

## **Chapter 5 – Open Channels**

Open channels are man-made ditches and channels and natural channels, that are used to convey stormwater flow. This section defines criteria and restrictions to be used in designing open channels. Where open channels are a part of a BMP, they shall comply with the state requirements for the purposes of water quality improvement; however, they shall also comply with this Design Manual’s requirements for water conveyance.

### **5.1 References**

The primary design references are:

- VDOT Drainage Manual
- VDOT Specifications
- VA E&SC Handbook
- Hydraulic Engineering Circular Number 15 (HEC-15), Design of Roadside Channels with Flexible Linings, Current Edition, as amended
- VA SWM Handbook

### **5.2 Design Methodology and Criteria**

#### **5.2.1 Major and Minor Manmade Open Channels**

A major channel is designed to convey over 5 acres.

A minor channel is designed to convey 5 acres or less.

#### **5.2.2 Design Flow**

Design flow for manmade open channels within a development is contained in Chapter 4.2.2. Additionally, all storm drainage designs for open channels, culverts, and storm drains shall be checked for the 100-year flow condition where there is the possibility of flooding residences, commercial or industrial buildings, overtopping primary roads, experiencing significant economic loss, or catastrophic failure.

#### **5.2.3 Hydrology**

See Chapter 4 for methodology used to determine peak flows for a given design frequency.

#### **5.2.4 Channel Hydraulics**

Open channel design will be based on Manning's Equation for open channel flow, unless good engineering practice dictates using HEC-RAS or other method. See the VA SWM Handbook and VDOT Drainage Manual, as appropriate.

$$Q = A \times 1.49/n \times R^{2/3} \times S^{1/2}$$

Where:

$Q$  = Flow in the open channel (cfs)

$A$  = Cross-section area of the channel ( $\text{ft}^2$ )

$R$  =  $A/\text{wetted perimeter}$  (ft)

$S$  = Channel slope (ft/ft)

$n$  = Channel roughness coefficient

Nomographs have been included in Appendix 5A for use in solving Manning's equation setting channel characteristics.

#### **5.2.5 Channel Velocity**

The lining of minor channels with drainage areas of five acres and less shall be designed to withstand the erosive effects of a 2-year storm. The lining of minor channels with drainage areas over five acres and major channels shall be designed to withstand the erosive effects of a 10-year storm. The final design shall be consistent with velocity limitations for the selected channel lining, as presented in Table 5-1.

Major channels associated with dam embankment spillways or other structures where catastrophic failure could result from a lining failure may be required to be designed to withstand a more severe storm event.

Where open channels receive flow from storm drains, culverts, or other open channels, or in other areas where channel velocity may cause scouring or erosion, outlet protection or energy dissipation may be necessary to reduce the potential for severe erosion. For the design of energy dissipation devices, see Chapter 10.

**TABLE 5-1**  
**Maximum Velocity Based on Channel Lining**

Channel Lining	Maximum Velocity (Design Storm)	
	Erosion Resistant Soils <sup>1</sup>	Easily Erodible Soils <sup>2</sup>
Vegetative Lined Channels		
Tall Fescue Grass Mixtures	6 fps	4 fps
Kentucky Bluegrass	6 fps	4 fps
Annual and Perennial Rye	4 fps	3 fps
Sod	4 fps	3 fps
Geosynthetic Lined Channels		
VDOT EC-2	4 fps	
VDOT EC-3, Type A	7 fps	
VDOT EC-3, Type B	10 fps	
Other	Per Mfr Recommendations	
Riprap (see VDOT Drainage Manual Appendix 7-D for n values)	Dependent on stone size and thickness, see HEC-15 for design of riprap channels	
Concrete	None	

<sup>1</sup> Erosion resistant soils include those with a high clay content and high plasticity, silty clay, sandy clay, and clay.

<sup>2</sup> Easily erodible soils include those with a high content of fine sand or silty, lower plasticity or non-plastic, sand, silt, sandy loam, and silty loam with an erodibility factor (K) greater than 0.35.

<sup>3</sup>Soils shall be presumed to be easily erodible; unless a geotechnical investigation is performed that samples and tests the soils.

<sup>4</sup>All channels constructed in fills shall be considered to be in easily erodible soils.

### 5.2.6 Channel Slope

Generally the channel slope shall be established by the site topography. Open channels must be graded to drain with no standing water following a rain event. The minimum allowable grade shall generally be 2 percent for vegetated-lined and riprap-lined open channels and 1 percent for a concrete open channel.

The maximum allowable grade for a stormwater channel shall be dependent on the channel lining materials and its ability to withstand erosion during the design storm.

### **5.2.7 Cross Sectional Area**

Open channel cross-section area shall be designed based on site restrictions and channel capacity requirements. The following information as a minimum shall be provided in either a table and/or detail on the design plans that includes the channel number if multiple swales are proposed, bottom width, top width, slope, side slopes, total depth including freeboard, and liner. Each swale should be included in the chart and not just a worst case scenario.

Additionally,  $Q_{10}$ ,  $Q_{10}$  water depth, freeboard provided, and  $V_2$  shall be clearly indicated in the calculations.

Acceptable cross-sectional area options include:

- Vee
- Parabolic
- Trapezoidal
- Rectangular
- Yard

#### **A. Vee**

For design aids, see the VDOT Drainage Manual and the VA E&SC Handbook. Additionally computer software such as North American Green, Flowmaster, etc. can be used for design aids.

The maximum side slope of a vee-shape open channel is 3 horizontal to 1 vertical for vegetated channels (including reinforced vegetated) and is 2 horizontal to 1 vertical for all other linings engineered to be stable at this slope.

#### **B. Parabolic**

For design aids, see the VDOT Drainage Manual and the VA E&SC Handbook. Additionally computer software such as North American Green, Flowmaster, etc can be used for design aids.

**C. Trapezoidal**

For design aids, see the VDOT Drainage Manual and the VA E&SC Handbook. Additionally computer software such as North American Green, Flowmaster, etc. can be used for design aids.

The maximum side slope of a trapezoidal-shape open channel is 3 horizontal to 1 vertical for vegetated channels (Including reinforced vegetated) and is 2 horizontal to 1 vertical for all other linings engineered to be stable at this slope.

**D. Rectangular**

Rectangular channels shall only be allowed where site restrictions prevent the installation of a vee, parabolic, or trapezoidal channel.

The requirements for rectangular channels apply to any open channel with side slopes greater than 2 horizontal to 1 vertical.

Rectangular channels must either be concrete or gabions.

An approved safety barrier must be placed on both sides for the length of the rectangular channel, where the channel is more than 3-feet deep.

Care must be taken to ensure that energy dissipation is placed at the outfall of the rectangular channel to prevent erosion at the discharge point.

**E. Yard**

Yard swales that do not convey stormwater over multiple lots can utilize a basic yard swale detail without providing calculations if the following conditions are met: less than 0.25 acres drainage area, 2.0% minimum longitudinal slope, 6% maximum longitudinal slope, side slope of 4:1 H:V (maximum 3:1), bottom width of 0 feet, total depth of 1.1' (including the 0.5' of required freeboard), applicable top width based on side slopes, and type of liner labeled (i.e. grass). The Designer shall show a detail on the plan that meets the basic yard swale criteria. All other yard swales will require calculations and an applicable detail.

Yard swales must have a grass liner.

### **5.2.8 Channel Lining**

An open channel lining shall be designed based on the cross-section, slope, and channel velocity requirements. The design may be based on a consideration of either permissive velocity or tractive force as described in the VDOT Drainage Manual.

The preferred method for analyzing channel linings is to compare the maximum permissible velocity for the channel lining, listed in Table 5.1 in this chapter of the Design Manual, to the design velocity computed using Manning's equation to verify that the selected lining is adequate. As an alternative, the selected lining may be analyzed using the Tractive Force Method published in the VDOT Drainage Manual. This method analyzes sediment critical shear loading on the open channel bottom and side slope. The permissible tractive force for various soils is located in the Appendix of the VDOT Drainage Manual.

Open channels may have different lining materials in different channel reaches based on velocity and potential erosion conditions. Care must be exercised to avoid erosion at open channel transition points.

The open channel lining will have an impact on the design capacity in the form of the roughness coefficient. A table of generally accepted roughness coefficient (n) for various channels and linings is included in Appendix 5A.

Allowable open channel linings include the following:

#### **A. Natural**

To the maximum extent possible, natural channels shall be preserved. Design discharges from permitted land disturbing activities shall comply with the VA SWM Regulations.

#### **B. Vegetative-Lined**

Vegetated or grass-lined channels include man made channels lined with established vegetation. These channels usually include a geosynthetic mat for channel stabilization.

The type of grass allowable for vegetative-lined open channels is dependant on the slope of the channel, and the peak calculated velocity. Table 5-1 details the maximum permissible velocities for various channel linings.

A permanent channel stabilization geosynthetic mat should be considered for all vegetated channels. There are a wide variety of geosynthetic stabilization mat options from various manufacturers. The geosynthetic mat selected should be adequate for the slope and design flow velocities calculated for the channel. Where appropriate, VDOT Road and Bridge Standard EC-2 or EC-3 may be used.

