Design of Stable Channels
CH-4

Riprap-Lined Channels

Providing Channel Protection

- In cases where vegetation is not suitable, riprap is often used to stabilize channels…
  - Riprap = rough, angular rocks of varying size
- Place riprap on surfaces that are well compacted and stable
  - Toe protection for channel bank riprap
- Design of riprap…
  - Select rock size large enough so that the force attempting to overturn the rocks is less than the gravitational force acting on the rocks

Providing Channel Protection

- Gradation of riprap:
  - Select particle size distribution such that voids between the larger particles are filled with smaller particles
  - Suggested gradation by Simons and Senturk (1977, 1992):

Size	% Finer
$0.2d_{50}$	0
$0.5d_{50}$	20%
d_{50}	50%
$2d_{50}$	100%

Sloping Bed

- Design procedures:
  - Federal Highway Administration (FHA)
  - SCS Procedure
  - CSU Procedure

Sloping Bed - FHA

- FHA:
  - Uses a maximum stable depth of flow given by the following equation (d_{50} and h_{max} in ft, and γ = 62.4 lb/ft^3):

$$h_{\max} = 5\left(\frac{d_{50}}{\gamma S_f}\right)$$

  - Velocity of flow given by Manning's equation with n given by…

$$n = 0.0395\left(d_{50}\right)^{1/6}$$

$$U = \frac{37.7}{\left(d_{50}\right)^{1/6}} R_h^{\ 2/3} S_f^{\ 1/2}$$

Example- 4.15

Determine the d_{50} riprap size required to convey 115 cfs down a 10% slope in a rectangular channel 18 ft wide. Riprap is for the bottom and use the FHA procedure.

Determine the D_{50} riprap size required to convey 115 cfs down a 10% slope in a rectangular channel 18 ft wide. Riprap is for the bottom only. Use the FHA procedure.

Solution: Assume $R = d_{max}$, $\gamma = 62.4$, $S = 0.10$. Then

$$d_{max} = \frac{5D_{50}}{\gamma S} = 0.801 D_{50}$$

$$v = \frac{37.7}{D_{50}^{1/6}}(d_{max})^{2/3} S^{1/2} = \frac{37.7}{D_{50}^{1/6}}(0.801 D_{50})^{2/3}(0.10)^{1/2}$$

$$v = 10.28 D_{50}^{1/2}$$

$$Q = vA = 10.28 D_{50}^{1/2} d_{max} B = 10.28 D_{50}^{1/2}(0.801 D_{50})(18)$$

$$115 = 148.22 D_{50}^{3/2}$$

$$D_{50} = 0.84 \text{ ft}$$

Note:

$$d_{max} = 0.68 \text{ ft}$$

$$R = \frac{db}{2d + b} = \frac{0.68(18)}{2(0.68) + 18} = 0.63 \text{ ft.}$$

Therefore, the assumption that $R = d$ is reasonable. If the Abt relationship for n is used, the result is $v = 8.4$ fps and $D_{50} = 0.95$ ft.

Sloping Bed - SCS

- SCS:
  - Also uses a maximum stable depth of flow
  - Equation (d_{75} and h_{max} in ft):

$$d_{75} = 13.5 h_{\max} S_f$$

$$d_{75} = 1.5 d_{50}$$

$$h_{\max} = \left(\frac{d_{50}}{9 S_f} \right)^{0.9}$$

  - Velocity of flow given by Manning's equation with n given by…

$$U = 12.84 d_{50}^{\ 0.51}$$

Example – 4.16

Determine the d_{50} riprap size required to convey 115 cfs down a 10% slope in a rectangular channel 18 ft wide. Riprap is for the bottom and use the SCS procedure.

Work Example Problem 4.15 using the SCS approximations.

