United States Army Corps of Engineers Engineering Manual EM 1110-2-1601

CECW-EH-D Engineer Manual 1110-2-1601	Department of the Army U.S. Army Corps of Engineers Washington, DC 20314-1000	EM 1110-2-1601 1 July 1991/ 30 June 1994
	Engineering and Design HYDRAULIC DESIGN OF FLOOD CONTROL CHANNELS	
	Distribution Restriction Statement Approved for public release; distribution is unlimited.	

CECW-EH-D Engineer Manual 1110-2-1601	Department of the Army U.S. Army Corps of Engineers Washington, DC 20314-1000	EM 1110-2-1601 1 July 1991/ 30 June 1994
	Engineering and Design HYDRAULIC DESIGN OF FLOOD CONTROL CHANNELS	

Chapter 3

Riprap Protection

Riprap Protection

- Section 1 – Introduction to Riprap
- Section 2 – Channel Characteristics
- Section 3 – Design Guidance for Stone Size
- Section 4 – Revetment Toe Scour Estimation and Protection
- Section 5 – Ice, Debris and Vegetation
- Section 6 – Quality Control

Introduction

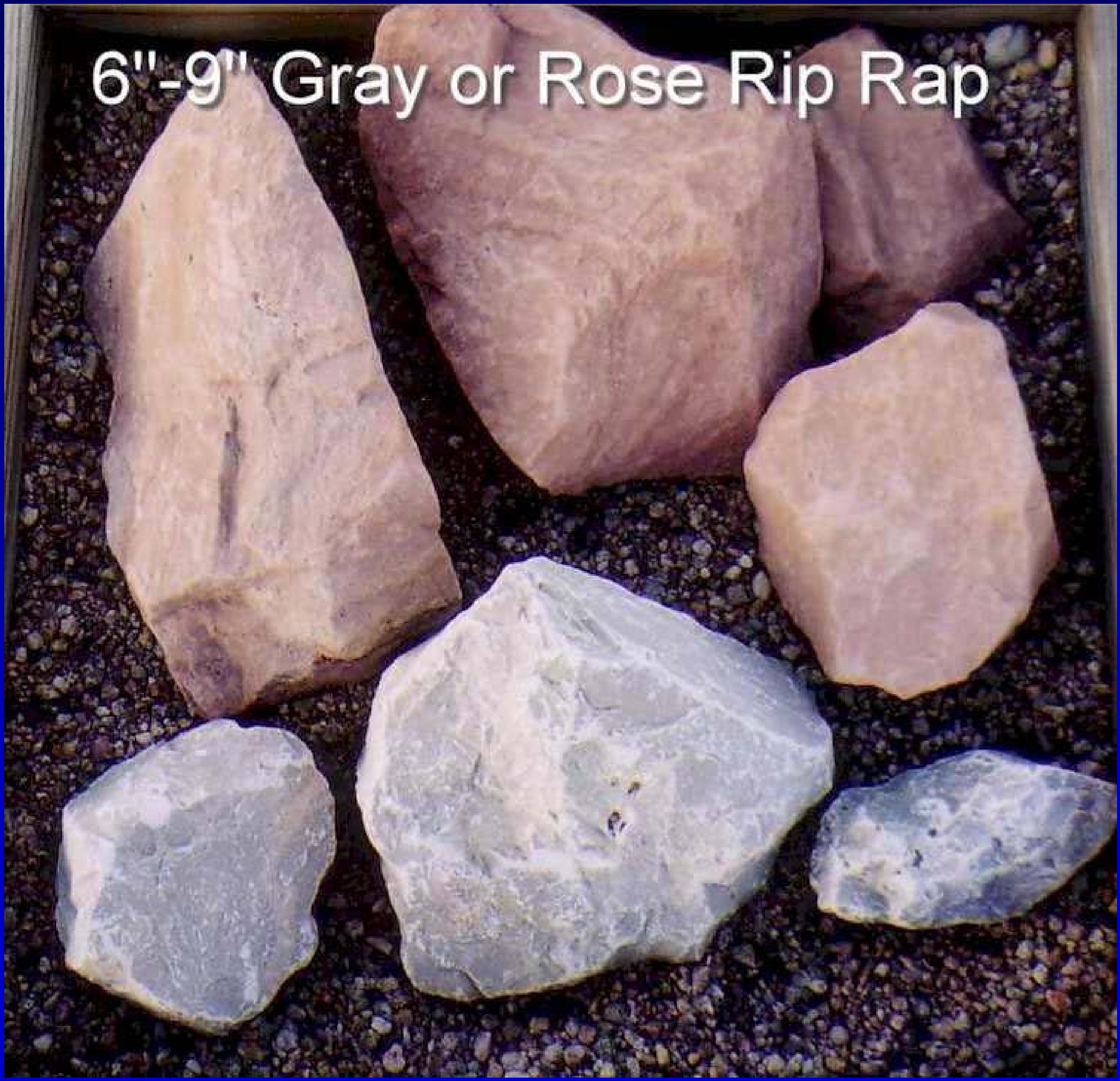
- Guidelines applicable for:
  - Open channels not immediately downstream of a stilling basin
  - Areas that are not highly turbulent
  - Channels with bed slopes of < 2%

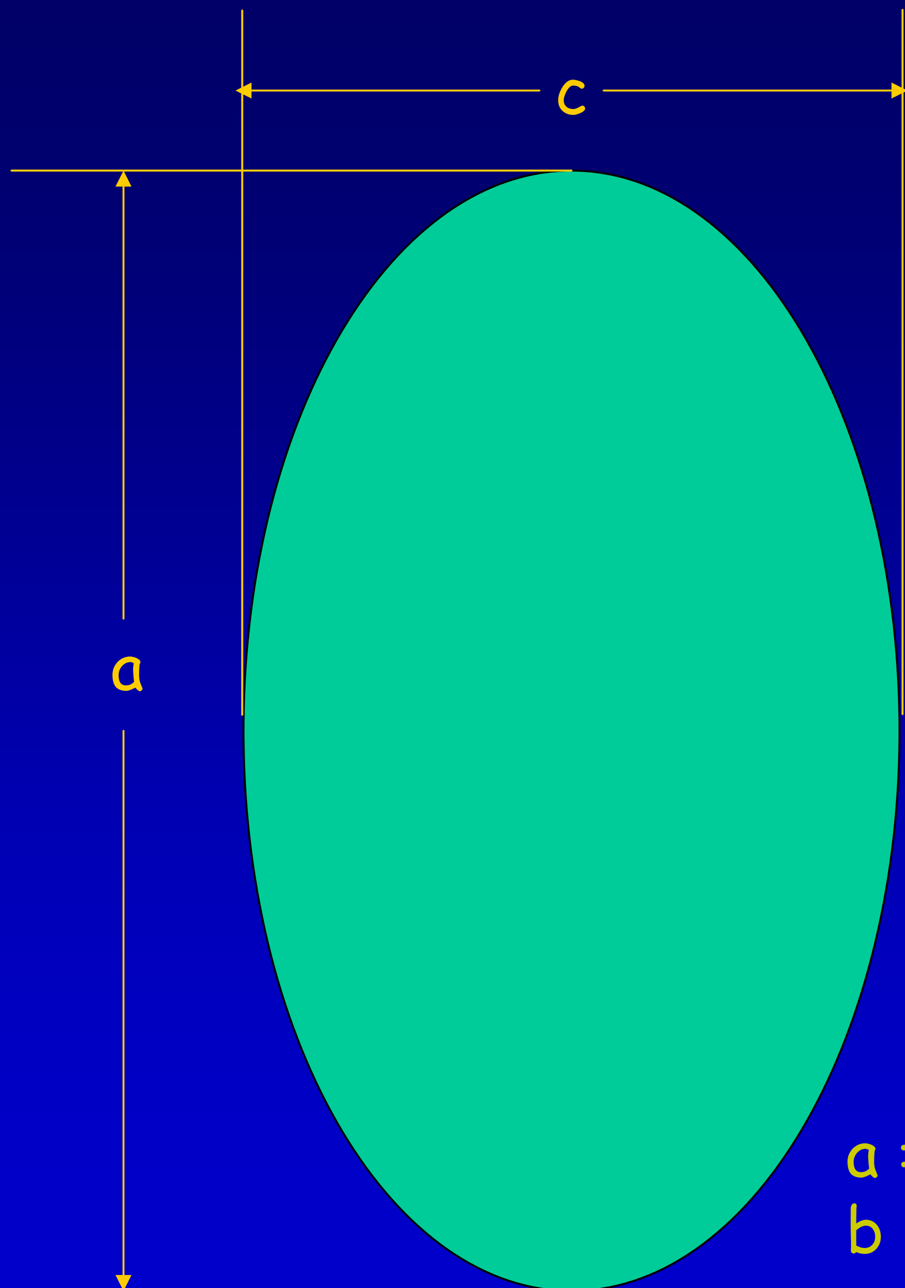
Introduction

- Successful design dependent on:
  - Stone shape
  - Stone size
  - Stone weight
  - Durability
  - Gradation
  - Layer thickness
  - Channel alignment
  - Channel slope
  - Velocity distribution