Where a permanent geosynthetic mat is used to provide channel stabilization, information on the proposed mat, in the form of manufacturer's catalog information, shall be submitted as a part of the stormwater management plan. The catalog information shall include the manufacturer's recommendations for maximum allowable velocity. Design drawings must state that the geosynthetic stabilization mat shall be installed in strict accordance with the manufacturer's recommendations.

Where a permanent channel stabilization geosynthetic is not used, a temporary geosynthetic lining designed to provide a measure of bank stability until such time a reasonably stable and mature stand of vegetation is established shall be provided.

#### **C. Riprap-Lined**

The use of vegetated and geosynthetic-lined open channels for gentle-sloped open channels and concrete for steep-sloped open channels is recommended. Riprap-lined channels will not be acceptable where vegetated or geosynthetic-lined open channels are feasible. However, where design flow velocities exceed the erosive capability of a natural or vegetative-lined channel, rip rap may be used as a channel liner in areas where erosion is a concern. For an extended length of high velocity channel, consideration should be given to using a concrete channel rather than rip rap. Riprap lining shall be properly embedded in accordance with VDOT standards to maintain intended ditch cross section.

Where riprap is required due to velocity conditions, it shall meet VDOT Standards and VDOT Specifications. VDOT recommended 50 percent stone size ( $D_{50}$ ) and weight ( $W_{50}$ ) and recommended thickness (T) for various riprap classifications is included in Appendix 5A.

#### **D. Concrete-Lined**

Reinforced concrete shall be considered where design velocities dictate or where there is a need to provide the maximum level of erosion protection.

### 5.2.9 Freeboard Requirements

Manmade channels within a development shall have a minimum of 6" of freeboard above the calculated water level during the design peak flow, unless flow is supercritical. Where flow is supercritical, a minimum of 12" of freeboard is required. Yard swales require 6" of freeboard. Flow is supercritical when:

$$V / (32.2 \times H)^{0.5} > 1$$

Where:

$$\begin{aligned} V &= \text{velocity (fps)} \\ H &= \text{depth of flow (feet)} \end{aligned}$$

At bends and curves, the freeboard shall be measured from the calculated water level, including the increased depth due to the superelevation of the water surface.

### 5.2.10 Calculation of Depth of Flow at Bends and Curves

Increases in the depth of flow occur at bends and curves due to the superelevation of the water surface. Superelevation of the water surface at bends and curves is calculated by:

$$\Delta Z = V^2 / (32.2 \times r_c) \times (r_o - r_i) \text{ where}$$

$\Delta Z$  = difference in water surface elevation between the concave and convex banks (ft)

V = average velocity (ft/s)

$r_c$  = radius of the center of the stream at the bend (ft)

$r_o$  = radius of the outside bank of the stream at the bend (ft)

$r_i$  = radius of the inside bank of the stream at the bend (ft)

The increase in the normal stream flow depth at the outer bank of an open channel bend is one half of  $\Delta Z$ .

### 5.2.11 Channel Location and Width Restrictions on Residential Lots

The tops of open channel banks shall be at least 20-feet from a residence.

Where manmade open channels collect stormwater from more than one lot and they are located on a residential zoned lot their use shall be restricted as follows. Where all requirements cannot be met, a closed pipe storm drain system is required.

- Residential lot size 1 acre or greater
  - No additional restrictions.
- Residential lot size 0.5 acre or greater, but less than 1 acre
  - Open channel top width shall be a maximum of 15 feet
  - Maximum drainage area passing through the open channel shall be 5 acres.
- Residential lot size less than 0.5 acre
  - Open channel top width shall be a maximum of 15 feet
  - Maximum drainage area passing through the open channel shall be 3 acres.

The above restrictions do not apply if any one of the following conditions is present:

- The open channel is a natural channel that has adequate capacity. The retention of natural channels is encouraged.
- The open channel is a perennial or intermittent stream that has adequate capacity and will remain undisturbed.
- It may be demonstrated that open channels are required as a part of an integrated design to obtain the necessary water quality treatment.

### **5.3 Environmental Considerations and Fishery Protection**

Construction or modifications to open channels shall comply with all applicable laws and regulations. The applicant is responsible for procuring all necessary permits, such as US Army Corps of Engineers and VA DEQ Wetland Permits, VA DEQ VPDES Permits, etc., prior to obtaining a Land Disturbance Permit. A copy of these permits shall be submitted to Roanoke County prior to scheduling the precon meeting or the Engineer shall submit a 3<sup>rd</sup> party report to the County that supports that the permits are not required.

### **5.4 Maintenance Requirements**

The permittee is responsible for maintenance of open channels until construction is complete, including final clean up and site stabilization, to the satisfaction of the County of Roanoke. After the completion of construction, the property owner is responsible for maintenance of open channels. Maintenance includes periodically pruning or mowing vegetation and removing debris.

## **5.5 Floodplain Studies**

A floodplain study shall be performed for all drainage areas greater than 100 acres that do not have detailed FEMA Flood Insurance Study flood profiles or elevations. See Chapter 12 for additional information on floodplain requirements.

**APPENDIX 5A****AIDS FOR OPEN CHANNEL DESIGN  
FROM CHAPTER 7, VDOT DRAINAGE MANUAL**

Appendix 7B-1, LD-268, Roadside and Median Ditch Design Form

Appendix 7B-3, Channel Stability Work Sheet

Appendix 7B-4, Riprap Design Work Sheet for Standard VDOT Riprap Sizes Only

Appendix 7B-5, Riprap Design Work Sheet for other than VDOT Standard Riprap Sizes

Appendix 7C-1, Nomograph for Solution of Manning's Equation

Appendix 7C-2, Trapezoidal Channel Capacity Chart

Appendix 7C-3, Nomograph for Solution of Normal Depth

Appendix 7D-1, Values of Roughness Coefficient n, 2 sheets

Appendix 7D-3, Standard VDOT Riprap Classifications, Weights, and Blanket Thickness

Appendix 7D-5, Selection of Stability Factors

Appendix 7D-6, Permissible Velocities for Erodible Linings

Appendix 7E-1, Angle of Repose of Riprap in Terms of Mean Size and Shape of Stone

Appendix 7E-2, Permissible Shear Stress for Non-Cohesive Soils

Appendix 7E-3, Permissible Shear Stress for Cohesive Soils

Appendix 7E-4, Bank Angle Correction Factor ( $K_1$ ) Nomograph

Appendix 7E-5, Correction Factor for Riprap Size

Appendix 7E-6, Riprap Size Relationship

Appendix 7E-7, Channel Side Shear Stress to Bottom Shear Stress Ratio

Appendix 7E-8, Tractive Force Ratio ( $K_2$ )

Appendix 7E-9, Determination of Mean Spherical Diameter

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**COUNTY OF ROANOKE**

## OPEN CHANNELS

## CHANNEL STABILITY WORKSHEET

### CHANNEL DATA

$Q = \underline{\hspace{2cm}}$  (cfs)       $P = \underline{\hspace{2cm}}$  (ft.)      Native Material  
 $S_0 = \underline{\hspace{2cm}}$  (ft/ft)       $R = \underline{\hspace{2cm}}$  (ft.)       $D_{50} = \underline{\hspace{2cm}}$   
 $d_n = \underline{\hspace{2cm}}$  (ft.)       $V_n = \underline{\hspace{2cm}}$  (fps)       $D_{75} = \underline{\hspace{2cm}}$   
 $A = \underline{\hspace{2cm}}$  ( $\text{ft}^2$ )      Side Slope =  $\underline{\hspace{1cm}} : 1$        $n = \underline{\hspace{1cm}}$

### STABILITY OF NATIVE MATERIAL

$$\tau_o = 62.4 \bullet R \bullet S_0 = 62.4 \bullet \underline{\hspace{2cm}} \bullet \underline{\hspace{2cm}} = \underline{\hspace{2cm}}$$

$$\tau_p \text{ Bed} = \underline{\hspace{2cm}} \text{ (Appendix 7E-2 or 3)}$$

$$\text{For } D_{50} = \underline{\hspace{2cm}} \quad \phi = \underline{\hspace{2cm}}^\circ \text{ (Appendix 7E-1)}$$

$$\text{For } D_{75} = \underline{\hspace{2cm}} \quad \phi = \underline{\hspace{2cm}}^\circ \text{ (Appendix 7E-9)}$$

$$\text{Side Slope} = \underline{\hspace{1cm}} : 1 \quad \theta = \underline{\hspace{2cm}}^\circ$$

$$K_1 = [1 - (\sin^2 \theta / \sin^2 \phi)]^{0.5}$$

$$K_1 = [1 - (\sin^2 \underline{\hspace{2cm}}^\circ / \sin^2 \underline{\hspace{2cm}}^\circ)]^{0.5} = \underline{\hspace{2cm}}$$

$$\tau_s \text{ Side Slope (SS)} = \tau_p \text{ Bed} \bullet K = \underline{\hspace{2cm}} \bullet \underline{\hspace{2cm}} = \underline{\hspace{2cm}}$$

$$\tau_p \text{ Bed} (\underline{\hspace{2cm}}) (<) (=) (>) \tau_o (\underline{\hspace{2cm}})$$

$\therefore$  Native Material on Bed is (stable) (unstable)

$$\tau_s \text{ SS} (\underline{\hspace{2cm}}) (<) (=) (>) \tau_o (\underline{\hspace{2cm}})$$

$\therefore$  Native Material on Side Slope is (stable) (unstable)

## RIPRAP DESIGN WORKSHEET (VDOT STANDARD SIZES)

### CHANNEL DATA

$Q = \underline{\hspace{2cm}}$  (cfs)       $P = \underline{\hspace{2cm}}$  (ft.)       $n = \underline{\hspace{2cm}}$

$S_o = \underline{\hspace{2cm}}$  (ft/ft)       $R = \underline{\hspace{2cm}}$  (ft.)

