CHAPTER 5

OPEN CHANNEL HYDROLOGY

5.11 Rectangular, Triangular, and Trapezoidal Design Figures

5.11.1 Introduction

The Federal Highway Administration has prepared numerous design figures to aid in the design of open channels. Copies of these figures, a brief description of their use, and several example design problems are presented. For design conditions not covered by the figures, a trial-and error solution of the Manning equation must be used.

5.11.2 Description of Figures

Figures given in Appendix A, B, and C at the end of this chapter are for the direct solution of the Manning equation for various sized open channels with rectangular, triangular, and trapezoidal cross sections. Each figure (except for the triangular cross section) is prepared for a channel of given bottom width and a particular value of Manning's n.

The figures for rectangular and trapezoidal cross section channels (Appendix A) are used the same way. The abscissa scale of discharge in cubic feet per second (cfs), and the ordinate scale is velocity in feet per second (ft/s). Both scales are logarithmic. Superimposed on the logarithmic grid are steeply inclined lines representing depth (ft), and slightly inclined lines representing channel slope (ft/ft). A heavy dashed line on each figure shows critical flow conditions. Auxiliary abscissa and ordinate scales are provided for use with other values of n and are explained in the example problems.

In the figures, interpolations may be made not only on the ordinate and abscissa scales but between the inclined lines representing depth and slope.

The chart for a triangular cross section in (Appendix B) is in nomograph form. It may be used for street sections with a vertical (or nearly vertical) curb face. The nomograph also may be used for shallow V-shaped sections following the instructions on the chart.

5.11.3 Instructions For Rectangular And Trapezoidal Figures

Figures in Appendix A provide a solution of the Manning equation for flow in open channels of uniform slope, cross section, and roughness, provided the flow is not affected by backwater and the channel has a length sufficient to establish uniform flow.

For a given slope and channel cross section, when n is 0.015 for rectangular channels or 0.03 for trapezoidal channels, the depth and velocity of uniform flow may be read directly from the figure for that size channel. The initial step is to locate the intersection of a vertical line through the discharge (abscissa) and the appropriate slope line. At this intersection, the depth of flow is read from the depth lines, and the mean velocity is read on the ordinate scale.

The procedure is reversed to determine the discharge at a given depth of flow. Critical depth, slope, and velocity for a given discharge can be read on the appropriate scale at the intersection of the critical curve and a vertical line through the discharge.

Auxiliary scales, labeled Qn (abscissa) Vn (ordinate), are provided so the figures can be used for values of n other than those for which the charts were basically prepared. To use these scales, multiple the discharge by the value of n and use the Qn and Vn scales instead of the Q and V scales, except for computation of critical depth or critical velocity. To obtain normal velocity V from a value on the Vn scale, divide the value by n. The following examples will illustrate these points.

Example Design Problem 1

Given: A rectangular concrete channel 5 ft wide with n = 0.015, .06 percent slope (S = .0006), discharging 60 cfs.

Find: Depth, velocity, and type of flow

Procedure:

1. From appendix A select the rectangular figure for a 5 ft width (Figure 5-11).

2. From 60 cfs on the Q scale, move vertically to intersect the slope line S = .0006, and from the depth lines read d_n = 3.7 ft.

3. Move horizontally from the same intersection and read the normal velocity, V = 3.2 ft/s, on the ordinate scale.

4. The intersection lies below the critical curve, and the flow is therefore in the subcritical range.

Example Design Problem 2

Given: A trapezoidal channel with 2:l side slopes and a 4 ft bottom width, with n = 0.030, 0.2 percent slope (S – 0.002), discharging 50 cfs.

Find: Depth, velocity, type flow.