Riprap Characteristics

- Stone shape
  - Predominately angular
  - a/c ratios

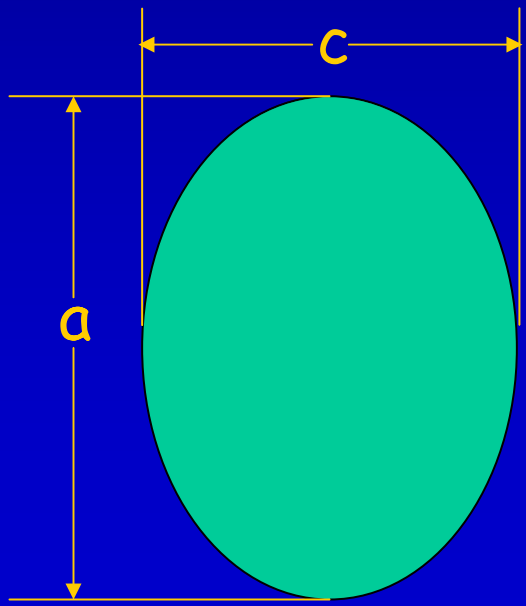

6"-9" Gray or Rose Rip Rap



a = long axis
b = intermediate axis
c = short axis

Riprap Characteristics

- Stone shape
  - Predominately angular
  - a/c ratios
    - Not more than 30% > 2.5
    - Not more that 15% > 3.0
    - No stone greater than 3.5



Riprap Characteristics

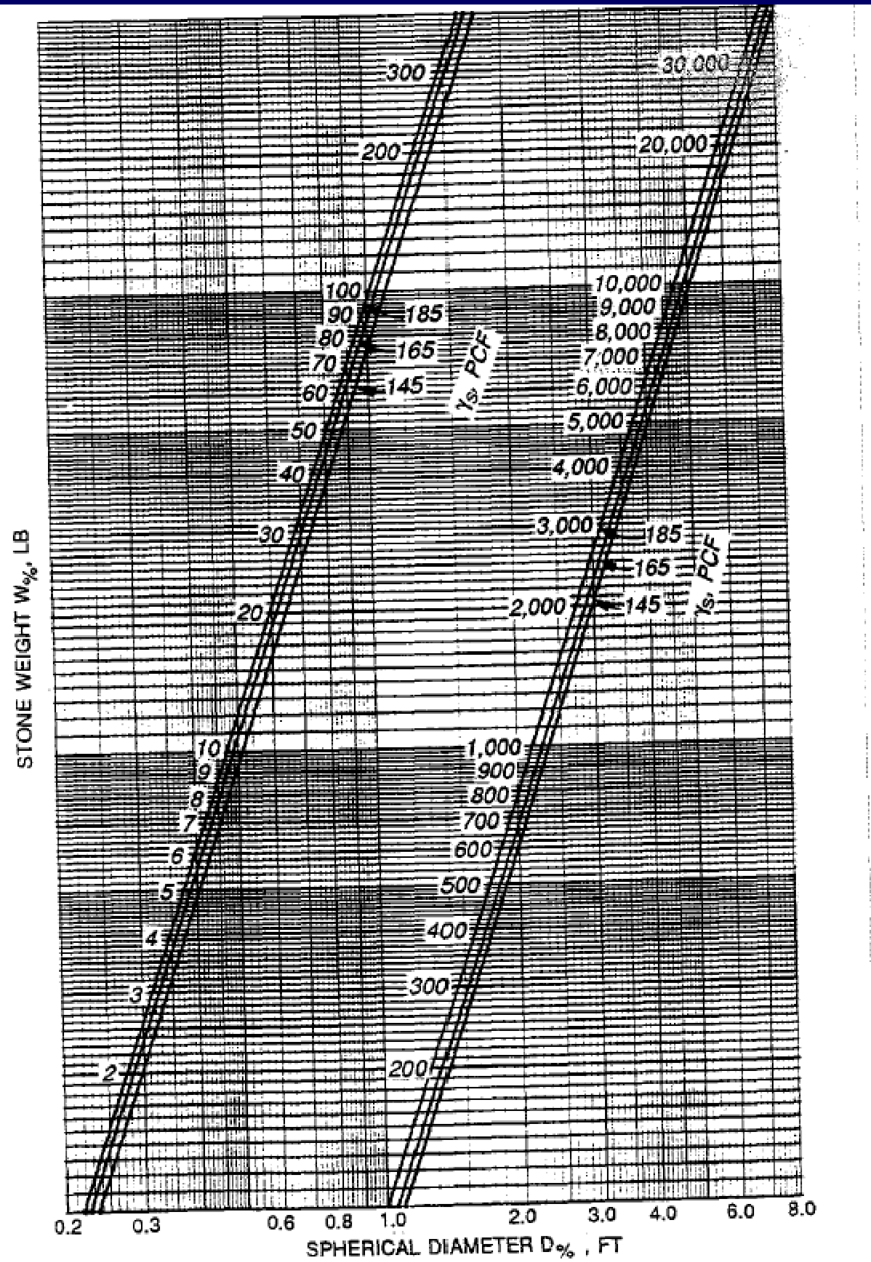
- Relation between stone size and weight
  - Design guidance typically is given as $D_{\%}$
    - % indicates the percentage of the total specified gradation weight that contains stones of less weight
  - Weight and size can be interchanged by:

Riprap Characteristics

$$D_{\%} = \left(\frac{6W_{\%}}{\pi \gamma_s} \right)^{1/3} \quad \text{and} \quad W_{\%} = \left(\frac{\pi \gamma_s D_{\%}{}^{3}}{6} \right)$$

Where

- $D_{\%}$ = equivalent volume spherical stone diameter, ft
- $W_{\%}$ = weight of individual stone of diameter $D_{\%}$
- γ_s = unit weight of stone



EQUATION:

$$W_{\%} = \frac{\pi \gamma_S D_{\%}^3}{6} \quad \text{OR} \quad D_{\%} = \left(\frac{6W_{\%}}{\pi \gamma_S}\right)^{1/3}$$

STONE WEIGHT VS SPHERICAL DIAMETER

Plate 31

Riprap Characteristics

- Unit weight
  - Typically ranges from 150 to 175 pcf
  - Equations are sensitive to assumption of unit weight
  - Common assumption is 165 pcf
- What if unknown??

Riprap Characteristics

- Gradation
  - Should be determined from a quarry test AND an in-place field test
  - Upper and lower limits typically specified
    - W_{100}
      - Lower limit $\geq$ 2 times lower limit of W_{50}
      - Upper limit $\leq$ 5 times lower limit of W_{50}
    - W_{50}
      - Lower limit > specified stone diameter
      - Upper limit $\leq$ 5 times lower limit of W_{15}
    - W_{15}
      - Lower limit $\geq$ 1/16 upper limit of W_{100}
      - Upper limit < upper limit of properly designed filter

Table 3-1
Gradations for Riprap Placement in the Dry, Low-Turbulence Zones

Limits of Stone Weight, lb[1], for Percent Lighter by Weight

D_{100}(max) in.	100 Max	100 Min	50 Max[2]	50 Min	15 Max[2]	15 Min	D_{30}(min) ft	D_{90}(min) ft
Specific Weight = 155 pcf								
9	34	14	10	7	5	2	0.37	0.53
12	81	32	24	16	12	5	0.48	0.70
15	159	63	47	32	23	10	0.61	0.88
18	274	110	81	55	41	17	0.73	1.06
21	435	174	129	87	64	27	0.85	1.23
24	649	260	192	130	96	41	0.97	1.40
27	924	370	274	185	137	58	1.10	1.59
30	1,268	507	376	254	188	79	1.22	1.77
33	1,688	675	500	338	250	105	1.34	1.94
36	2,191	877	649	438	325	137	1.46	2.11
42	3,480	1,392	1,031	696	516	217	1.70	2.47
48	5,194	2,078	1,539	1,039	769	325	1.95	2.82
54	7,396	2,958	2,191	1,479	1,096	462	2.19	3.17
Specific Weight = 165 pcf								
9	36	15	11	7	5	2	0.37	0.53
12	86	35	26	17	13	5	0.48	0.70
15	169	67	50	34	25	11	0.61	0.88
18	292	117	86	58	43	18	0.73	1.06
21	463	185	137	93	69	29	0.85	1.23
24	691	276	205	138	102	43	0.97	1.40
27	984	394	292	197	146	62	1.10	1.59
30	1,350	540	400	270	200	84	1.22	1.77
33	1,797	719	532	359	266	112	1.34	1.96
36	2,331	933	691	467	346	146	1.46	2.11
42	3,704	1,482	1,098	741	549	232	1.70	2.47
48	5,529	2,212	1,638	1,106	819	346	1.95	2.82
54	7,873	3,149	2,335	1,575	1,168	492	2.19	3.17
Specific Weight = 175 pcf								
9	39	15	11	8	6	2	0.37	0.53
12	92	37	27	18	14	5	0.48	0.70
15	179	72	53	36	27	11	0.61	0.88
18	309	124	92	62	46	19	0.73	1.06
21	491	196	146	98	73	31	0.85	1.23
24	733	293	217	147	109	46	0.97	1.40
27	1,044	417	309	209	155	65	1.10	1.59
30	1,432	573	424	286	212	89	1.22	1.77
33	1,906	762	565	381	282	119	1.34	1.94
36	2,474	990	733	495	367	155	1.46	2.11
42	3,929	1,571	1,164	786	582	246	1.70	2.47
48	5,864	2,346	1,738	1,173	869	367	1.95	2.82
54	8,350	3,340	2,474	1,670	1,237	522	2.19	3.17

Riprap Characteristics

- Layer thickness
  - the upper limit of D_{100}
  - 1.5 times the upper limit of D_{50}
  - Thickness should be increased by 50% if riprap is placed underwater
  - Oversized stones not contained within the prescribed layer can cause voids within the layer that inhibit interlocking and induce particle movement