$d_n = \underline{\hspace{2cm}}$  (ft.)       $V_n = \underline{\hspace{2cm}}$  (fps)

$A = \underline{\hspace{2cm}}$  (ft.<sup>2</sup>)      Side Slope =  $\underline{\hspace{2cm}} : 1$

### DETERMINE RIPRAP SIZE

$\phi = 42^\circ$  Side Slope =  $\underline{\hspace{2cm}} : 1$     $\theta = \underline{\hspace{2cm}}^\circ$

$$K_1 = [1 - (\sin^2 \theta / \sin^2 \phi)]^{0.5}$$

$$K_1 = [1 - (\sin^2 \underline{\hspace{2cm}}^\circ / \sin^2 42^\circ)]^{0.5} = \underline{\hspace{2cm}}$$

For Specific Gravity = 2.65 and Stability Factor = 1.2

$$D_{50} = 0.001 \cdot V_a^3 / (d_{avg}^{0.5} \cdot K_1^{1.5})$$

$$D_{50} = 0.001 \cdot \underline{\hspace{2cm}}^3 / (\underline{\hspace{2cm}}^{0.5} \cdot \underline{\hspace{2cm}}^{1.5})$$

$D_{50}$  Computed =  $\underline{\hspace{2cm}}$

Note: All VDOT standard riprap (Class AI through Type II) is assumed to have a  $\phi$  of approximately  $42^\circ$  and a Specific Gravity of 2.65. Therefore, the Computed  $D_{50}$  should be adjusted by the Stability Correction Factor ( $C_{SF}$ ) (if any) to derive a Final  $D_{50}$ . The VDOT standard class of riprap with the next higher  $D_{50}$  should be specified.

Correction Factor For Stability Factor (SF) other than 1.2 (Default = 1.0)

$$C_{SF} = (SF / 1.2)^{1.5} = (\underline{\hspace{2cm}} / 1.2)^{1.5} = \underline{\hspace{2cm}}$$

$$\text{Final } D_{50} = C_{SF} \cdot \text{Computed } D_{50} = \underline{\hspace{2cm}} \cdot \underline{\hspace{2cm}} = \underline{\hspace{2cm}}$$

RIPRAP RECOMMENDATION: VDOT (Class) (Type)  $\underline{\hspace{2cm}}$

Thickness (T) =  $\underline{\hspace{2cm}}$ " ( $2 \cdot D_{50}$  MSD minimum)

## RIPRAP DESIGN WORKSHEET (NON-VDOT STANDARD SIZES)

## CHANNEL DATA

Q = \_\_\_\_\_ (cfs)      P = \_\_\_\_\_ (ft.)      n = \_\_\_\_\_

S<sub>o</sub> = \_\_\_\_\_ (ft/ft)      R = \_\_\_\_\_ (ft.)d<sub>n</sub> = \_\_\_\_\_ (ft.)      V<sub>n</sub> = \_\_\_\_\_ (fps)A = \_\_\_\_\_ (ft<sup>2</sup>)      Side Slope = \_\_\_\_\_ : 1ASSUMED RIPRAP SIZE - D<sub>50</sub> = \_\_\_\_\_

## VERIFY ASSUMED RIPRAP SIZE

ϕ = \_\_\_\_\_ ° (Appendix 7E-1)

Side Slope = \_\_\_\_\_ : 1   θ = \_\_\_\_\_ °

K<sub>1</sub> = [1 - (sin<sup>2</sup> θ / sin<sup>2</sup> ϕ)]<sup>0.5</sup>K<sub>1</sub> = [1 - (sin<sup>2</sup> \_\_\_\_\_ ° / sin<sup>2</sup> \_\_\_\_\_ °)]<sup>0.5</sup> = \_\_\_\_\_

For Specific Gravity = 2.65 and Stability Factor = 1.2

D<sub>50</sub> = 0.001 • V<sub>a</sub><sup>3</sup> / (d<sub>avg</sub><sup>0.5</sup> • K<sub>1</sub><sup>1.5</sup>)D<sub>50</sub> = 0.001 • \_\_\_\_\_<sup>3</sup> / ( \_\_\_\_\_<sup>0.5</sup> • \_\_\_\_\_<sup>1.5</sup>) = \_\_\_\_\_D<sub>50</sub> Computed ( \_\_\_\_\_ ) (<) (=) (>) D<sub>50</sub> Assumed ( \_\_\_\_\_ )Assumed D<sub>50</sub> is (correct) (incorrect)

Note: The above process of assuming a D<sub>50</sub> size, determining the natural angle of repose (ϕ) and computing a D<sub>50</sub> size should be repeated until the Assumed D<sub>50</sub> size equals the Computed D<sub>50</sub> size. Once the D<sub>50</sub> size determination has been made, it should be adjusted for the Specific Gravity Correction Factor C<sub>sg</sub> (if any) and the Stability Correction Factor (C<sub>SF</sub>) (if any) to derive a Final D<sub>50</sub>.

Correction Factor For Riprap Specific Gravity (S<sub>s</sub>) other than 2.65 (Default = 1.0)C<sub>sg</sub> = 2.12 / (S<sub>s</sub> - 1)<sup>1.5</sup> = 2.12 / ( \_\_\_\_\_ - 1)<sup>1.5</sup> = \_\_\_\_\_

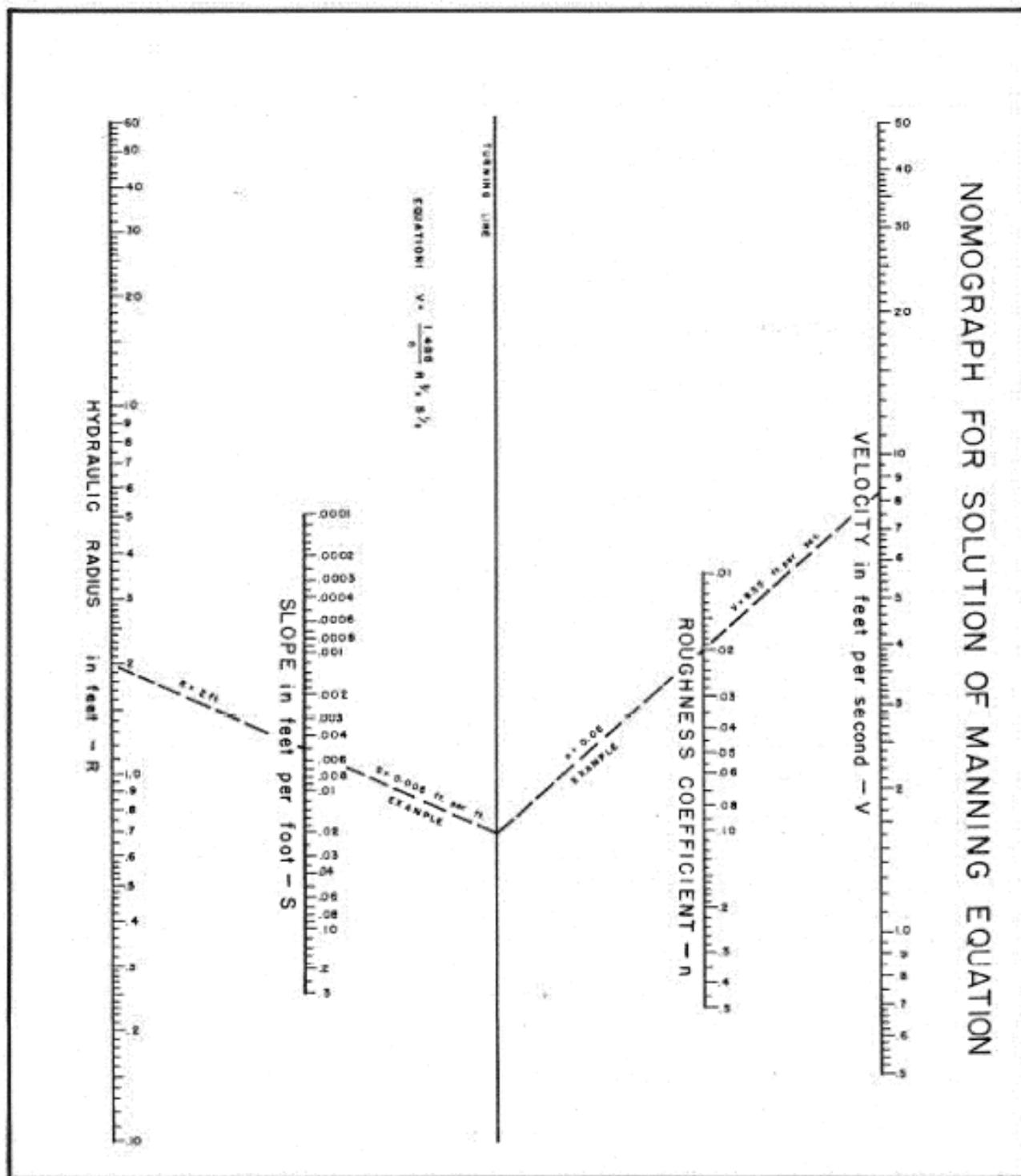
Correction Factor For Stability Factor (SF) other than 1.2 (Default = 1.0)

