement for channel D is identical to the filter designed for Channel C.
7. Freeboard

   From Table 4.4 $C_{fb} = 1.0$

   $C_{fb}(d) = 1.0(0.46) = 0.46 < 1.0$; use 1.0 ft.

   $$F.B. = C_{fb}(d) + \frac{1}{2}\Delta Z = 1.0 + 0 = 1.0 \text{ ft.}$$

The final channel dimensions are given in Figure 10.12.

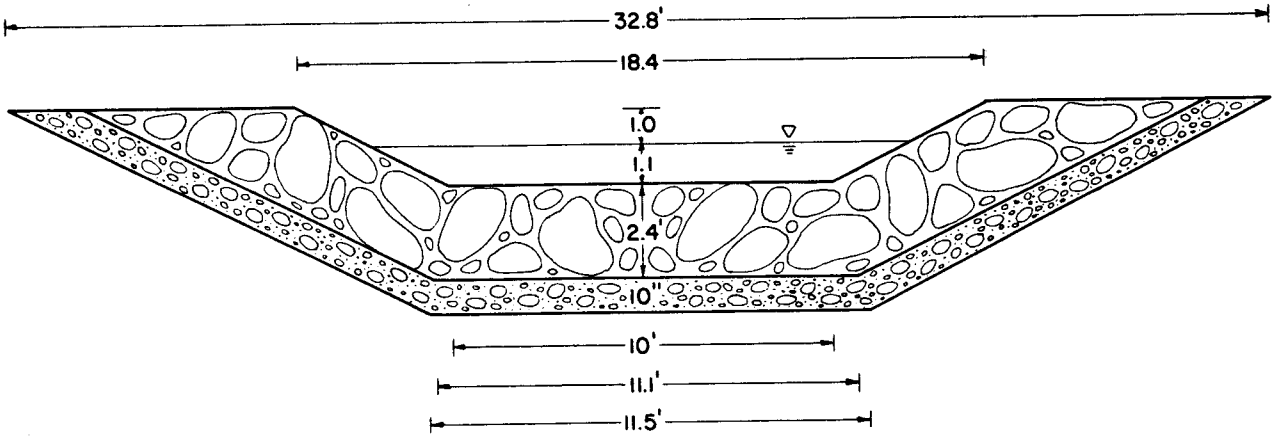

Figure 10.10. Diversion channel C dimensions.