Procedure:

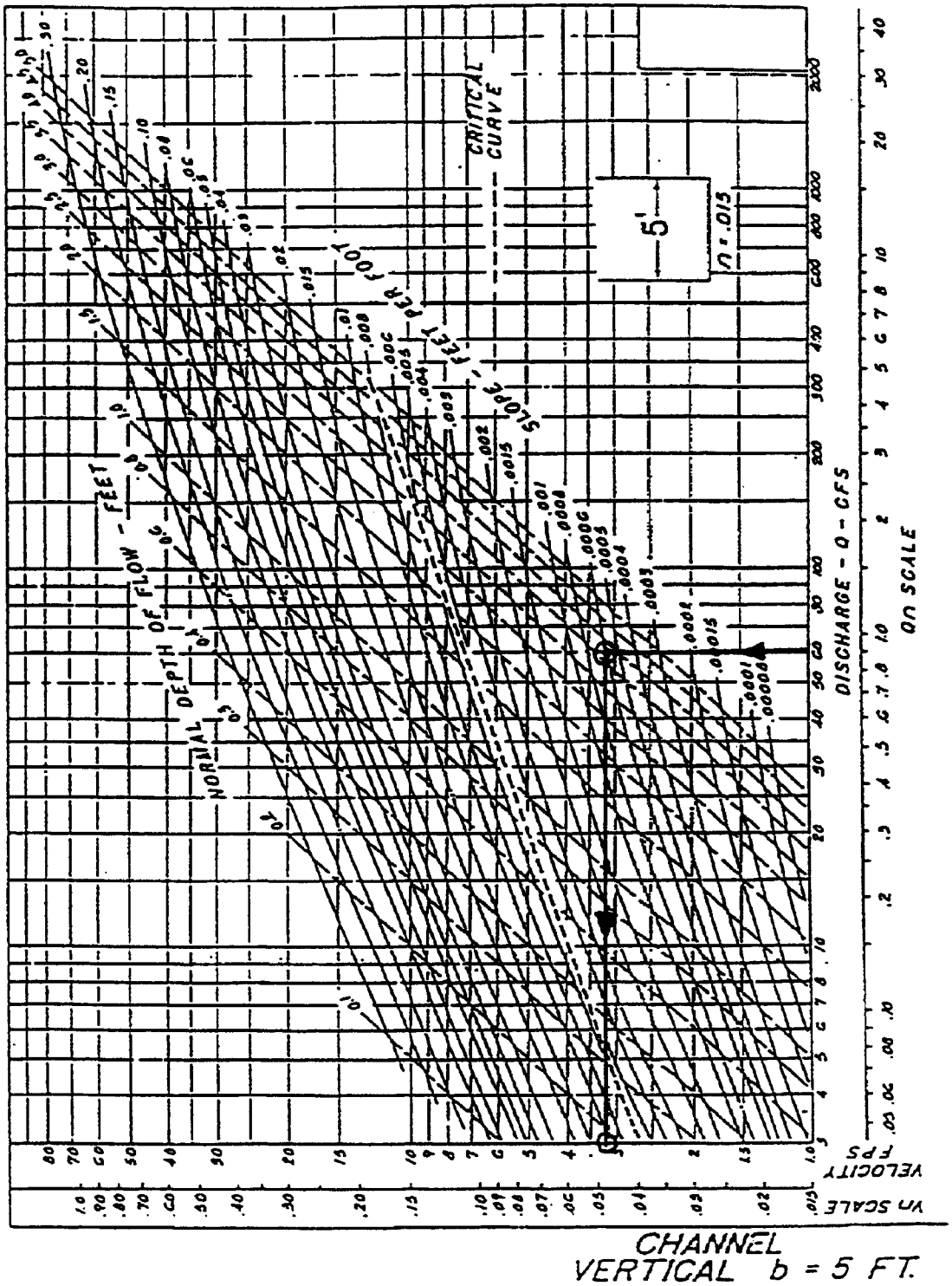
1. Select the trapezoidal figure for b = 4 ft.

2. From 50 cfs on the Q scale, move vertically to intersect the slope line S = 0.002 and from the depth lines read d_n = 2.2 ft (Figure 5.11.4-1).