C<sub>SF</sub> = (SF / 1.2)<sup>1.5</sup> = ( \_\_\_\_\_ / 1.2)<sup>1.5</sup> = \_\_\_\_\_Final Correction Factor = C = C<sub>sg</sub> • C<sub>SF</sub> = \_\_\_\_\_ • \_\_\_\_\_ = \_\_\_\_\_Final D<sub>50</sub> = C • Computed D<sub>50</sub> = \_\_\_\_\_ • \_\_\_\_\_ = \_\_\_\_\_

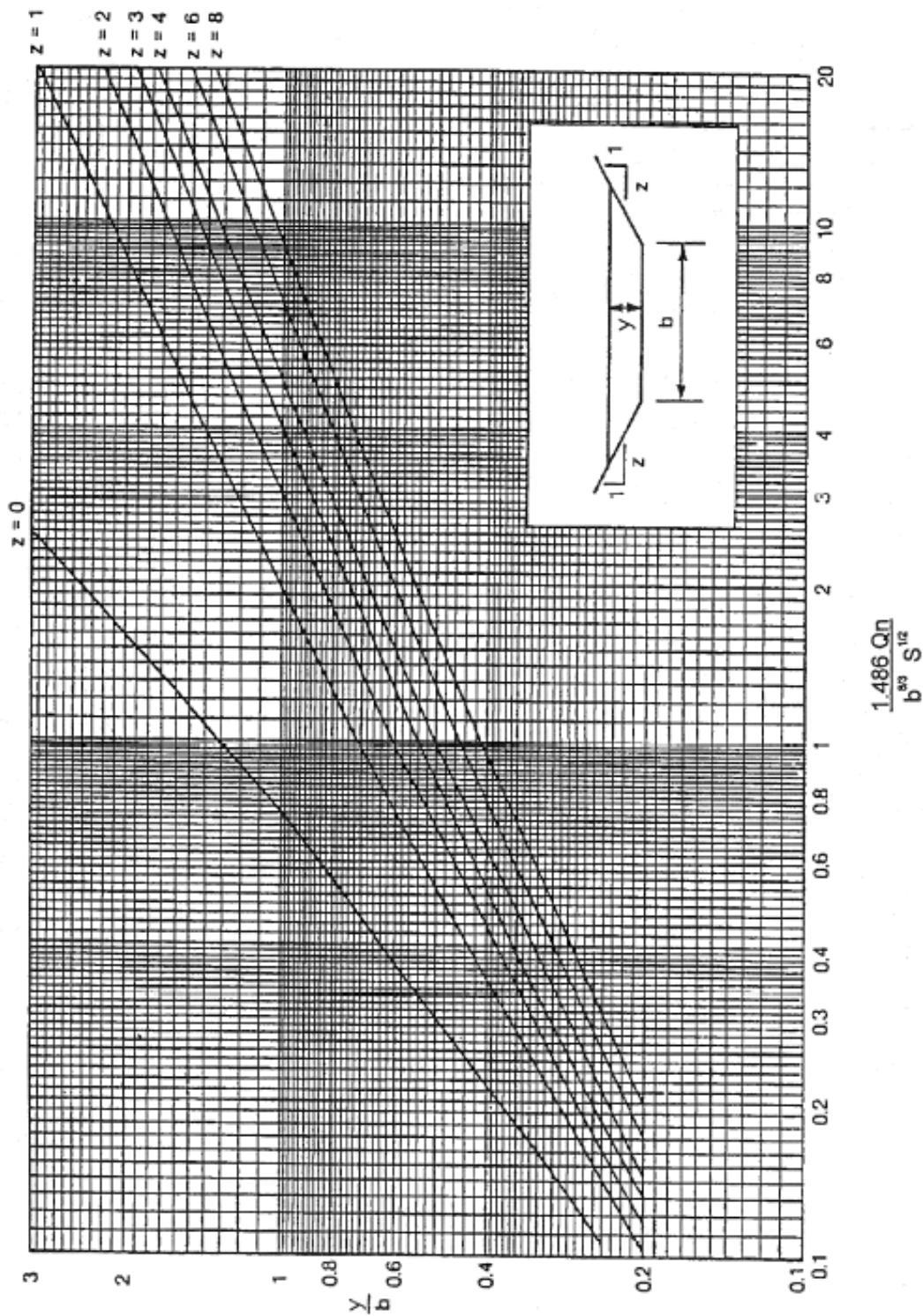
RIPRAP RECOMMENDATION: \_\_\_\_\_

Thickness (T) = \_\_\_\_\_ " (2 • D<sub>50</sub> MSD minimum)