Riprap Protection

- Section 1 – Introduction to Riprap
- Section 2 – Channel Characteristics
- Section 3 – Design Guidance for Stone Size
- Section 4 – Revetment Toe Scour Estimation and Protection
- Section 5 – Ice, Debris and Vegetation
- Section 6 – Quality Control

Channel Characteristics

- Side slope
  - Slopes should not be greater than 1.5:1
  - For constant hydraulic conditions, rock size increases with increasing side slope
  - Erosion protection, NOT slope stability

Channel Characteristics

- Roughness
  - Form of Strickler's equation

$$n = K\left[D_{90}(\min)\right]^{1/6}$$

Where

D_{90}(min) = size where 90% is finer from lower limit of gradation

K = 0.034 for velocity and stone sizing calculations

K = 0.038 for capacity and freeboard calculations

* For wet placement, n is increased ~ 15%

Riprap Protection

- Section 1 – Introduction to Riprap
- Section 2 – Channel Characteristics
- Section 3 – Design Guidance for Stone Size
- Section 4 – Revetment Toe Scour Estimation and Protection
- Section 5 – Ice, Debris and Vegetation
- Section 6 – Quality Control

Design Guidance for Stone Size

- Design Considerations
- Stone Size
- Revetment Top and End Protection

Design Considerations

- Lift and drag forces
- Undermining by scour
- Stone weight
- Stone interlocking
- Critical flow conditions

Rock Sizing

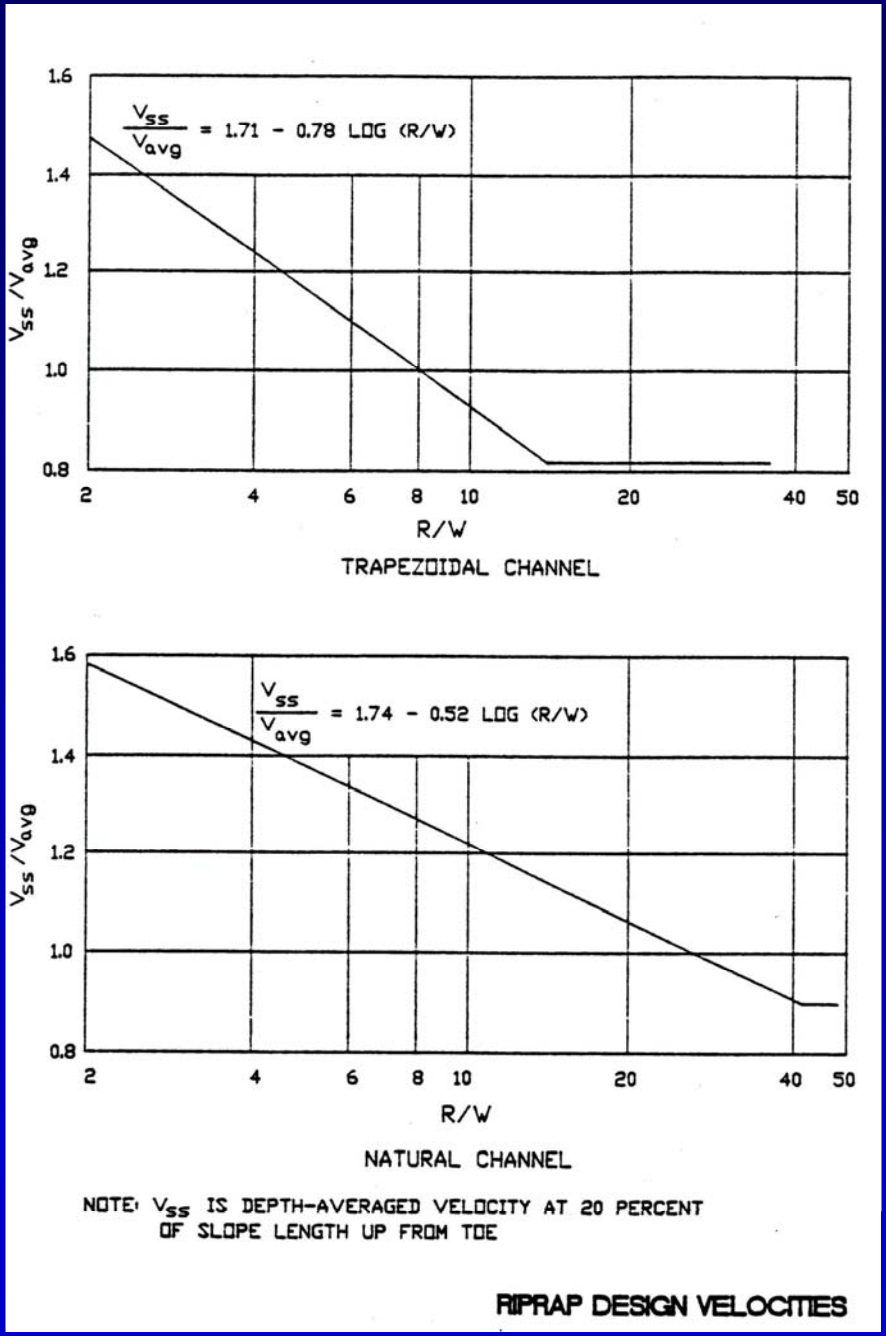
- Utilizes depth averaged velocity and flow depth
- Resisting forces
  - Rock size and weight
- Based on laboratory data and “verified” with prototype data
- Incorporates wide range of gradations
- Applicable for side slopes of 1.5:1 or flatter

Velocity estimation

- V_{ss} – characteristic velocity for side slopes
  – Depth averaged velocity at point 20% of the slope length, measured from the toe
  – Typically determined in relation to V_{avg}