Solution

$$Q = vA = 12.84D_{50}^{0.51}(dB) = 12.84D_{50}^{0.51}\left(\frac{D_{50}}{9S}\right)^{0.91} 18$$

$$115 = 254D_{50}^{1.42}$$

$$D_{50} = 0.57 \text{ ft}$$

$$d_{\max} = \left(\frac{0.57}{9(0.1)}\right)^{0.91} = 0.66 \text{ ft.}$$

For this problem, the FHA and SCS criteria result in similar designs with the FHA procedure resulting in larger estimates for the required D_{50}. This will generally be the case.

Sloping Bed - CSU

- CSU Procedure (Simons and Senturk, 1977, 1992):
  - Safety Factor (SF) concept
    - SF = ratio of resisting forces (moments) to driving forces (moments)
    - SF = 1 (Point of incipient motion)
    - Recommend SF > 1.5 to account for variability in particle sizes

Sloping Bed - CSU

- CSU Procedure (Simons and Senturk, 1977, 1992):
  – Consider forces acting on a channel bed sloped at an angle θ:

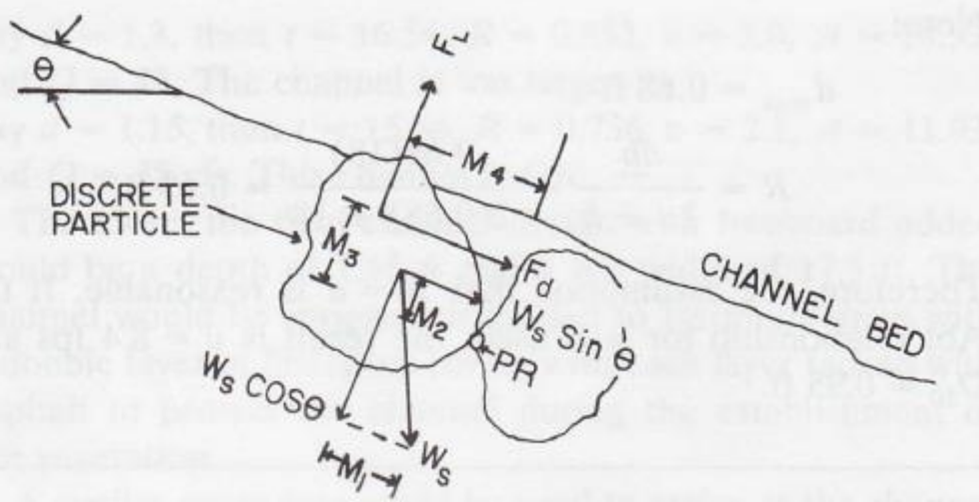


Figure 4.16 Forces on a particle in a channel bed. F_d, drag force; F_L, lift force; *PR*, point of rotation.

Sloping Bed - CSU

- CSU Procedure (Simons and Senturk, 1977, 1992):

$$SF_b = \frac{\cos(\theta)\tan(\varphi)}{\sin(\theta) + \eta_b \tan(\varphi)}$$

$$\eta_b = \frac{21\tau_o}{\gamma(s_s - 1)d_{50}}$$

Example – 4.17

Determine the d_{50} riprap size required to convey 115 cfs down a 10% slope in a rectangular channel 18 ft wide. Riprap is for the bottom (neglect stability problems associated with the side slopes). Assume a specific gravity of sediment of 2.65 with $\varphi = 42^o$. Design for a safety factor of 1.5.

Solution: The solution procedure involves a trial and error approach of selecting a riprap size, calculating the depth of flow required to convey the flow, and checking the safety factor to ensure that the channel is stable. Assume a D_{50} of 2.5 ft, from Eq. (4.32).