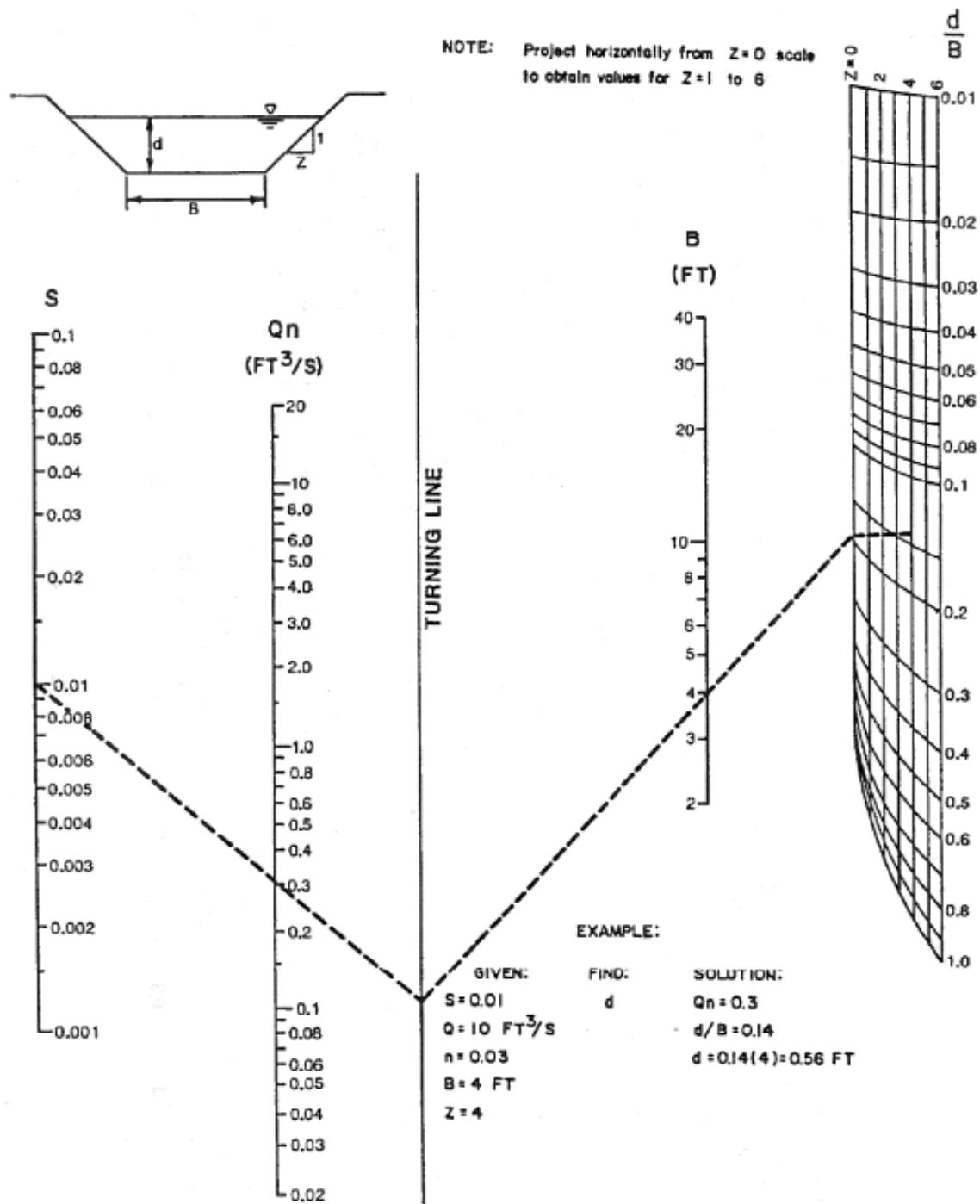
## NOMOGRAPH FOR SOLUTION OF MANNINGS EQUATION



## TRAPEZOIDAL CHANNEL CAPACITY CHART



## NOMOGRAPH FOR SOLUTION OF NORMAL DEPTH



**VALUES OF ROUGHNESS COEFFICIENT 'n'  
CHANNELS**

Type of Channel and Description	Minimum	Normal	Maximum
LINED CHANNELS (Selected linings)			
a. Concrete			
1. Trowel finish	0.011	0.013	0.015
2. Float finish	0.013	0.015	0.016
3. Gunite, good section	0.016	0.019	0.023
b. Asphalt			
1. Smooth	0.013	0.013	---
2. Rough	0.016	0.016	---
EXCAVATED OR DREDGED			
a. Earth, straight and uniform			
1. Clean, recently completed	0.016	0.018	0.020
2. Clean, after weathering	0.018	0.022	0.025
3. Gravel, uniform section, clean	0.022	0.025	0.030
4. With short grass, few weeds	0.022	0.027	0.033
b. Earth, winding and sluggish			
1. No vegetation	0.023	0.025	0.030
2. Grass, some weeds	0.025	0.030	0.035
3. Dense weeds or aquatic plants in deep channels	0.030	0.035	0.040
4. Earth bottom and rubble sides	0.025	0.030	0.035
5. Stony bottom and weedy sides	0.025	0.035	0.045
6. Cobble bottom and clean sides	0.030	0.040	0.050
c. Dragline excavated or dredged			
1. No vegetation	0.025	0.028	0.033
2. Light brush on banks	0.035	0.050	0.060
d. Rock cuts			
1. Smooth and uniform	0.025	0.035	0.040
2. Jagged and irregular	0.035	0.040	0.050
e. Channels not maintained, weeds and brush uncut			
1. Dense weeds, high as flow depth	0.050	0.080	0.120
2. Clean bottom, brush on sides	0.040	0.050	0.080
3. Same, highest stage of flow	0.045	0.070	0.110
4. Dense brush, high stage	0.080	0.100	0.140

## VALUES OF ROUGHNESS COEFFICIENT 'n' NATURAL STREAMS

Type of Channel and Description	Minimum	Normal	Maximum
NATURAL STREAMS			
1. Minor streams (top width at flood stage <100 ft)			
a. Streams on Plain			
1. Clean, straight, full stage, no rifts or deep pools	0.025	0.030	0.033
2. Same as above, more stones and weeds	0.030	0.035	0.040
3. Clean, winding, some pools/shoals	0.033	0.040	0.045
4. Same as above, but some weeds and stones	0.035	0.045	0.050
5. Same as above, lower stages, more ineffective slopes and sections	0.040	0.048	0.055
6. Same as 4, but more stones	0.045	0.050	0.060
7. Sluggish reaches, weedy, deep pools	0.050	0.070	0.080
8. Very reedy reaches, deep pools or floodways with heavy stand of timber and underbrush	0.075	0.100	0.150
b. Mountain Streams (no vegetation in channel, banks usually steep, trees and brush along banks submerged at high stages)			
1. Bottom: gravels, cobbles, few boulders	0.030	0.040	0.050
2. Bottom: cobbles with large boulders	0.040	0.050	0.070
2. Floodplains			
a. Pasture, no brush			
1. Short grass	0.025	0.030	0.035
2. High grass	0.030	0.035	0.050
b. Cultivated area			
1. No crop	0.020	0.030	0.040
2. Mature row crops	0.025	0.035	0.045
3. Mature field crops	0.030	0.040	0.050
c. Brush			
1. Scattered brush, heavy weeds	0.035	0.050	0.070
2. Light brush and trees, in winter	0.035	0.050	0.060
3. Light brush and trees, in summer	0.040	0.060	0.080
4. Medium to dense brush, in winter	0.045	0.070	0.110
5. Medium to dense brush, in summer	0.070	0.100	0.160
d. Trees			
1. Dense willows, summer, straight	0.110	0.150	0.200
2. Cleared land with tree stumps, no sprouts	0.030	0.040	0.050
3. Same as above, but with heavy sprout growth	0.050	0.060	0.080
4. Heavy stand of timber, a few down trees, little undergrowth, flood stage below branches	0.080	0.100	0.120
5. Same as above, but with flood stage reaching branches	0.100	0.120	0.160
3. Major Streams (top width at flood stage >100 ft)			
a. Regular section with no boulders or brush	0.025	---	0.060
b. Irregular and rough section	0.035	---	0.100
(The n value is less than that for minor streams of the same description, because banks offer less effective resistance.)			

## STANDARD VDOT RIPRAP CLASSIFICATIONS, WEIGHTS, AND BLANKET THICKNESS

Classification	D <sub>50</sub> (ft)	W <sub>50</sub> (lbs)	T (in)
Class AI	0.8	50	20
Class I	1.1	100	26
Class II	1.6	300	38
Class III	2.2	1000	53
Type I	2.8	2000	60
Type II	4.5	8000	97