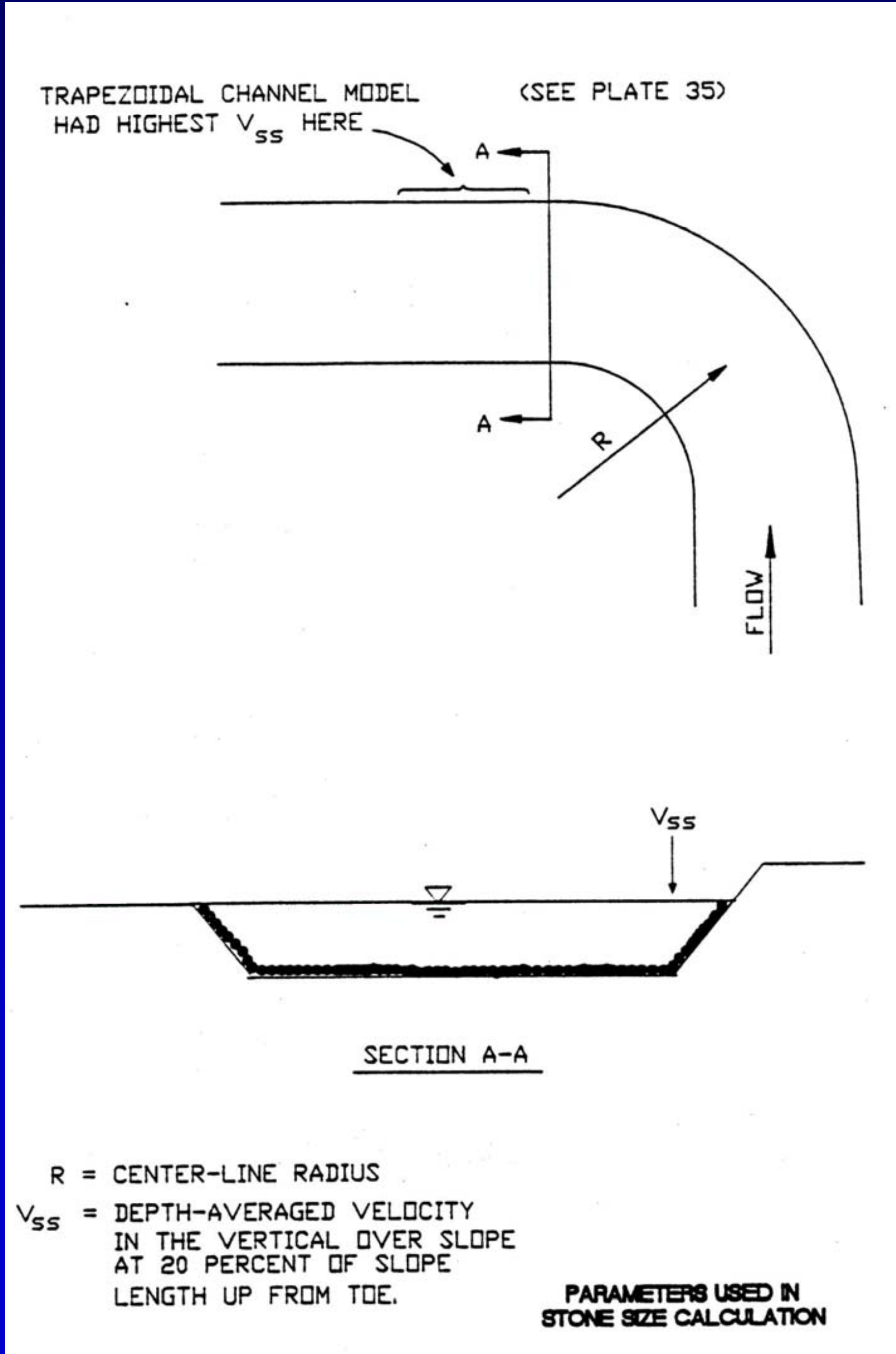
Velocity estimation

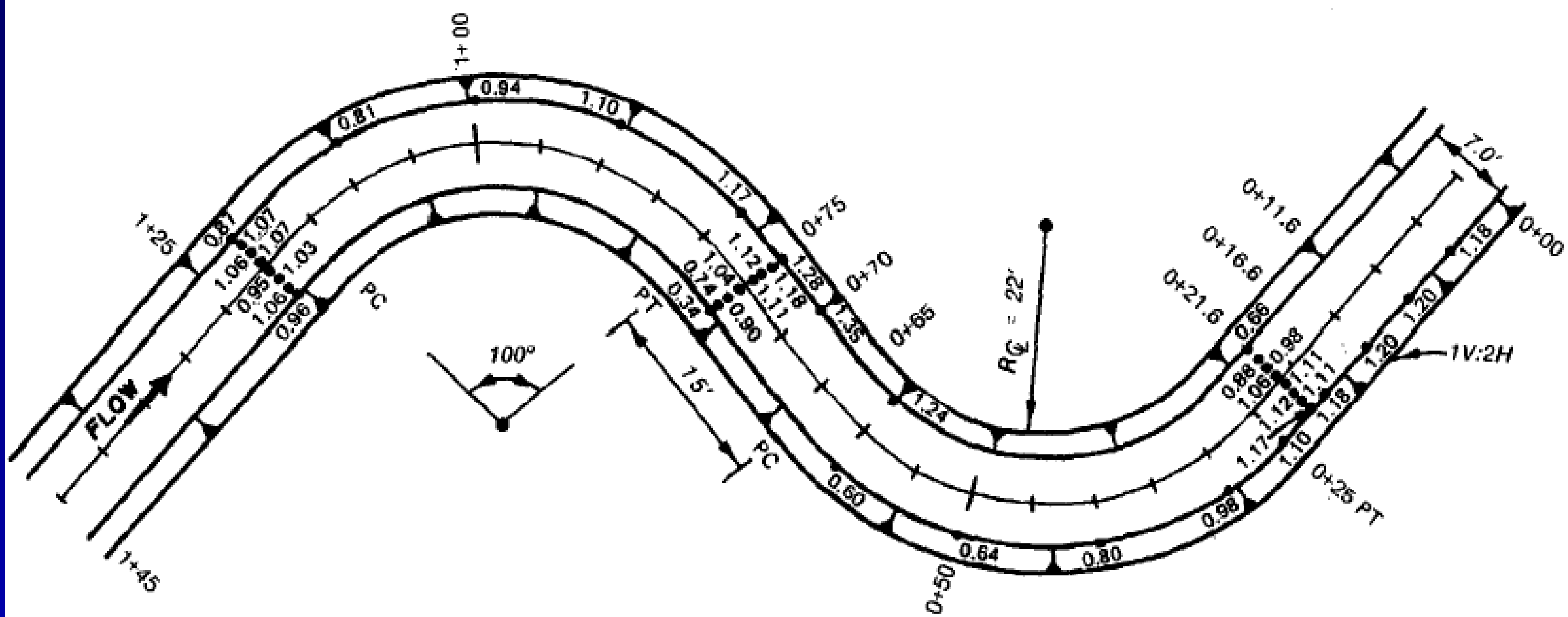
- V_{avg} - Average channel velocity
  - Expressed as function of R/W
  - Computed at upstream end of bend
  - For locations away from bends (>5W), assume large value of R/W
  - Channel width/depth ratios important in defining V_{avg}
- Plates 33 - 36



1.6
1.4
1.2
1.0
0.8
V_{ss}/V_{avg}
$\frac{V_{ss}}{V_{avg}}$ = 1.71 - 0.78 LOG (R/W)
2
4
6
8
10
20
40
50
R/W
TRAPEZOIDAL CHANNEL
1.6
1.4
1.2
1.0
0.8
V_{ss}/V_{avg}
$\frac{V_{ss}}{V_{avg}}$ = 1.74 - 0.52 LOG (R/W)
2
4
6
8
10
20
40
50
R/W
NATURAL CHANNEL
NOTE: V_{ss} IS DEPTH-AVERAGED VELOCITY AT 20 PERCENT OF SLOPE LENGTH UP FROM TOE
RIPRAP DESIGN VELOCITIES

Plate 33


TRAPEZOIDAL CHANNEL MODEL
HAD HIGHEST V_{ss} HERE
(SEE PLATE 35)
A
A
R
FLOW
V_{ss}
SECTION A-A
R = CENTER-LINE RADIUS
V_{ss} = DEPTH-AVERAGED VELOCITY IN THE VERTICAL OVER SLOPE AT 20 PERCENT OF SLOPE LENGTH UP FROM TOE.
PARAMETERS USED IN STONE SIZE CALCULATION



NOTE: • 1.04 REPRESENTS $\frac{\text{AVERAGE VELOCITY IN VERTICAL}}{\text{AVERAGE CHANNEL VELOCITY}}$

BOTTOM SLOPE ≈ WATER-SURFACE SLOPE = 0.0025 FT/FT

RIPRAP: 50% #4 – 3/8, 50% 3/8 – 1/2

AVERAGE CHANNEL VELOCITY = 1.87 FPS

FROUDE NO. = 0.52

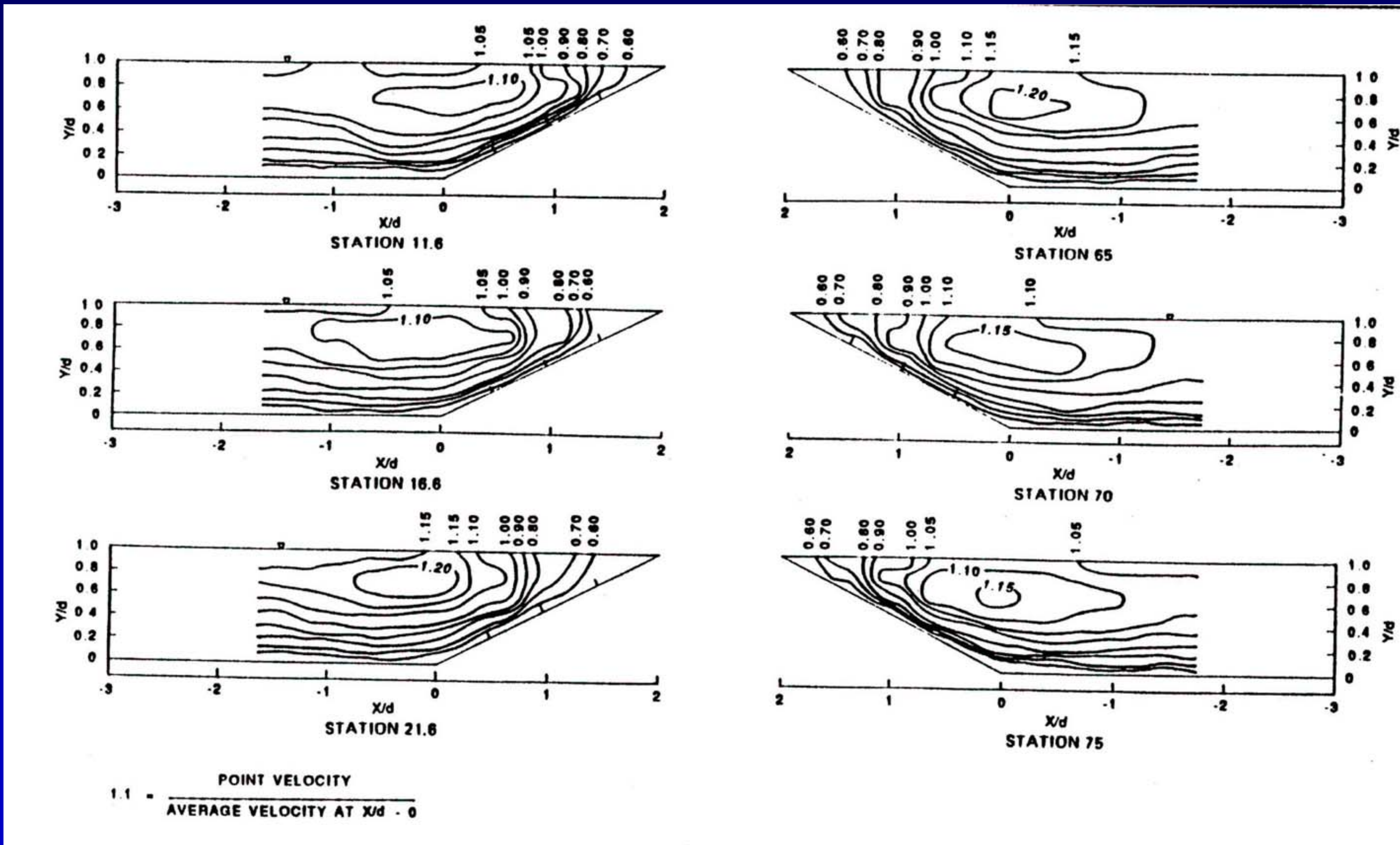
STATIONARY IN FEET

SEE PLATE 36 FOR VELOCITY X-SECTIONS

VELOCITY DISTRIBUTION IN
TRAPEZOIDAL CHANNEL

DISCHARGE 6.75 CFS DEPTH 0.455 FT

IV: 2H SIDE SLOPES



SIDE SLOPE VELOCITY DISTRIBUTION
IN CHANNEL BENDS

Plate 36

USACE Method

$$D_{30} = S_f C_s C_v C_t d \left(\left(\frac{\gamma_w}{\gamma_s - \gamma_w} \right)^{0.5} \frac{V}{\sqrt{K_1 g d}} \right)^{2.5}$$