3. Move horizontally from the same intersection and read the normal velocity, V = 2.75 ft/s, on the ordinate scale. The intersection lies below the critical curve, the flow is therefore subcritical.

Figure 5.11.3-1

Source: Federal Highway Administration



Example Design Problem 3

Given: A rectangular cement rubble masonry channel 5 ft wide, with n = 0.025, 05 percent slope (S-0.005), discharging 80 cfs.

Find: Depth velocity and type of flow

Procedure:

1. Select the rectangular figure for a 5 ft width (Figure 5.11.4-2).

2. Multiply Q by n to obtain Qn: 80 x 0.025 = 2.0.

3. From 2.0 on the Qn scale, move vertically to intersect the slope line, S = 0.005, and at the intersection read d_n = 3.1 ft.

4. Move horizontally from the intersection and read Vn = .13, then Vn/n = 0.13/0.025 = 5.2 ft/s.

5. Critical depth and critical velocity are independent of the value of n so their values can be read at the intersection of the critical curve with a vertical line through the discharge. For 80 cfs, on figure 5-17, d_c = 2.0 ft and V_c = 7.9 ft/s. The normal velocity, 5.2 ft/s (from step 4), is less than the critical velocity, and the flow is therefore subcritical. It will also be noted that the normal depth, 3.0 ft, is greater than the critical depth, 2.0 ft, which also indicates subcritical flow.

6. To determine the critical slope for Q = 80 cfs and n = 0.025, start at the intersection of the critical curve and a vertical line through the discharge, Q = 80 cfs, finding d_c (2.0 ft) at this point. Follow along this d_c line to its intersection with a vertical line through Qn = 2.0 (step 2), at this intersection read the slope value S_c = 0.015.

5.11.4 Grassed Channel Figures

The Manning equation can be used to determine the capacity of a grass-lines channel, but the value of n varies with the type of grass, development of the grass cover, depth, and velocity of flow. The variable value of n complicates the solution of the Manning equation. The depth and velocity of flow must be estimated and the manning equation solved using the n value which corresponds to the estimated depth and velocity. The trial solution provides better estimates of the depth and velocity for a new value of n and the equation is again solved.

The procedure is repeated until a depth is found that carries the design discharge.