$$n = 0.0395 D_{50}^{1/6} = 0.046.$$

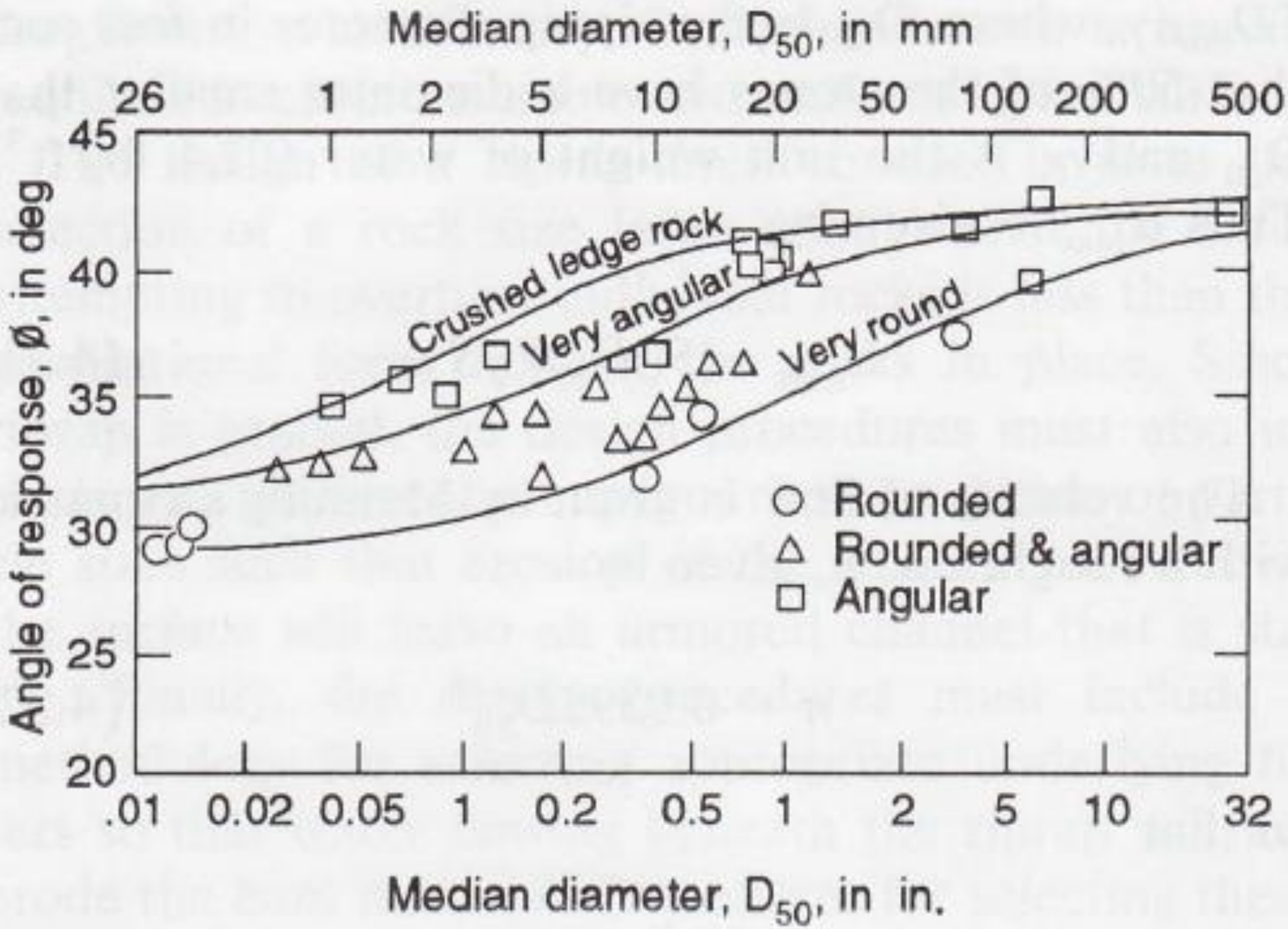
From Manning's equation, assuming a wide channel,

$$Q = Av = bd\frac{1.49}{n}d^{2/3}S^{1/2}$$

$$d = \left[\frac{nQ}{1.49bS^{1/2}}\right]^{3/5} = \left[\frac{0.046(115)}{1.49(18)(0.10)^{1/2}}\right]^{3/5}$$

$d = 0.75$ ft depth required to convey the flow.