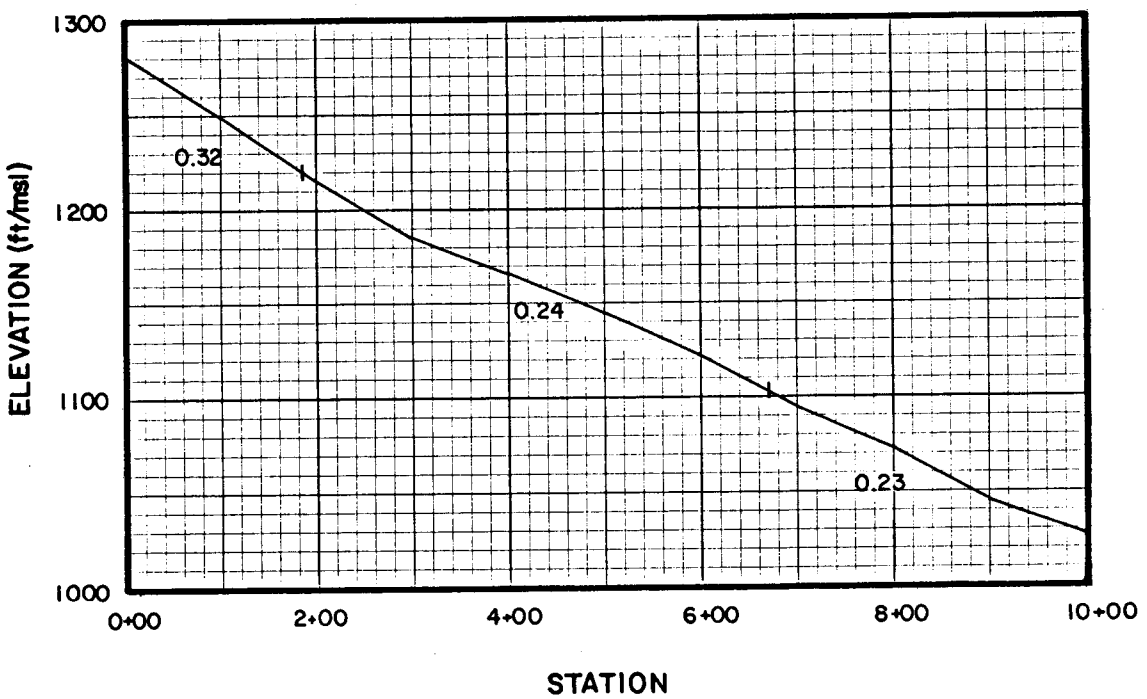

Figure 10.11. Longitudinal profile of diversion channel D.

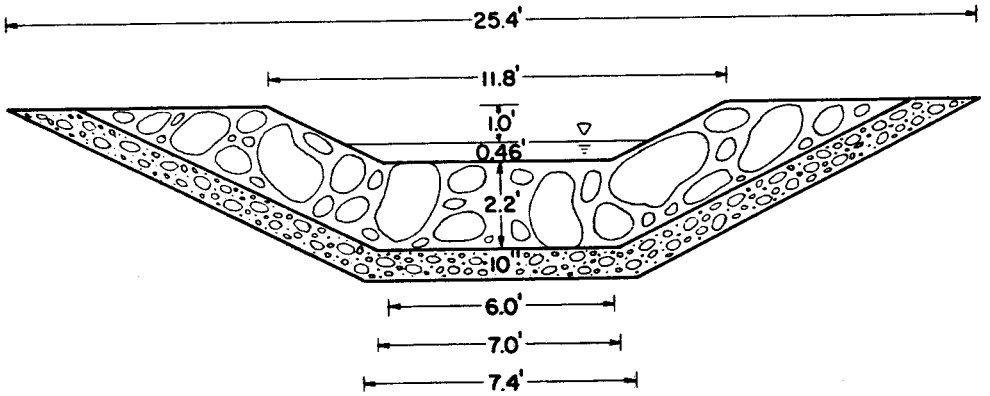

Figure 10.12. Diversion channel D dimensions.

10.4 Transition Design

10.4.1 Channels A and B

In both Channels A and B, transition design is required for the entrance to and exit from the steep slope channel. The transition length should be protected with the same riprap size used on the steep slope. The transition length is computed from the guidelines given in Section 5.4.

The downstream depth of flow, used to evaluate the length of protection needed at the change in grade, is computed for the 10 percent channel reach between Stations 0+00 and 1+00 in Channel C. From Figure 5.2 for $Q = 180$ cfs and $S = 0.10$

$$d \cong 1.1 \text{ ft.}$$

$$\text{Length of protection} = 5d = 5.5 \text{ ft.}$$

Since 5.5 ft < 15 ft, the minimum protection of 15 feet is required. The riprap size calculated for the steep slope sections of Channels A and B should be extended for a distance of 15 ft in Channel C (i.e., from Station 0+00 to 0+15). In this example the riprap size in both steep channels sections of Channels A and B is identical. If the rock size was different, protection below the chanel in grade should be provided by using the larger riprap gradation. Protection should also be provided at the entrance sections from mild to steep slopes in Channels A and B. Steep slope riprap protection should be extended 15 ft above the steep slope sections. There will be no other significant transition problems since the cross section geometry (6 ft bottom width and 2:1 side slope) is the same for the steep and mild channels.

10.4.2 Channels C and D

The entrance protection for Channel C has already been established by the exit protection required for Channels A and B. The exit of Channel C is to the existing natural waterway downstream of the junction of the natural waterway containing diversion Channel D. It is recommended that the riprap of Channel C be extended through the junction to insure the stability of this area. The entrance of the natural waterway containing diversion Channel D should also be riprapped in this region.

The bottom width of Channel D was chosen to approximate the natural waterway upstream and downstream. Although the change in roughness may cause a greater depth in the riprapped diversion channel than in the natural water-

way, the steep slope conditions will minimize this effect. Therefore, considering these factors, no transition problems are anticipated in Channel D.