Figure 5.11.4-1

Source: Federal Highway Administration

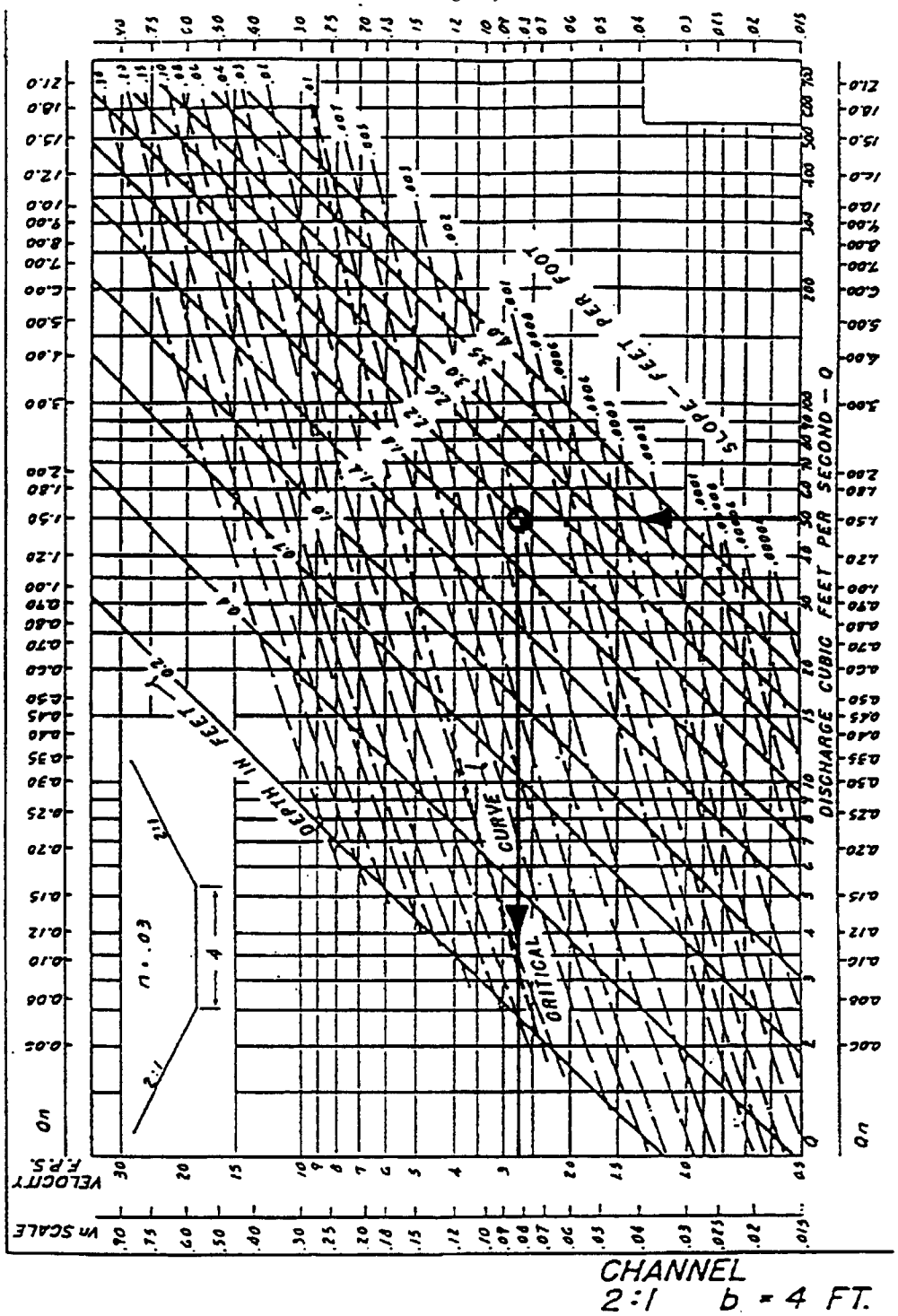
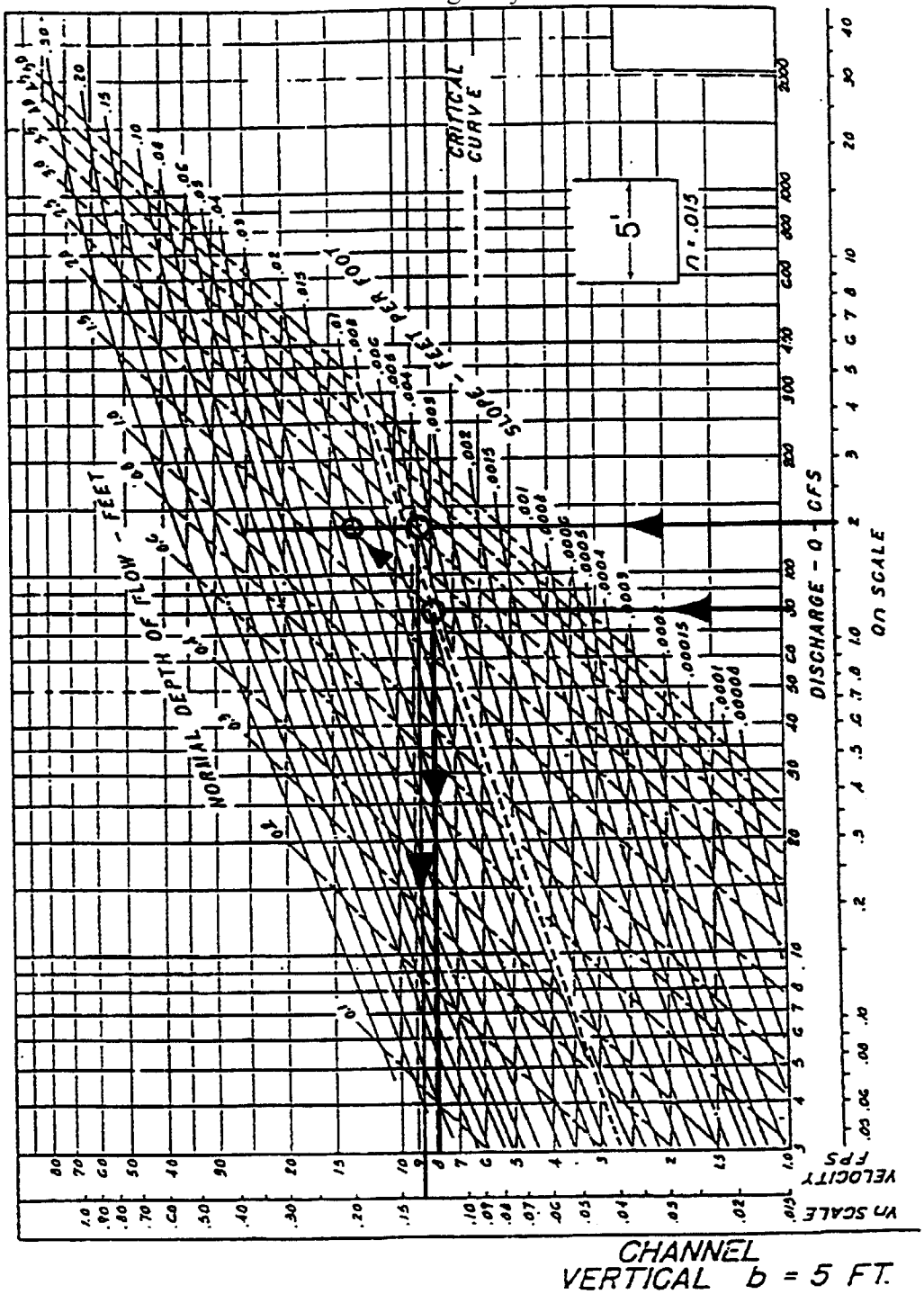