USACE Method

$$D_{30} = S_f C_s C_v C_t d \left(\left(\frac{\gamma_w}{\gamma_s - \gamma_w} \right)^{0.5} \frac{V}{\sqrt{K_1 g d}} \right)^{2.5}$$

Where:

D_{30} = stone size (ft)

S_f = safety factor (minimum of 1.1 recommended)

C_s = stability coefficient for incipient failure where layer thickness is 1 D_{100}(max) or 1.5 D_{50}(max), and D85/D15 between 1.7 and 5.2

C_s = 0.30 for angular rock
C_s = 0.36 for rounded rock

USACE Method

$$D_{30} = S_f C_s C_v C_t d\left(\left(\frac{\gamma_w}{\gamma_s - \gamma_w}\right)^{0.5} \frac{V}{\sqrt{K_1 g d}}\right)^{2.5}$$

Where:

C_v = vertical velocity distribution coefficient

= 1.0 for straight channels, inside bends

= 1.283 – 0.2 log (R/W), outside bends

= 1.25 downstream of concrete channels

= 1.25 for the end of dikes/groins

C_t = thickness coefficient

= 1.0 for 1*D_{100} or 1.5*D_{50} otherwise use Plate 40

USACE Method

$$D_{30} = S_f C_s C_v C_t d \left(\left(\frac{\gamma_w}{\gamma_s - \gamma_w} \right)^{0.5} \frac{V}{\sqrt{K_1 g d}} \right)^{2.5}$$

Where:

d = local depth of flow (ft)

γ_s = unit weight of stone (lbs/ft^3)

γ_W = unit weight of water (lbs/ft^3)

V = local depth averaged velocity (ft/s)

g = gravitational constant (ft/s^2)

USACE Method

$$D_{30} = S_f C_s C_v C_t d \left(\left(\frac{\gamma_w}{\gamma_s - \gamma_w} \right)^{0.5} \frac{V}{\sqrt{K_1 g d}} \right)^{2.5}$$

Where:

K_1 = side slope correction factor

= 1.0 for bottom riprap

or = $\left(1 - \frac{\sin^2\theta}{\sin^2\phi} \right)^{0.5}$

where

θ = side slope angle

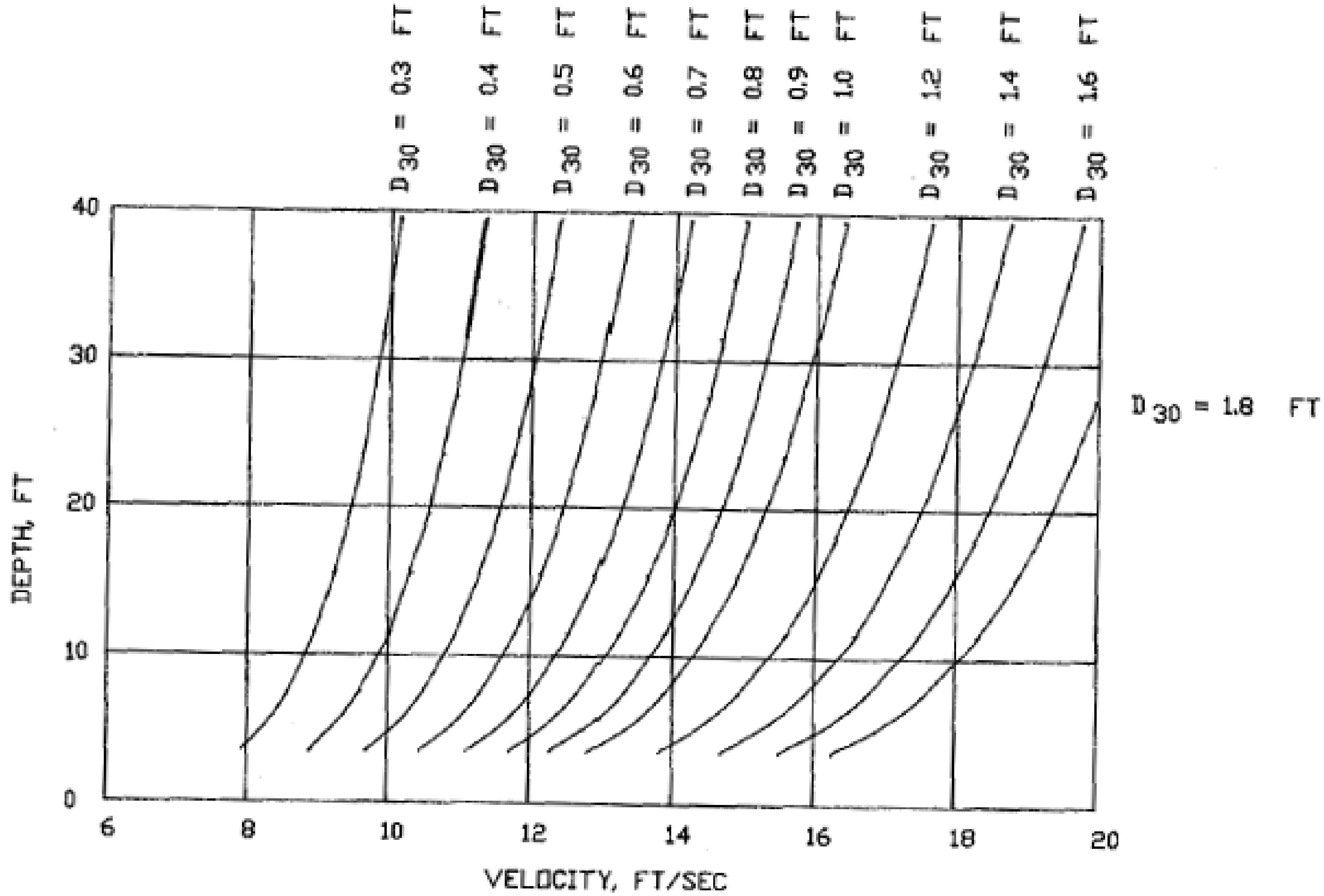
Φ = *angle of repose*

Safety Factor

- Basic value is 1.1
- Should be increased for:
  - Potential of impact forces
  - Uncertainty of velocity, depth and rock weight estimations
  - Potential for vandalism
  - Uncertainty of gradation and/or placement quality control (stockpiling)
  - If freeze/thaw is expected

Applications

- Plate 37 developed assuming:
  - Straight channel
  - Thickness = 1D100(max)
  - Rock weight of 165 pcf
  - Sf = 1.1

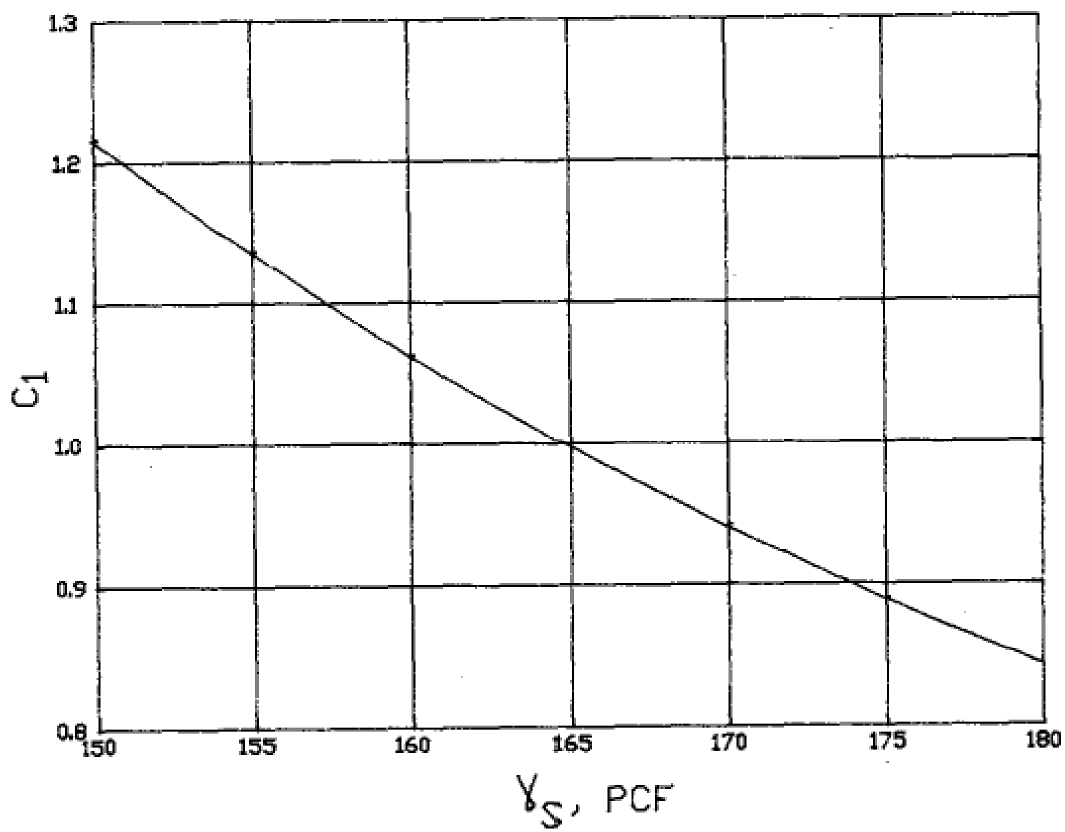


NOTE: APPLICABLE TO THICKNESS $1D_{100}$ (max)
AND CHANNEL BOTTOMS OR SIDE SLOPES
FLATTER THAN OR EQUAL TO 1V ON 4H.
STONE WEIGHT 165 pcf, C_S = 0.30, C_V = C_T = 1.0
S_f = 1.1 BASED ON EQUATION 3-3.