Checking for stability using Eqs. (4.44) and (4.39),



Median diameter, D_{50}, in mm
26
1
2
5
10
20
50
100
200
500
45
40
35
30
25
20
Angle of response, Ø, in deg
Crushed ledge rock
Very angular
Very round
Rounded
Rounded & angular
Angular
.01
0.02
0.05
1
0.2
0.5
1
2
5
10
32
Median diameter, D_{50}, in in.

$$\tau = \gamma d S = (62.4)(0.75)(0.10) = 4.68 \text{ lb/ft}^2$$

$$\eta_b = \frac{21\tau}{\gamma(\text{SG} - 1) D_{50}} = \frac{21(4.68)}{62.4(2.65 - 1)2.5} = 0.382.$$

Assuming an angular riprap, Fig. 4.17 gives $\phi = 42°$. For a 10% slope, $\theta = 5.71°$. Hence, from Eq. (4.39),

$$\text{SF}_b = \frac{\cos\theta \tan\phi}{\sin\theta + \eta_b \tan\phi} = \frac{(\cos 5.71)(\tan 42)}{\sin 5.71 + 0.382 \tan 42}$$

$\text{SF}_b = 2.02$ over designed.

Calculations to select a better design are contained in Table 4.12. Use a riprap with a D_{50} of 1.7 ft on the channel bed. Obviously, there is a problem with stability of the side slopes. Also the gradation of riprap must be specified and a filter blanket selected. This is covered in subsequent sections and examples.

Channel Bank Stability

- CSU Procedure - Stevens and Simons (1971) and Simons and Senturk (1977, 1992):
  - Difference from bed is that drag forces are not aligned with the down slope gravitational forces
  - Equations assume that the ratio of lift to drag forces is 0.5

Channel Bank Stability

$$SF_b = \frac{\cos(\alpha)\tan(\varphi)}{\sin(\alpha)\cos(\beta) + \eta' \tan(\varphi)}$$

$$\beta = \tan^{-1}\left(\frac{\cos(\theta)}{\frac{2\sin(\alpha)}{\eta\tan(\phi)} + \sin(\theta)}\right)$$

$$\eta = \frac{21\tau_o}{\gamma(s_s - 1)d_{50}}$$

$$\eta' = \eta\frac{1 + \sin(\theta + \beta)}{2}$$

Example – 4.19

Determine the d_{50} riprap size that will be stable on the bed and channel side slopes with m = 2.5 in a trapezoidal channel (18 ft bottom width). The channel needs to convey 115 cfs down a 10% slope. Assume a specific gravity of sediment of 2.65 with $\varphi = 42^{o}$. Design for a safety factor of 1.5.

Solution: First the safety factor of the riprap selected in Example Problem 4.17 is calculated assuming the same material is used on the sides. From Example Problem 4.17,

$$D_{50} = 1.7 \text{ ft}; \qquad n = 0.043; \qquad \theta = 5.71^\circ; \qquad d = 0.722 \text{ ft}.$$

For a trapezoidal channel, the flow depth can be calculated to be 0.72 ft, which is insignificantly smaller than 0.722 ft for the rectangular channel in Example 4.17; hence we use 0.722 ft.

From Fig. 4.8 τ_{max} is given by $0.76\gamma\, dS$:

$$\tau_{max} = (0.76)(62.4)(0.722)(0.10) = 3.41 \text{ lb/ft}^2$$

$$\eta = \frac{21\tau_{max}}{\gamma(\text{SG} - 1)D_{50}} = \frac{21(3.41)}{62.4(2.65 - 1)1.7} = 0.408.$$

Assuming uniform flow, the streamlines are parallel to the channel bottom and

$$\lambda = \theta = 5.71^\circ.$$

Also, for a 2.5 : 1 sideslope,

$$\alpha = \tan^{-1}\frac{1}{2.5} = 21.8^\circ.$$