Figure 5.11.4-2

Source: Federal Highway Administration



To prevent excessive erosion, the velocity of flow in a grass-lined channel must be kept below some maximum value (referred to as permissible velocity). The permissible velocity in a grass-lined channel depends upon the type of grass, condition of the grass cover, texture of the soil comprising the channel bed, channel slope, and to some extent the size and shape of the drainage channel. To guard against overtopping, the channel capacity should be computed for taller grass than is expected to be maintained, while the velocity used to check the adequacy of the protection should be computed assuming a lower grass height than will likely be maintained.

To aid in the design of grassed channels the Federal Highway Administration has prepared numerous design figures. Copies of these figures are in Appendix C at the end of this chapter. Following is a brief description of general design criteria, instructions on how to use the figures, and several example design problems. For design conditions not covered by the figures, a trial-and error solution of the Manning equation must be used.

5.11.5 Grassed Channel Design Criteria

Grassed channels may be any shape suitable to the location and environmental conditions. The following are general criteria for designing grassed channels.

5.11.5.1 Side Slopes – The flatter the side slope, the better. A normal minimum side slope is 4:1. Under special conditions the slopes may be as steep as 3:1 which is also the practical limit for mowing equipment.

5.11.5.2 Depth – the maximum depth should be limited to 3.5 ft, though larger depths are acceptable where good maintenance can be expected and expected and where durations of peak flows are short.

5.11.5.3 Bottom Width – The bottom width should be at least 6 to 8 times the depth of flow. Twenty to 30 times the depth is common. For ease of maintenance, the bottom width should be a minimum of 7 ft.

5.11.5.4 Trickle Channel – Trickle channels should be used on all urban grassed channels.

Low flows in channels in urban areas must be given specific attention. Continuous flow will destroy a grass stand. Thus, low flows must be carried in a trickle channel with a capacity in cubic feet per second approximately 1.3 times the contributing drainage area in square miles. A trickle channel is subject to erosion and must therefore be protected with appropriate erosion control devices.