DEPTH-AVERAGED VELOCITY VS D30 AND DEPTH

Applications

- Variable thickness
  - Utilize Plate 38



$D_{30} = C_1 * (D_{30}$ FROM PLATE 37)

WHERE C_1 = CORRECTION FOR UNIT STONE WEIGHT

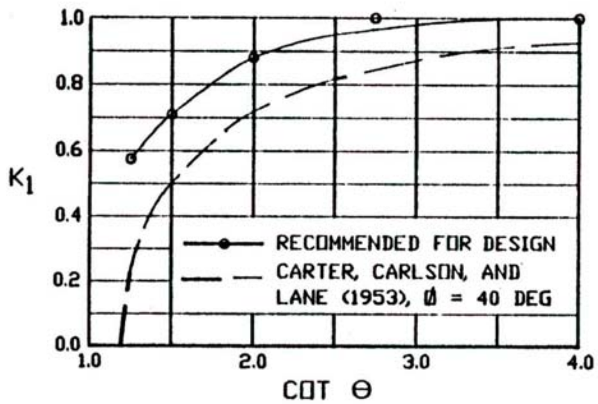
NOTE: DO NOT MAKE THIS CORRECTION IF D_{30} COMPUTED FROM EQUATION 3-3

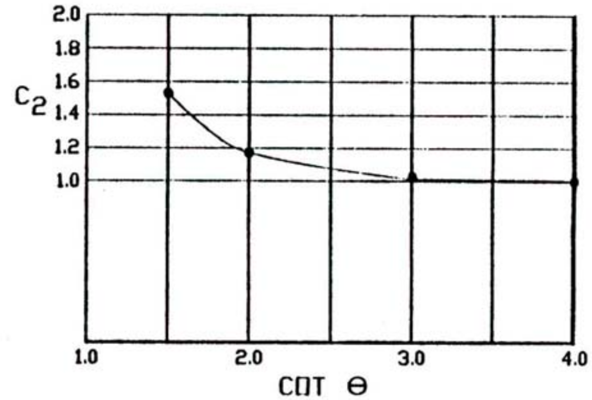
Plate 38

Applications

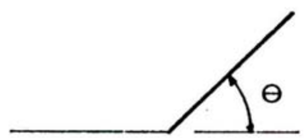
- Varying side slope
  - Equation 3-4 and Plate 39

Plate 39





K_1 = SIDE SLOPE CORRECTION COEFFICIENT
FOR USE IN EQUATION 3-3 ONLY.



D_{30} = C_2*(D_{30} FROM PLATE 37)

WHERE C_2 = CORRECTION FOR SIDE SLOPE ANGLE

NOTE : DO NOT MAKE THIS CORRECTION IF
D_{30} COMPUTED FROM EQUATION 3-3.

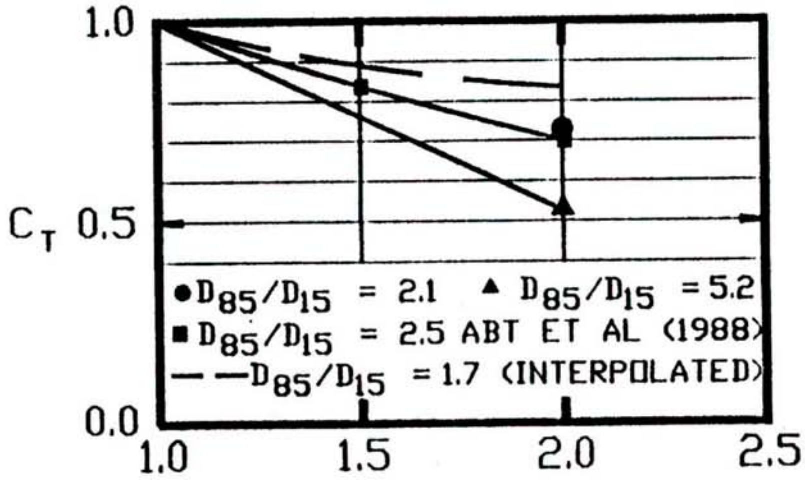
CORRECTION FOR SIDE SLOPE ANGLE

$$K_1 = \sqrt{1 - \frac{\sin^2 \theta}{\sin^2 \phi}}$$

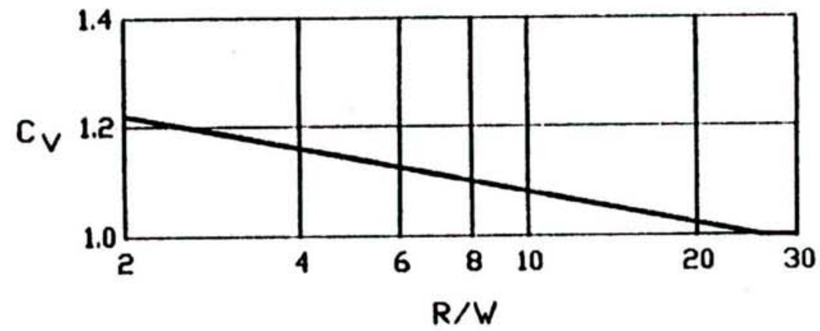
EQ. 3-4

Applications

- Variations in vertical velocity distribution in bends
  - Use Plate 40



$$N = \frac{\text{THICKNESS}}{T*}$$



WHERE C_T = CORRECTION FOR THICKNESS

$$= \frac{D_{30} \text{ FOR THICKNESS OF } NT*}{D_{30} \text{ FOR THICKNESS OF } T*}$$

$T* = 1D_{100}$ OR $1.5D_{50}$, WHICHEVER IS GREATER

$D_{30} = C_V * (D_{30}$ FROM PLATE 37)

WHERE C_V = CORRECTION FOR VERTICAL VELOCITY DISTRIBUTION

CORRECTION FOR VERTICAL VELOCITY DISTRIBUTION IN BEND AND RIPRAP THICKNESS

Design Procedure

- Determine average channel velocity V_{avg}
- Calculate V_{ss} using Plate 33
- Find D30 from Equation 3-3 or Plate 37
- If needed, correct for:
  - Unit weight
  - Side slope
  - Vertical velocity distribution
  - Layer thickness
- Compute gradation having D_{30}(min) > computed D_{30}

USACE Method-Limitations

$$D_{30} = S_f C_s C_v C_t d\left(\left(\frac{\gamma_w}{\gamma_s - \gamma_w}\right)^{0.5} \frac{V}{\sqrt{(K_1 gd)}}\right)^{2.5}$$

- Method based on lab data from late 80's
  - D_{50}: 0.5 – 2.0 inches
  - Thickness: 0.75 – 2 inches
  - Average velocity: 0.6 – 6.6 ft/s
  - Discharge: 15 – 100 cfs
  - Bed slope: 0.00087 – 0.015
  - Max side slope: 1.5:1
- Verified with some field data

USACE Method-Steep Slopes

$$D_{30} = \frac{1.95 * S^{0.555} q^{2/3}}{g^{1/3}}$$

Where

S = bed slope

q = unit discharge

USACE Method-Steep Slopes

$$D_{30} = \frac{1.95 * S^{0.555} q^{2/3}}{g^{1/3}}$$

Limitations

- thickness = 1.5 D_{100}
- angular rock
- unit weight = 167 pcf
- 1.7 < D_{85}/D_{15} > 2.7
- Bed slope from 2 - 20 %
- uniform flow with NO tailwater

Design Procedure

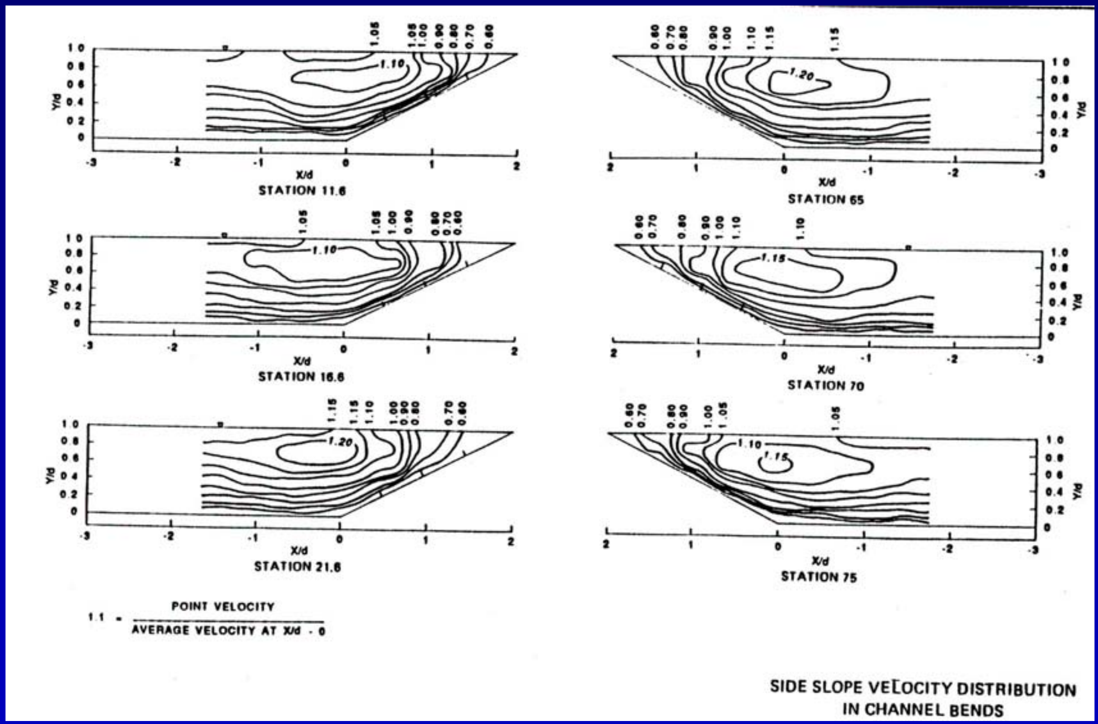
- Estimate unit discharge
- Apply flow concentration factor of 1.25 to unit discharge
- Compute D30
- Specify uniform gradation where D85/D15 < 2, as in Table 3.1
- Restrict use to straight channels with side slopes of 2.5:1 or flatter
- Specify filter fabric beneath rock