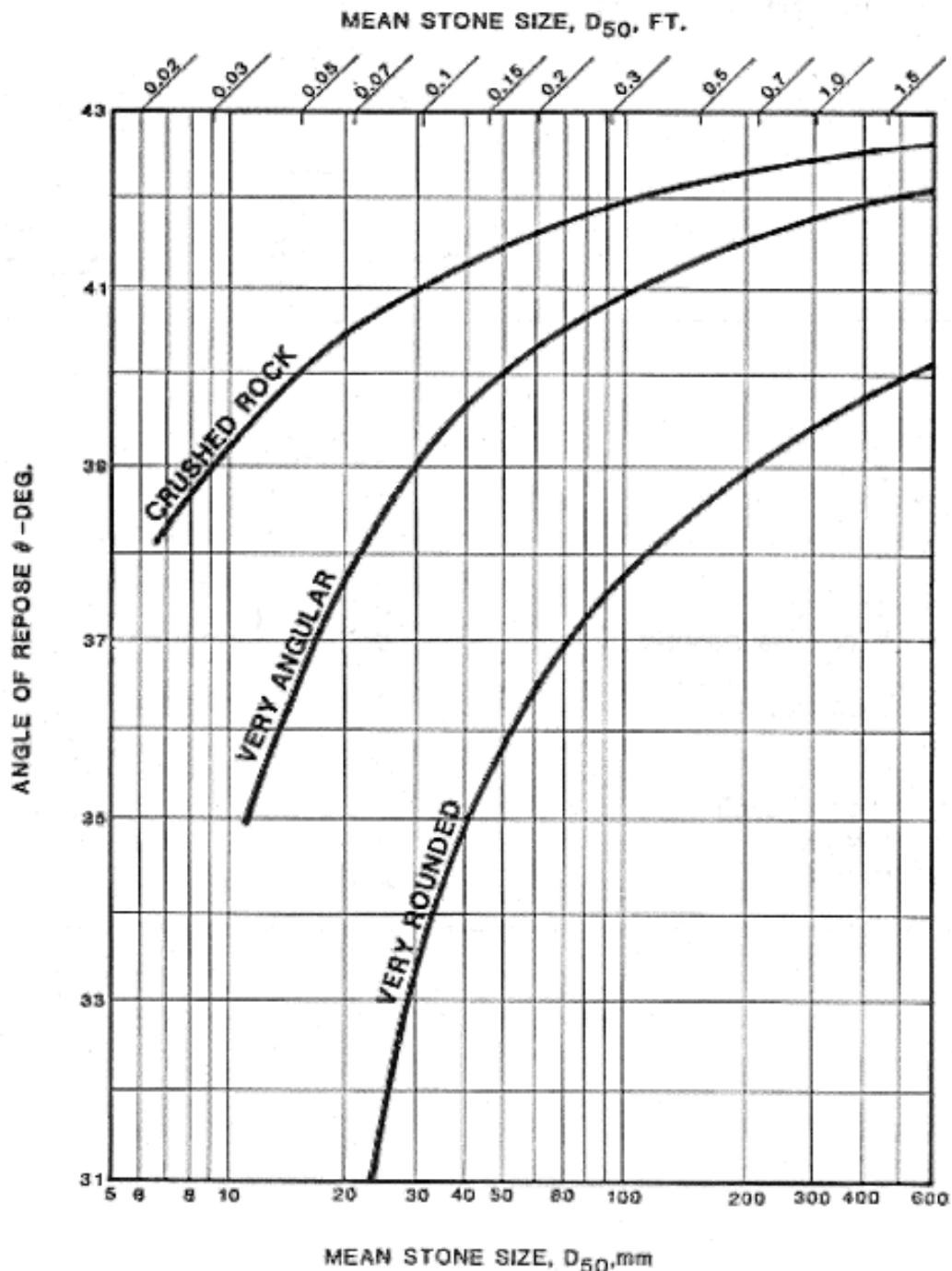
## SELECTION OF STABILITY FACTORS

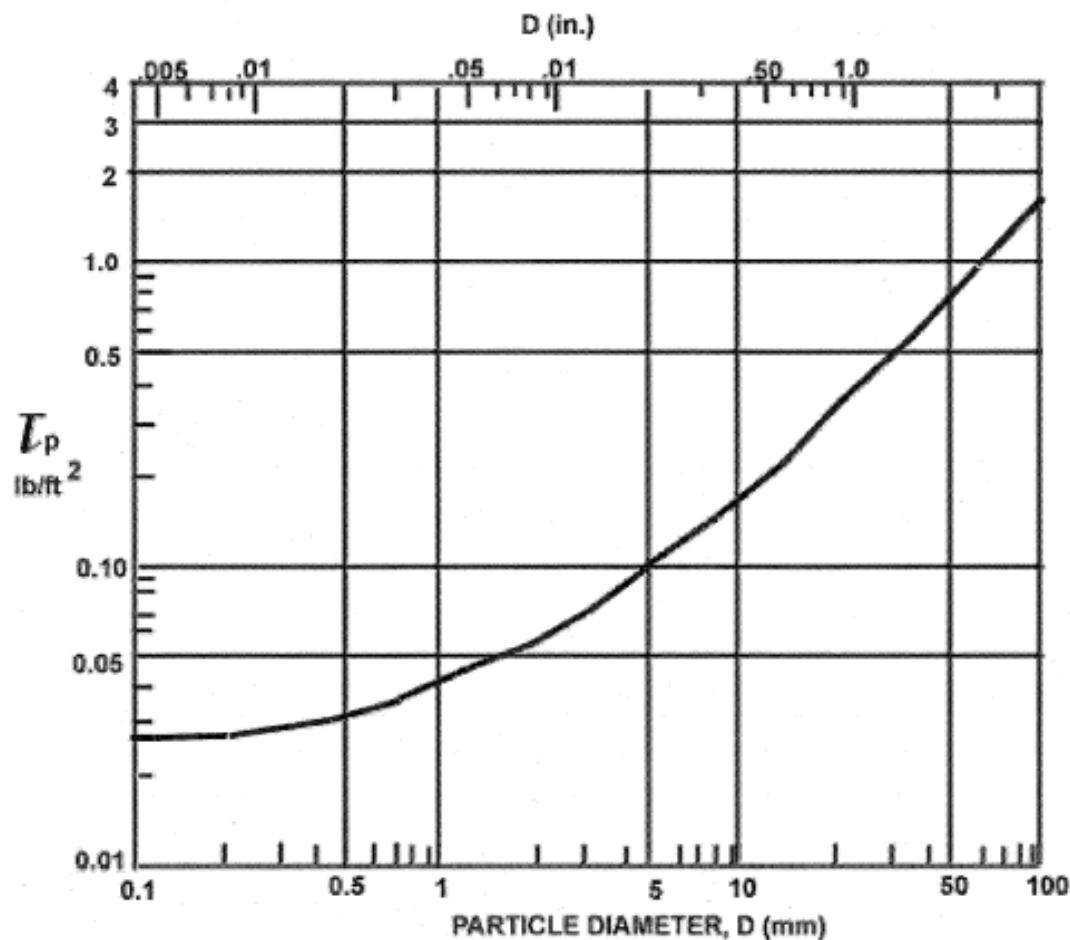
Condition	Stability Factor Range
Uniform flow; straight or mildly curving reach (curve radius/channel width >30); impact from wave action and floating debris is minimal; little or no uncertainty in design parameters.	1.0 - 1.2
Gradually varying flow; moderate bend curvature (30 > curve radius/channel width > 10); impact from waves or floating debris is moderate.	1.3 - 1.6
Approaching rapidly varying flow; sharp bend curvature (30 > curve radius/channel > 10); significant impact from floating debris and/or ice, significant wind and/or bore generated waves (1-2 feet); high flow turbulence; mixing flow at bridge abutments; significant amount of uncertainty in design parameters.	1.6 - 2.0
Channel bends when ratio of curve radius to channel width (R/W) > 30.	1.2
Channel bends when 30 > R/W > 10.	1.3 - 1.6
Channel bends when R/W < 10.	1.7

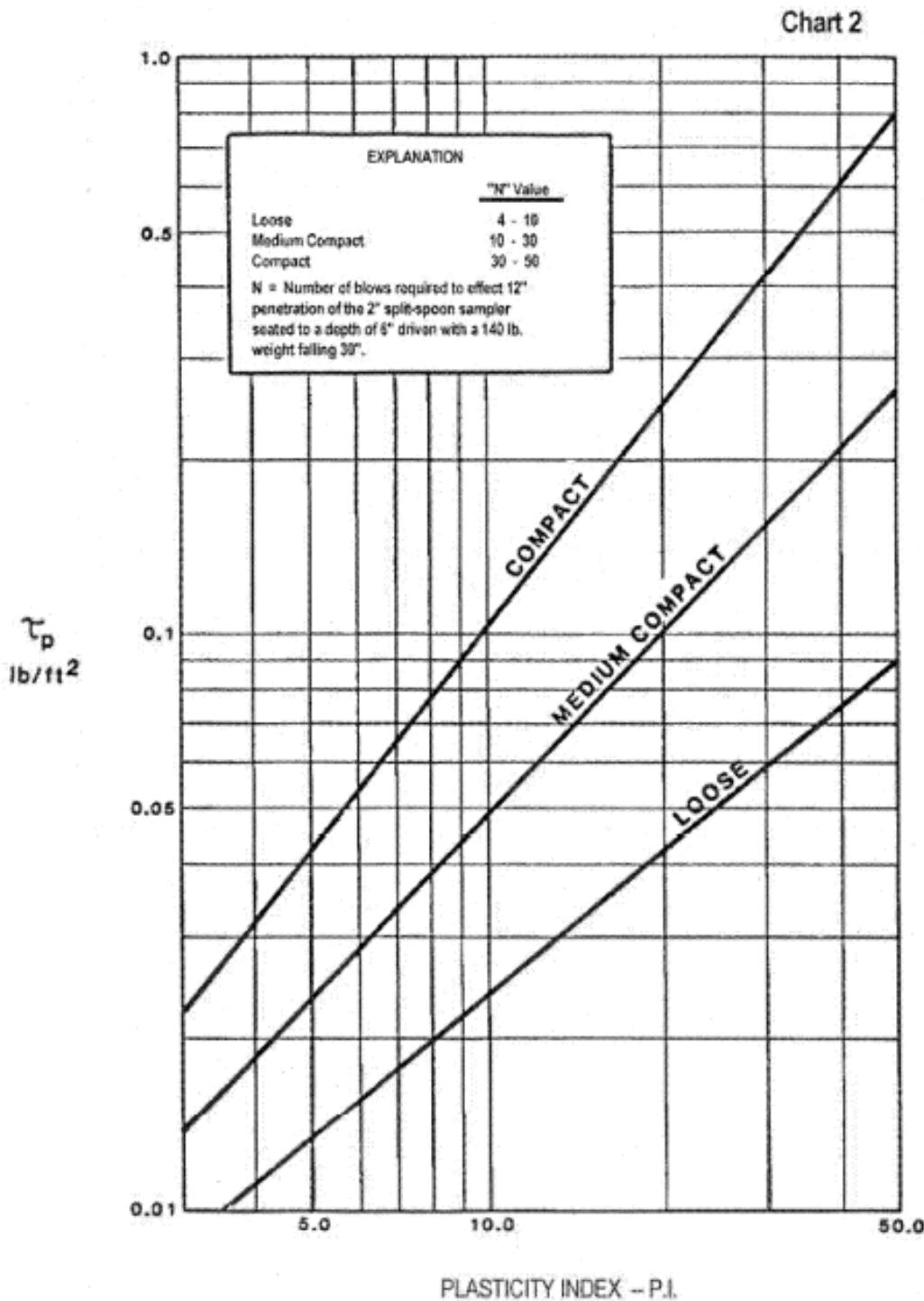
## PERMISSIBLE VELOCITIES FOR ERODIBLE LININGS

Soil type or lining (earth; no vegetation)	Maximum permissible velocities (ft/sec) for		
	Clear water	Water carrying fine silts	Water carrying sand and gravel
Fine sand (non colloidal)	1.5	2.5	1.5
Sandy loam (non colloidal)	1.7	2.5	2.0
Silt loam (non colloidal)	2.0	3.0	2.0
Ordinary firm loam	2.5	3.5	2.2
Volcanic ash	2.5	3.5	2.7
Fine gravel	2.5	5.0	3.7
Stiff clay (very colloidal)	3.7	5.0	3.0
Graded, loam to cobbles (non colloidal)	3.7	5.0	5.0
Graded, silt to cobbles (colloidal)	4.0	5.5	5.0
Alluvial silts (non colloidal)	2.0	3.5	2.0
Alluvial silts (colloidal)	3.7	5.0	3.0
Coarse gravel (non colloidal)	4.0	6.0	6.5
Cobbles and shingles	5.0	5.5	6.5
Shales and hard pans	6.0	6.0	5.0