5.11.6 Description of Figures

The figures in Section 5.14 are designed for use in the direct solution of the Manning equation for various channel sections lined with grass. The figures are similar in appearance and use to those for trapezoidal cross sections described earlier. However, their construction is much more difficult because the roughness coefficient (n) changes as higher velocities and/or greater depths change the condition of the grass. The effect of velocity and depth of flow on n is evaluated by the product of velocity and hydraulic radius V times R. The variation of Manning's n with the retardance (Table 5.4.4-3) and the product V times R is shown in Figure 5.4.4-1. As indicated in Table 5.4.4-3 retardance varies with the height of the grass and the condition of the stand. Both of these factors depend upon the type of grass planting conditions, and maintenance practices. Table 5.4.4-3 is used to determine retardance classification.

The grassed channel figures each have two graphs, the upper graph for retardance D and the lower graph of retardance C. The figures are plotted with discharge in cubic feet per second on the abscissa and slope in feet per foot on the ordinate. Both scales are logarithmic.

Superimposed on the logarithmic grid are lines for velocity in feet per second and lines for depth in feet. A dashed line shows the position of critical flow.

5.11.7 Instructions For Grassed Channel Figures

The grassed channel figures provide a solution of the Manning equation for flow in open grassed channels of uniform slope and cross section. The flow should not be affected by backwater and the channel should have length sufficient to establish uniform flow. The figures are sufficiently accurate for design of drainage channels of fairly uniform cross section and slope, but are not appropriate for irregular natural channels.

The design of grassed channels requires two operations: (1) selecting a section which has the capacity to carry the design discharge on the available slope and (2) checking the velocity in the channel to insure that the grass lining will not be eroded. Because the retardance of the channel is largely beyond the control of the designer, it is good practice to compute the channel capacity using retardance C and the velocity using retardance D. The calculated velocity should then be checked against the permissible velocities listed in Table 5.3-1 and 5.3-2. The use of the figures is explained in the following steps:

(1) Select the channel cross section to be used and find the appropriate figure.

(2) Enter the lower graph (for retardance C) on the figure with the design discharge value on the abscissa and move vertically to the value of the slope on the ordinate scale. As this intersection, read the normal velocity and normal depth and note the position of the critical curve. If the

intersection point is below the critical curve, the flow is subcritical if it is above, the flow is supercritical.

(3) To check the velocity developed against the permissible (Tables 5.3-1 and 5.3-2), enter the upper graph on the same figure and repeat step 2. Then compare the computed velocity with the velocity permissible for the type of grass, channel slope, and erosion resistance of the soil. If the computed velocity is less, the design is acceptable. If not, a different channel section must be selected and the process repeated.

Example Design Problem 1

Given: A trapezoidal channel in easily eroded soil, lined with a grass mixture with 4:1 side slopes, and a 4 ft bottom width on slope of 0.02 ft per foot (S = .02), discharging 20 cfs.

Find: Depth, velocity, type of flow, and adequacy of grass to prevent erosion.

Procedure:

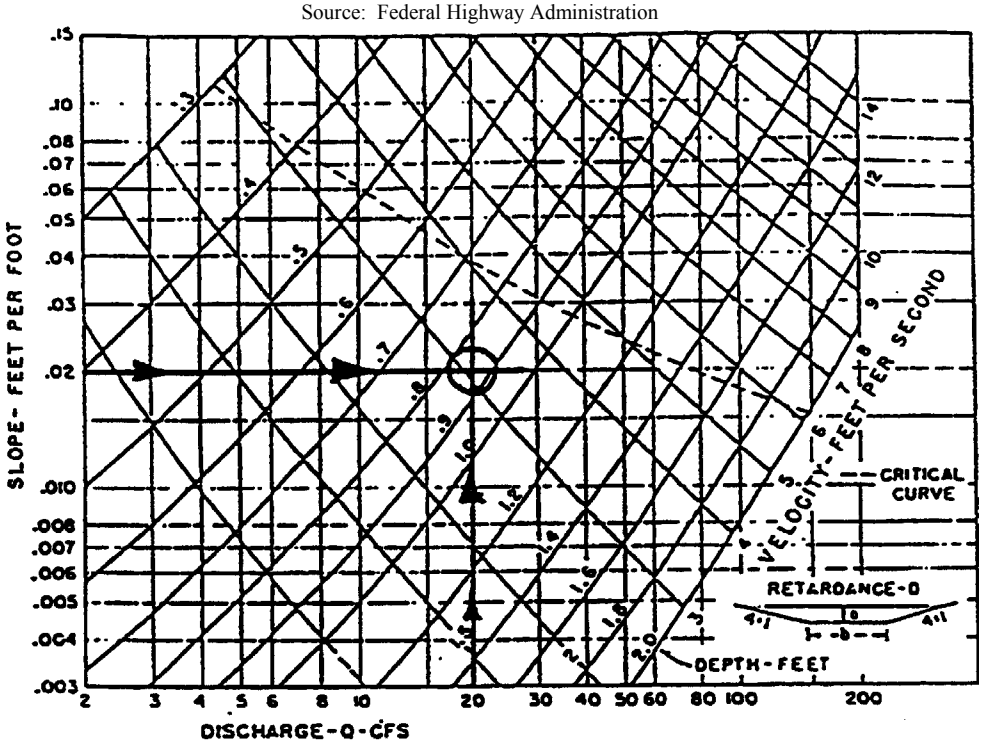
1. From Section 5.14 select figure for 4:1 side slopes (Figure 5-14 on the next page).

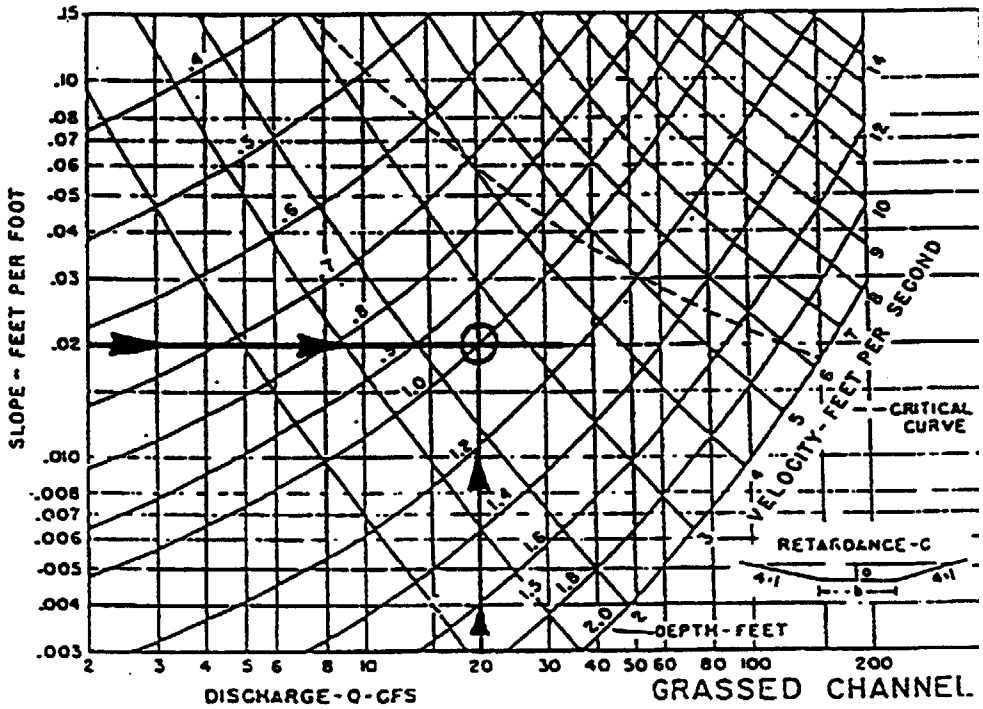
2. Enter the lower graph with Q = 20 cfs, and move vertically to the line for S = 0.02. At this intersection read d_n = 1.0 ft, and normal velocity V_n 2.6 ft/s.