Revetment Top and End Protection

- Revetment Top
  - How far upslope should be protected?
    - Waves
    - Debris
    - Calculation uncertainties
    - Return flows
    - Site specific conditions

Begin 13 OCT

Balance between



and

$$

Revetment End Protection

- Upstream and downstream ends protected by
  - Increasing thickness
  - Extending protection to area of low velocity
- Three proposed methods

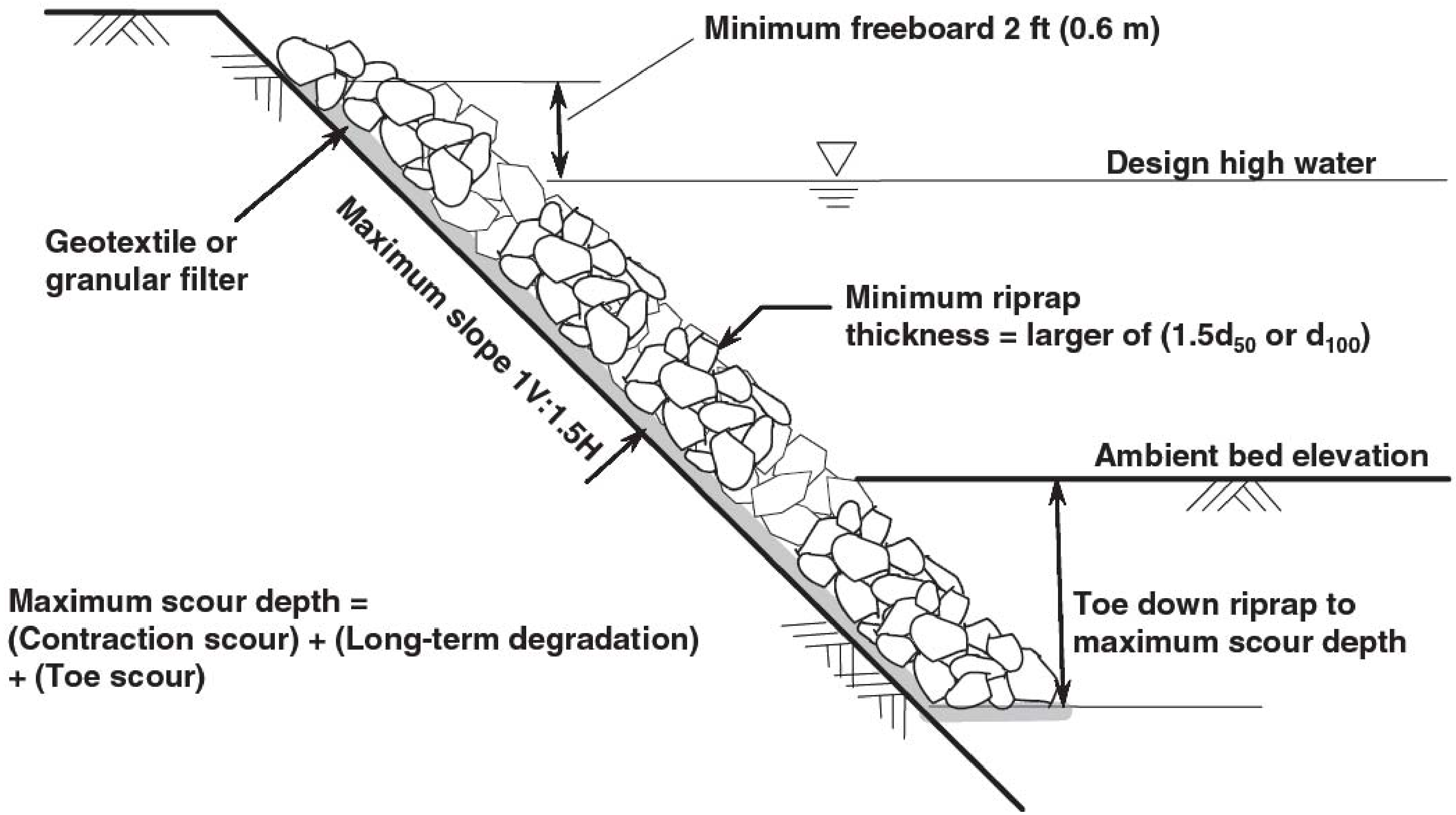
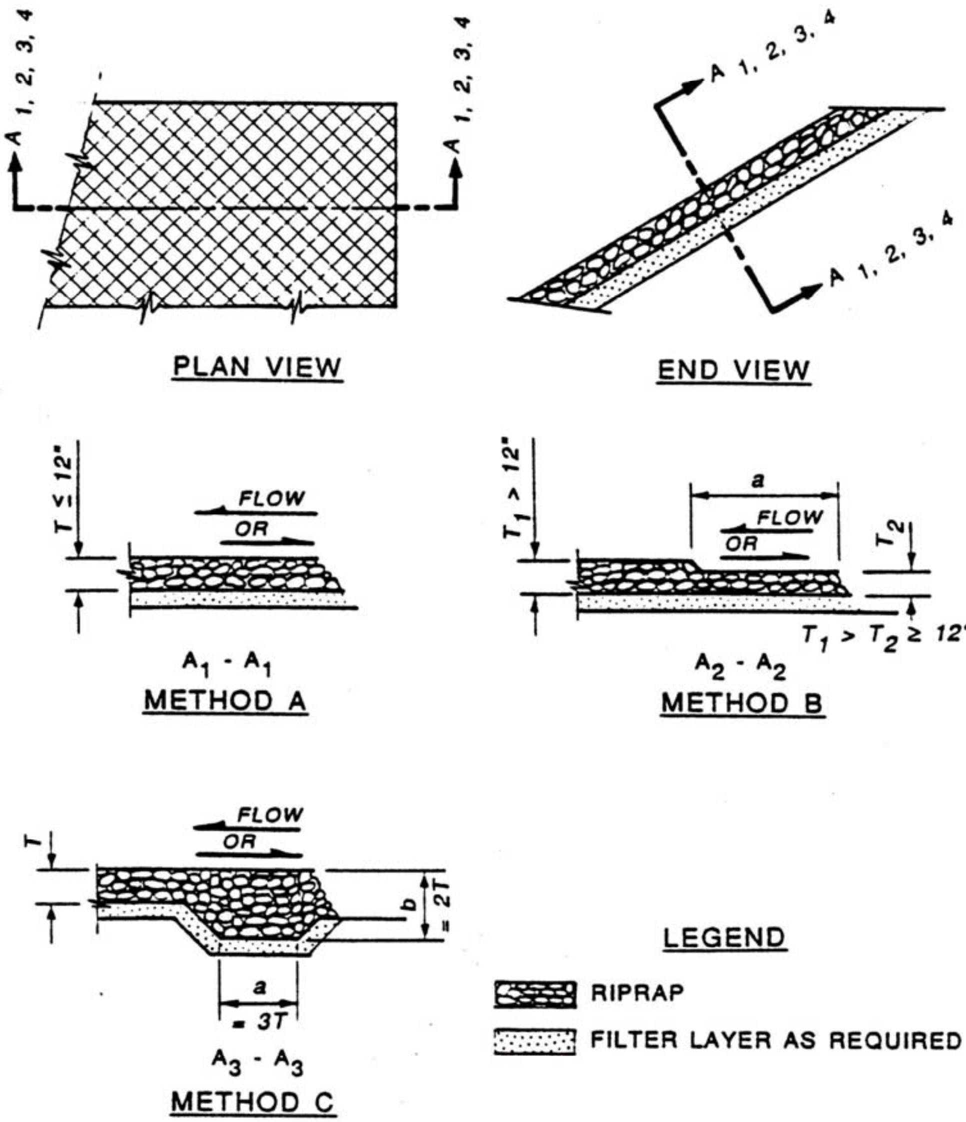


Figure C2.1. Revetment riprap with buried toe.