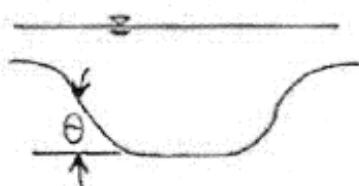
**ANGLE OF REPOSE OF RIPRAP  
IN TERMS OF MEAN SIZE AND SHAPE OF STONE**



**PERMISSIBLE SHEAR STRESS FOR NON-COHESIVE SOILS**

**PERMISSIBLE SHEAR STRESS FOR COHESIVE SOILS**

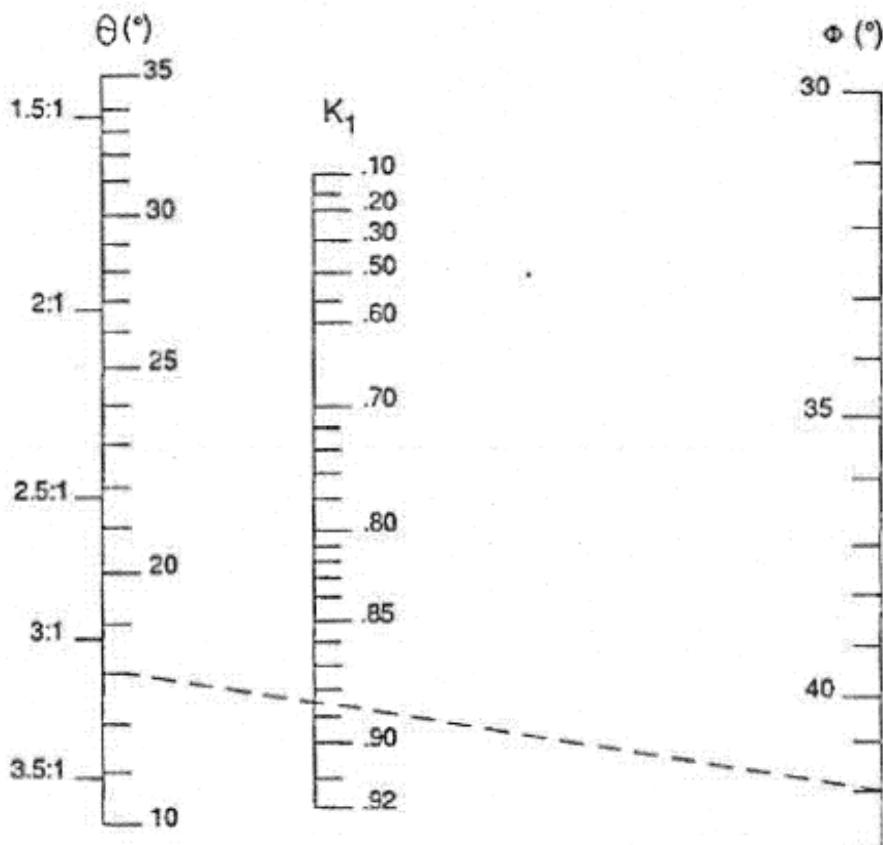
PLASTICITY INDEX – P.I.

**BANK ANGLE CORRECTION FACTOR ( $K_1$ ) NOMOGRAPH**

$$K_1 = \left[ 1 - \frac{\sin^2 \theta}{\sin^2 \phi} \right]^{0.5}$$

$\theta$  = Bank angle with horizontal

$\phi$  = Material angle of repose  
(See chart 4)

**Example**

Given:

 $\theta = 18^\circ$ 

Very Angular

 $D_{50} = 1.5$  ft.

Find:

 $K_1$ 

Solution:

 $\phi = 42^\circ$  $K_1 = 0.885$

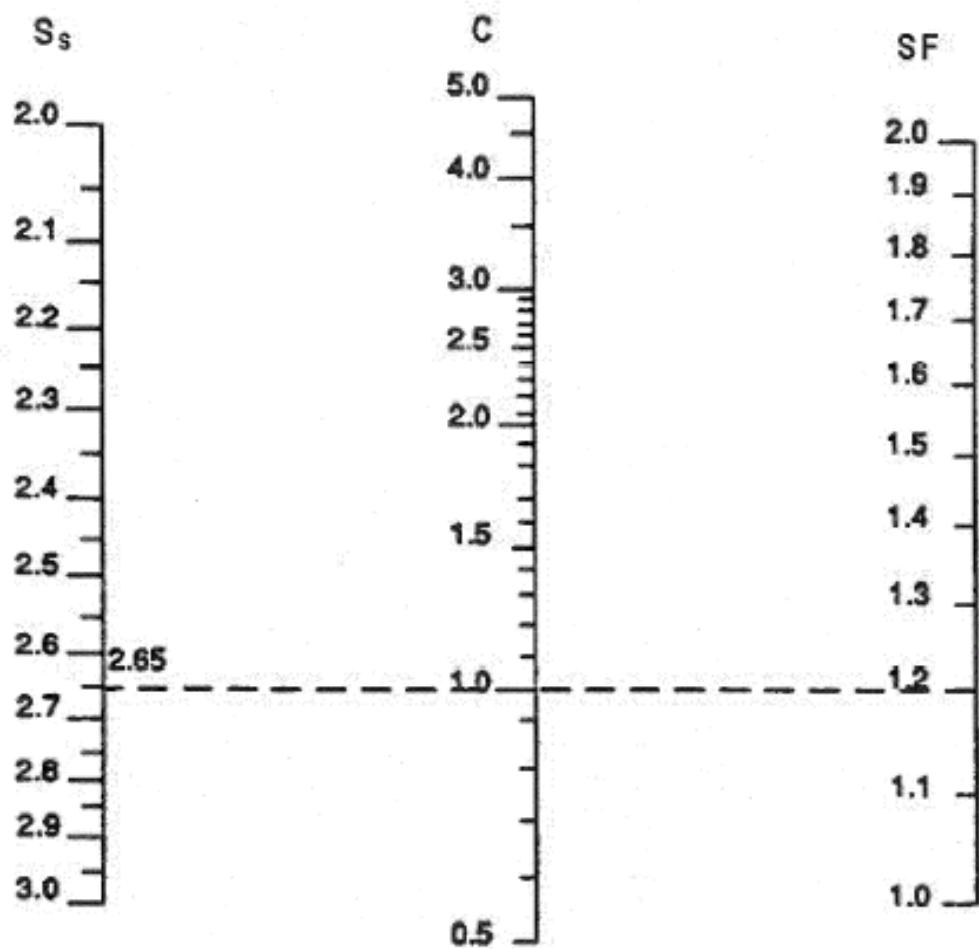
**CORRECTION FACTOR FOR RIPRAP SIZE**

$$C = 1.61 SF^{1.5} / (S_g - 1)^{1.5}$$

$C = D_{50}$  CORRECTION FACTOR

SF = STABILITY FACTOR

$S_g$  = SPECIFIC GRAVITY OF ROCK



Example:

Given:

$S_g = 2.65$

SF = 1.2

Solution:

$C = 1.0$

## RIPRAP SIZE RELATIONSHIP

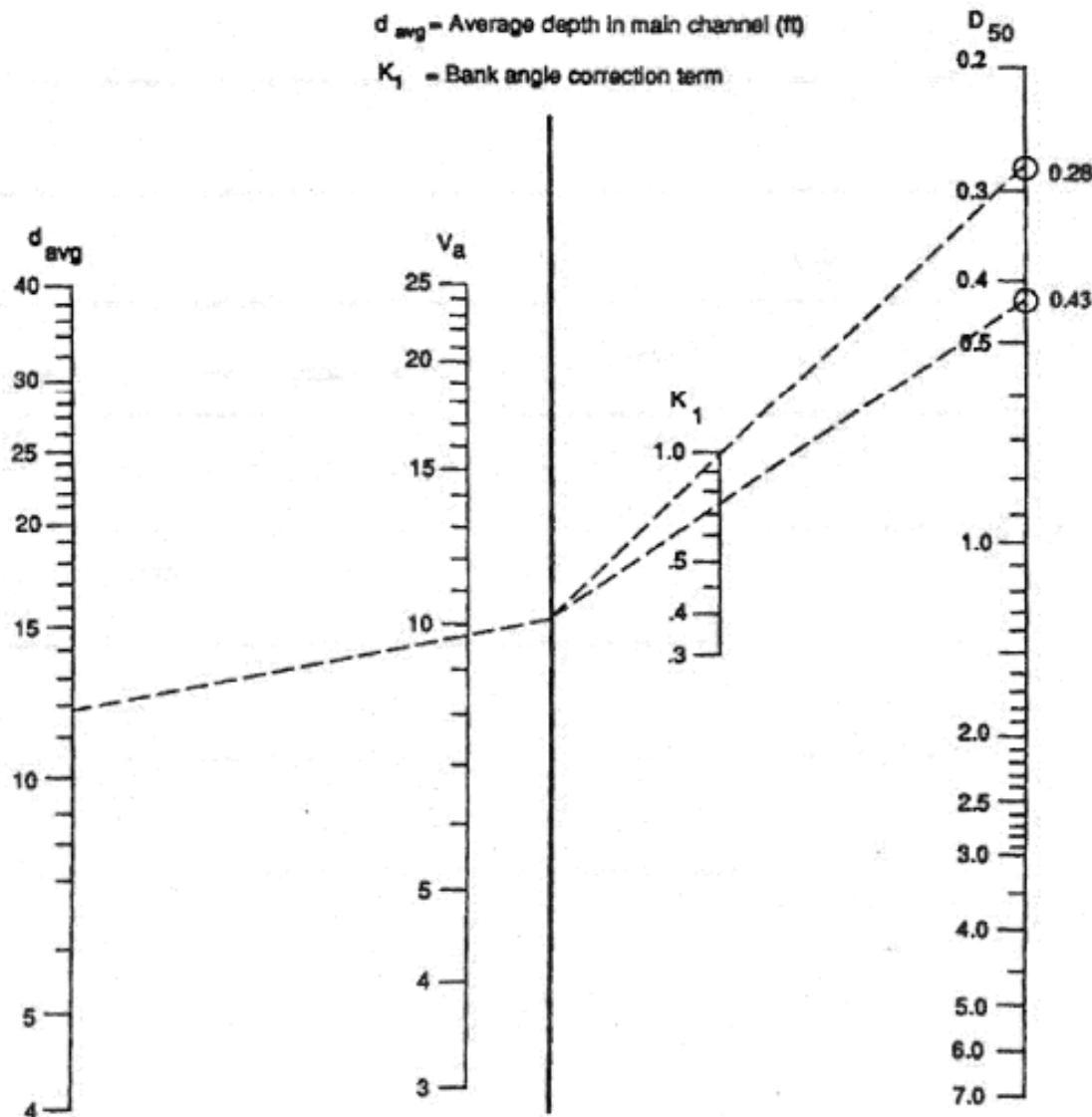
$$D_{50} = 0.001 V_a^3 / (d_{avg}^{1/2} K_1^{3/2})$$

$D_{50}$  = Median Riprap Size (ft.)

