CHAPTER 5

OPEN CHANNEL HYDROLOGY

5.8 Uniform Flow – Example Problems

5.8.1 Example 1 – Direct Solution of Manning's Equation

Use Manning's Equation to find the velocity, v, for an open channel with a hydraulic radius value of 0.6 ft, an n value of 0.020, and slope of 0.003 ft/ft. Solve using Figure 5.4.5-1:

5.8.1.1 Connect a line between the slope scale at 0.003 and the roughness scale at 0.020 and note the intersection point on the turning line.

5.8.1.2 Connect a line between that intersection point and the hydraulic radius scale at 0.6 ft and read the velocity of 2.9 ft/s from the velocity scale.

5.8.2 Example 2 – Grassed Channel Design Stability

A trapezoidal channel is required to carry 50 cfs at a bottom slope of 0.015 ft/ft. Find the channel dimensions required for design stability criteria (retardance Class D) for a grass mixture.

Figure 5.8-1
Riprap Lining d_{30} Stone Size – Function Of Mean Velocity And Depth

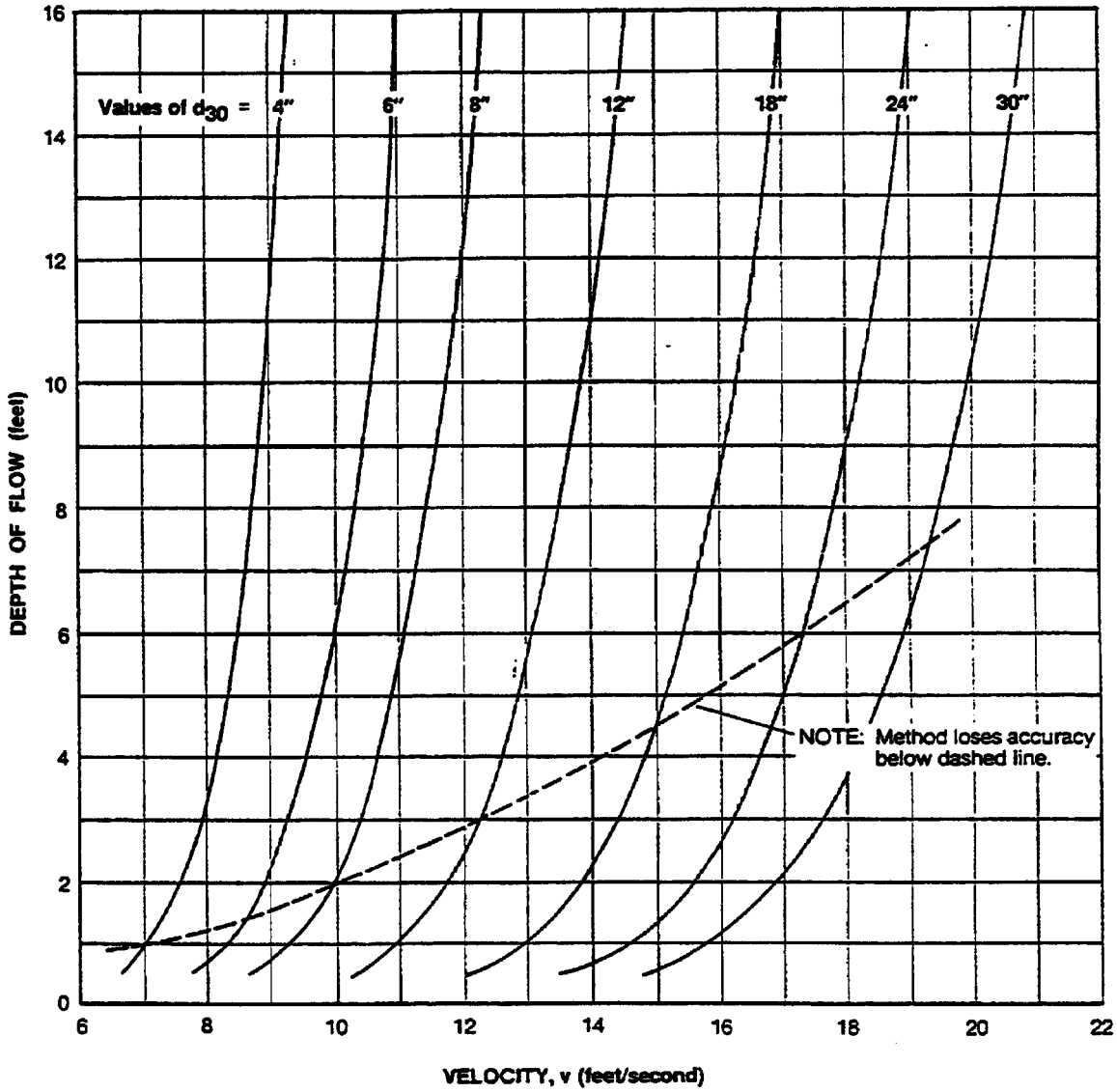
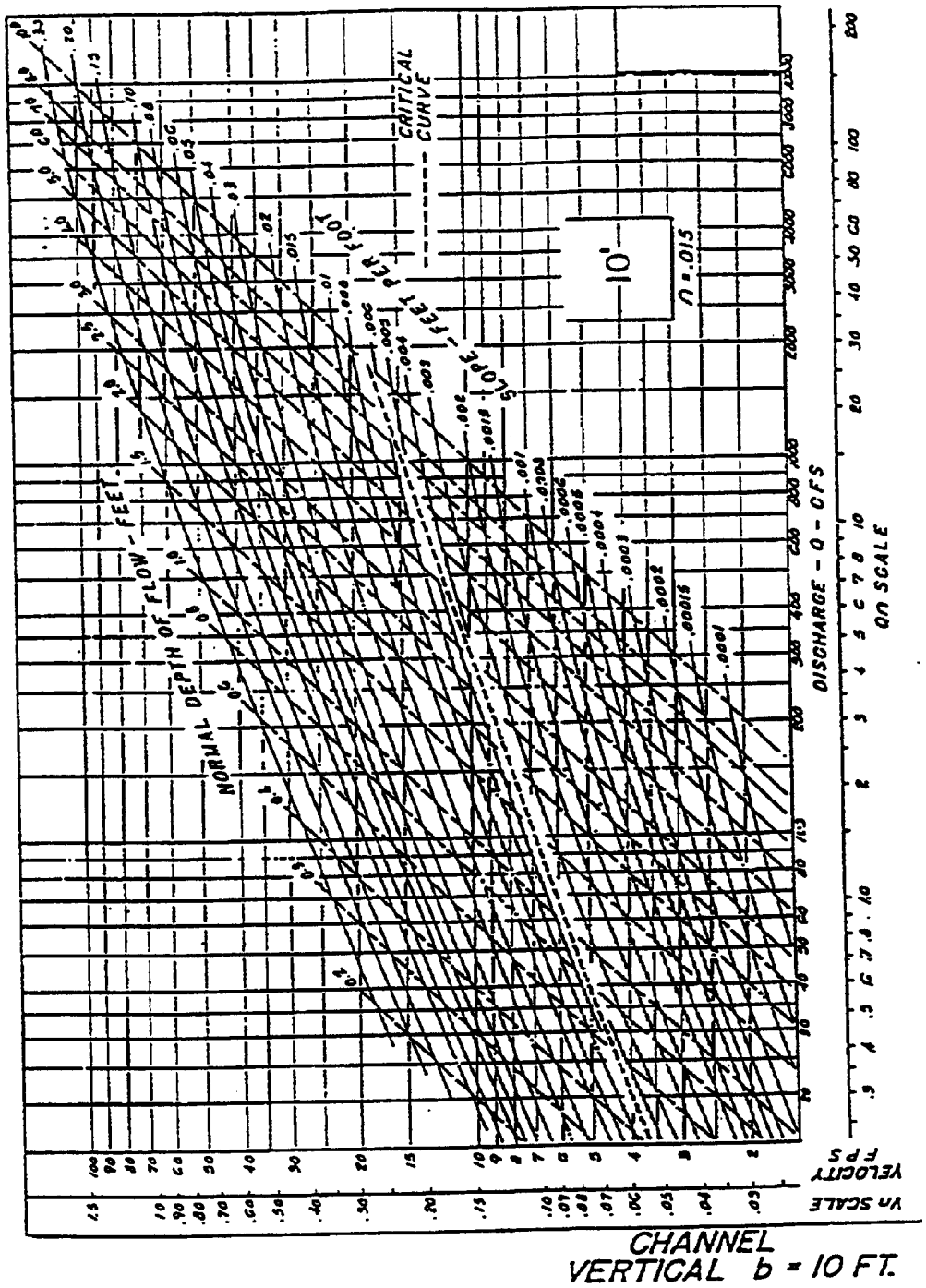