3. The velocity for checking the adequacy of the grass cover should be obtained from the upper graph, for retardance D. Using the same procedure as in step 2, the velocity is found to be 3.0 ft/s. This is about three quarters of that listed as permissible, 4.0 ft/s in Table 5.3-2.

Figure 5.11.7-1

Source: Federal Highway Administration





GRASSED CHANNEL

4:1 b = 4 ft.

Example Design Problem 2

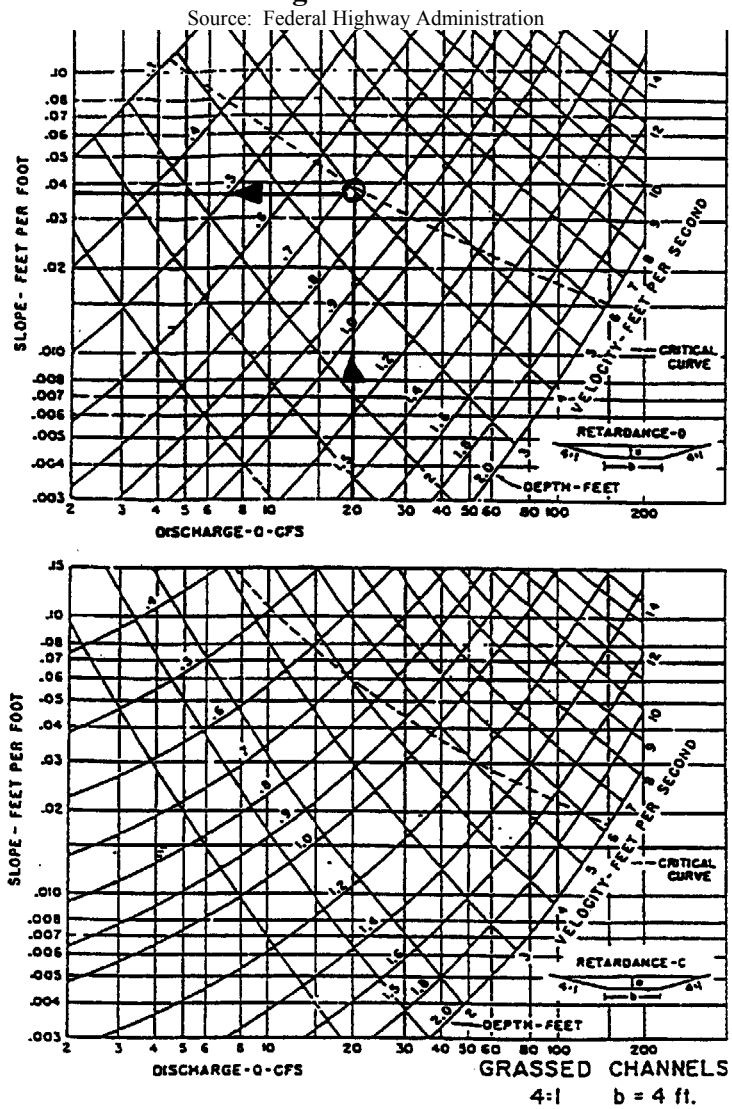
Given: The channel and discharge of Example 1
Find: The maximum grade on which the 20 cfs could safely be carried

Procedure:

1. With increase in slope (but still less than 5%), the allowable velocity is estimated to be 4 ft/s (see Table 5.3-2). On the upper graph Figure 5.11.7-2 for short grass, the intersection of the 20 cfs line and the 4 ft/s line indicates a slope of 3.7 percent and a depth of 0.73 ft.

Figure 5.11.7-2

Source: Federal Highway Administration



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