$V_a$  = Average velocity in main channel (ft/sec)

$d_{avg}$  = Average depth in main channel (ft)

$K_1$  = Bank angle correction term



### Example

Given:

$V_a = 9.7$

$d_{avg} = 11.8$  ft.

$K_1 = 0.73$

Find:

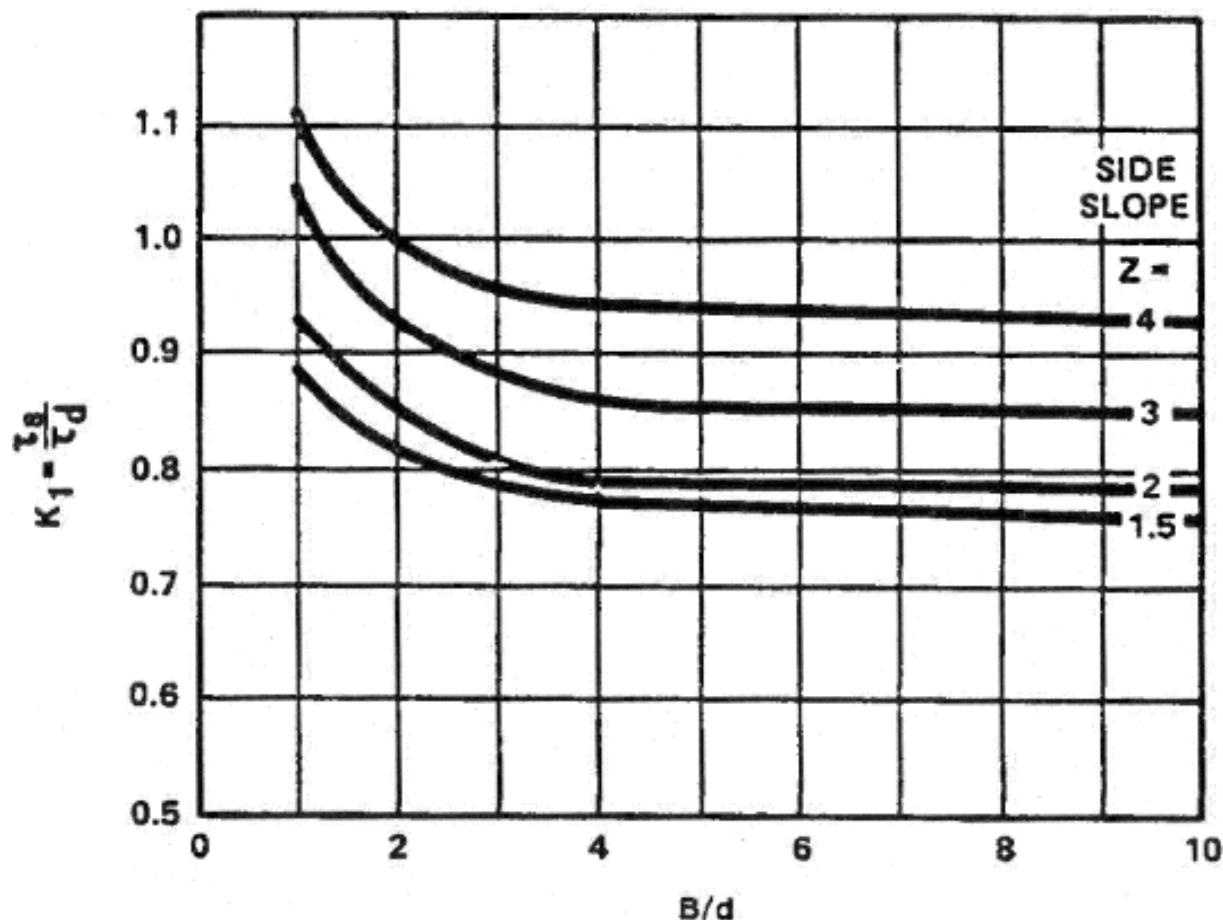
$D_{50}$

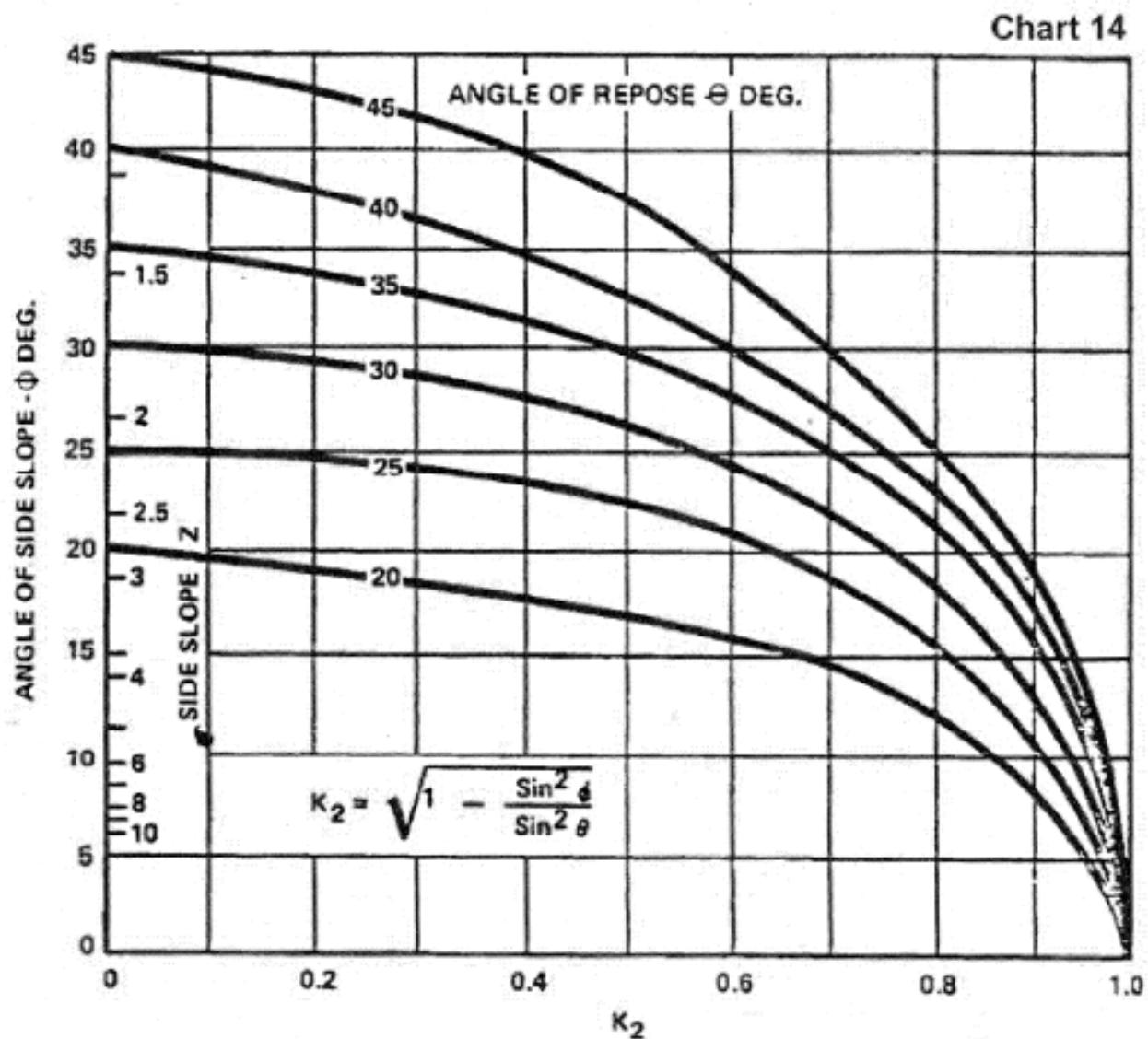
Solution:

$D_{50} = 0.43$

### CHANNEL SIDE SHEAR STRESS TO BOTTOM SHEAR STRESS RATIO

Chart 13



TRACTIVE FORCE RATIO ( $K_2$ )

## DETERMINATION OF MEAN SPHERICAL DIAMETER