Figure 5.8-2
Riprap Lining Thickness Adjustment For d_{85}/d_{15} = 2.0 to 2.3



Source: Federal Highway Administration

5.8.2.1 From Table 5.3-2, the maximum velocity, v_m, for a grass mixture with a bottom slope less than 5 percent is 4 ft/s.

5.8.2.2 Assume an n value of 0.035 and find the value of vR from Figure 5.4.4-1. vR = 5.4

5.8.2.3 Use equation 5.6.2.4-1 to calculate the value of R: R = 5.4/4 = 1.35 ft

5.8.2.4 Use equation 5.6.2.5-1 to calculate the value of vR:
$vR = [1.49\ (1.35)^{5/3}\ (0.015)^{1/2}]/0.035 = 8.60$

5.8.2.5 Since the vR value calculated in Step 4 is higher than the value obtained from Step 2, a higher n value is required and calculations are repeated. The results from each trial of calculations are presented below:

Assumed n Value	vR (Figure 5-1)	R (equation 5.9)	vR (equation 5.10)
0.035	5.40	1.35	8.60
0.038	3.8	0.95	4.41
0.039	3.4	0.85	3.57
0.040	3.2	0.80	3.15

Select n = 0.040 for stability criteria.

5.8.2.6 Use Figure 5.4.6-1 to select channel dimensions for a trapezoidal shape with 3:1 side slopes.

Qn = (50) (0.040) = 2.0
S = 0.015
For b = 10 ft, d = (10) (0.098) = 0.98 ft
b = 8 ft, d = (8) (0.14) = 1.12 ft

Select: b = 10 ft, such that R is approximately 0.80 ft
z = 3
d = 1 ft
v = 3.9 ft/s (equation 5.1)
Fr = 0.76 (equation 5.8)
Flow is subcritical

Design capacity calculations for this channel are presented in Example 3 below.

5.8.3 Example 3 – Grassed Channel Design Capacity

Use a 10-ft bottom width and 3:1 side-slopes for the trapezoidal channel sized in Example 2 and find the depth of flow for retardance Class C.

5.8.3.1 Assume a depth of 1.0 ft and calculate the following (see Figure 5.5.2-1):
$A = (b + zd)\ d = [10 + (3)\ (1)\ ]\ (1) = 13.0$ square ft
$R = \{[b + zd]\ d\}/\{b + [2d(1 + z^2)^{0.5}]\} = [10 + (3)(1)](1)\}/\{10+[(2)(1)(1 + 3^2)0^{.5}]\}$
$R = 0.796$ ft

5.8.3.2 Find the velocity. $v = Q/A = 50/13.0 = 3.85$ ft/s

5.8.3.3 Find the value of vR. $vR = (3.85)\ (0.796) = 3.06$

5.8.3.4 Using the vR product from Step 3, find Manning's n from Figure 5.4.4-1 for retardance Class C.
$n = 0.047$

5.8.3.5 Use Figure 5.4.5-1 or equation 5.4.2-1 to find the velocity for $S = 0.015$, $R = 0.796$, and $n = 0.047$.
$v = 3.34$ ft/s

5.8.3.6 Since 3.34 ft/s is less than 3.85 ft/s, a higher depth is required and calculations are repeated. Results from each trial of calculations are presented below:

Assumed Depth (ft)	Area (ft^2)	R (ft)	Velocity Q/A (ft/sec)	vR	Manning's n (Fig. 5.4.6-1)	Velocity (Eq. 5.6.3.8-1)
1.0	13.00	0.796	3.85	3.06	0.047	3.34
1.05	13.81	0.830	3.62	3.00	0.047	3.39
1.1	14.63	0.863	3.42	2.95	0.048	3.45
1.2	16.32	0.928	3.06	2.84	0.049	3.54

5.8.3.7 Select a depth of 1.1 with an n value of 0.048 for design capacity requirements. Add at least 0.2 ft for freeboard to give a design depth of 1.3 ft. Design data for the trapezoidal channel are summarized as follows:

Vegetation lining = grass mixture, $v_m = 4$ ft/s

$Q = 50$ cfs
$b = 10$ ft. $d = 1.3$ ft, $z = 3$, $S = 0.015$
Top width = (10) + (2) (3) (1.3) = 17.8 ft

n(stability) = 0.040, 1.0 ft, v = 3.9 ft/s, Froude number = 0.76
(equation 5.5.2.4-1)
n(capacity) = 0.048, d = 1.1 ft, v + 3.45 ft/s, Froude number = 0.64
(equation 5..5.2.4-1)

5.8.4 Example 4 – Riprap Design

A natural channel has an average bankfull channel velocity of 8 ft per second with a top width of 20 ft and a bend radius or 50 ft. The depth over the toe of the outer bank is 5 ft. Available stone weight is 170 lbs/ft^3. Stone placement is on a side slope of 2:1 (horizontal: vertical).

5.8.4.1 Use 8 ft per second as the design velocity, because the reach is short and the bend is not protected.

5.8.4.2 Determine the bend correction coefficient for the ratio of R_b/T = 50/20 = 2.5. From Figure 5.7.2-1, C_b = 1.55. The adjusted effective velocity is (8) (1.55) = 12.4 ft/s.

5.8.4.3 Determine the correction coefficient for the specific weight of 170 lbs from Figure 5.7.2-2 as 0.98. The adjusted effective velocity is (12.4) (0.98) = 12.15 ft/s.

5.8.4.4 Determine minimum d_{30} from Figure 5.8-1 or equation 5.7.2.4-1 as about 10 inches.

5.8.4.5 Use a gradation with a minimum d_{30} size of 12 inches and is acceptable. Usually those have enough fines that a filter course will not be required.

5.8.4.6 (Optional) Another gradation is available with a d_{30} of 8 inches. The ratio of desired to standard stone size is 8/10 or 0.8. From Figure 5.8-2, this gradation would be acceptable if the blanket thickness was increased from the original d_{100} (diameter of the largest stone) thickness by 35 percent (a ratio of 1.35 on the horizontal axis).

5.8.4.7 Perform preliminary design. Make sure that the stone is carried up and downstream far enough to ensure stability of the channel and that the toe will not be undermined. The downstream length of protection for channel bends can be determined using Figure 5.6.3-1.

END OF SECTION 5.8