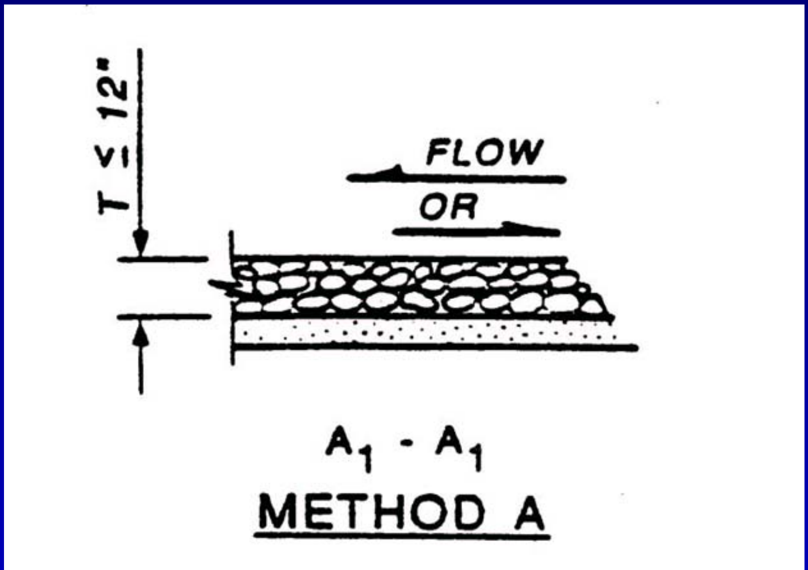


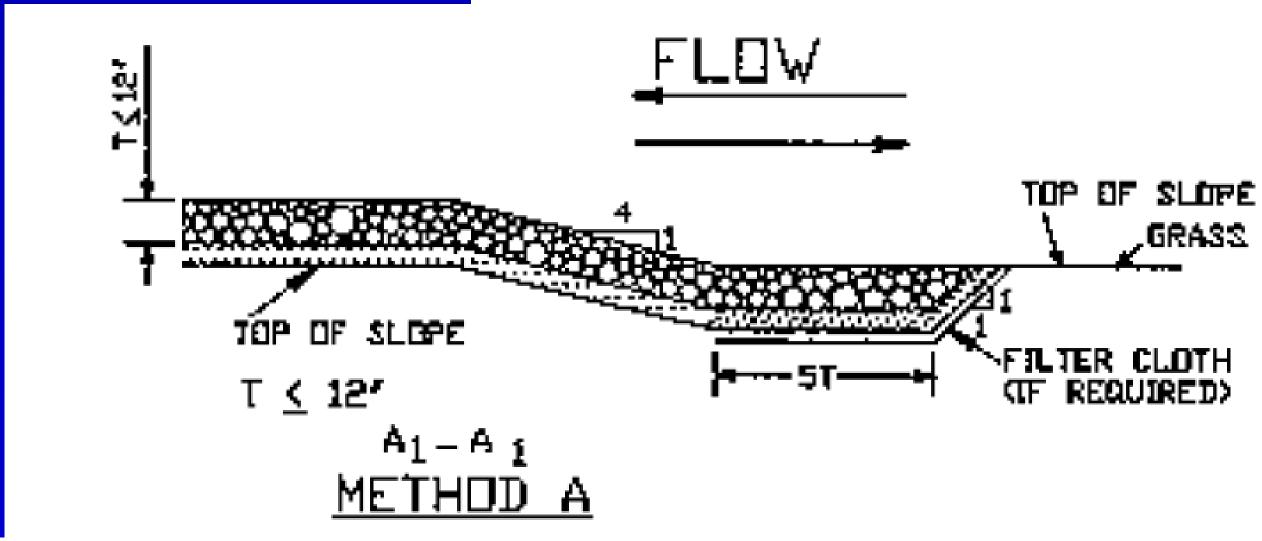
RIPRAP
END PROTECTION

Plate 41

Revetment End Protection

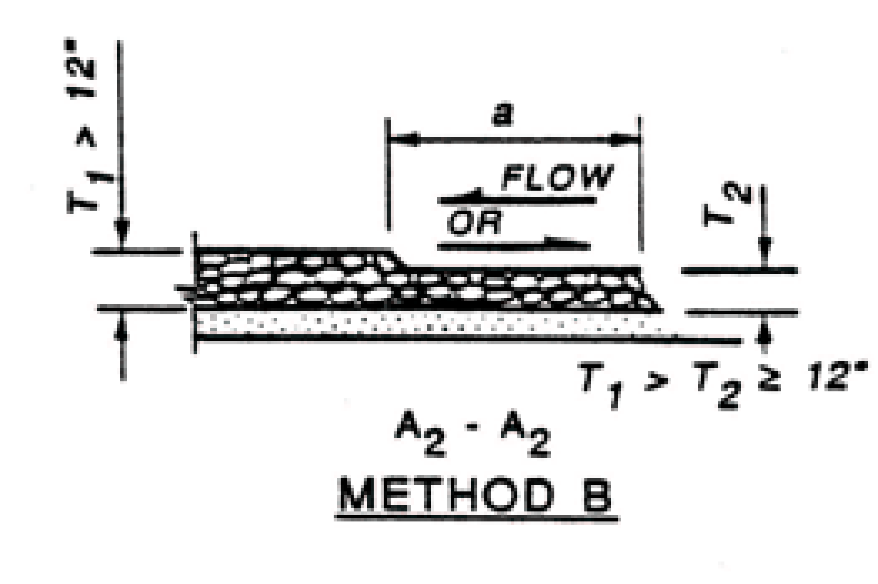
- Method A
  - For revetments 12 inch thick, or less extend to area of non-erodible velocity

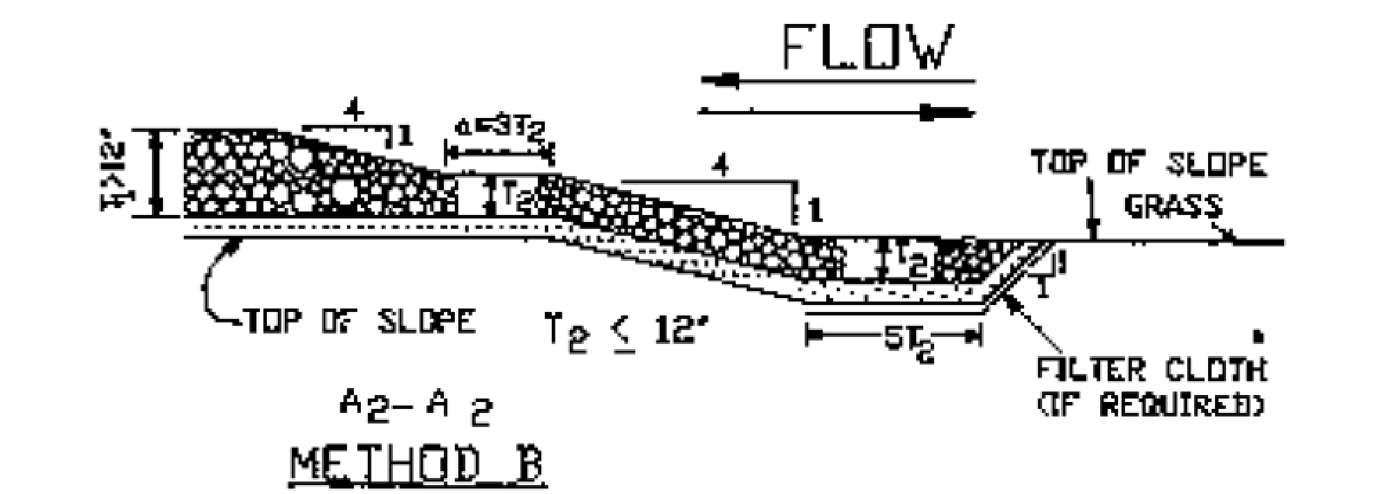




Revetment End Protection

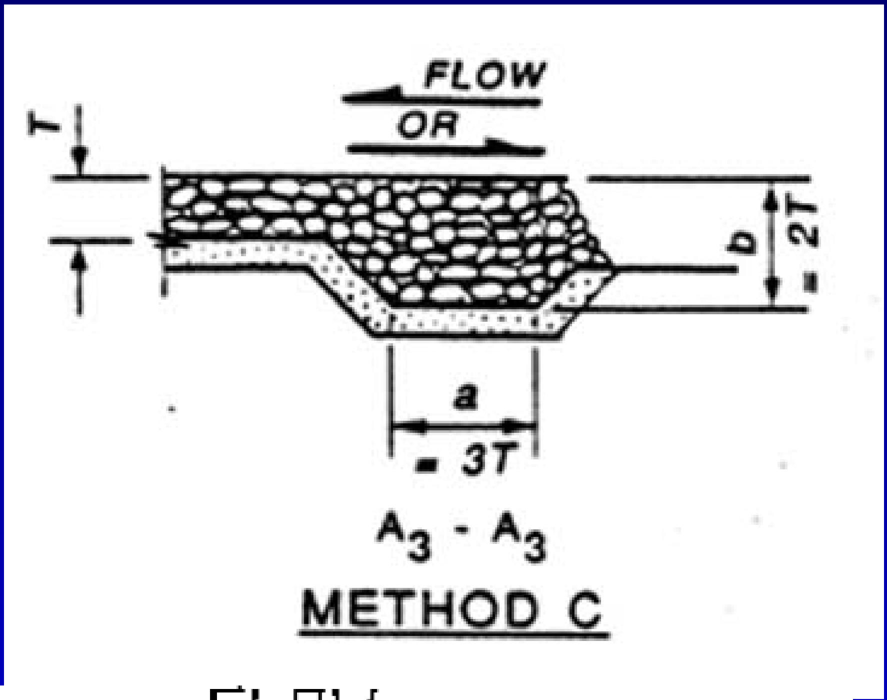
- Method B
  - > 12" thick, one or more reductions in stone size and thickness may be incorporated
  - Extend to a location of non-eroding velocity

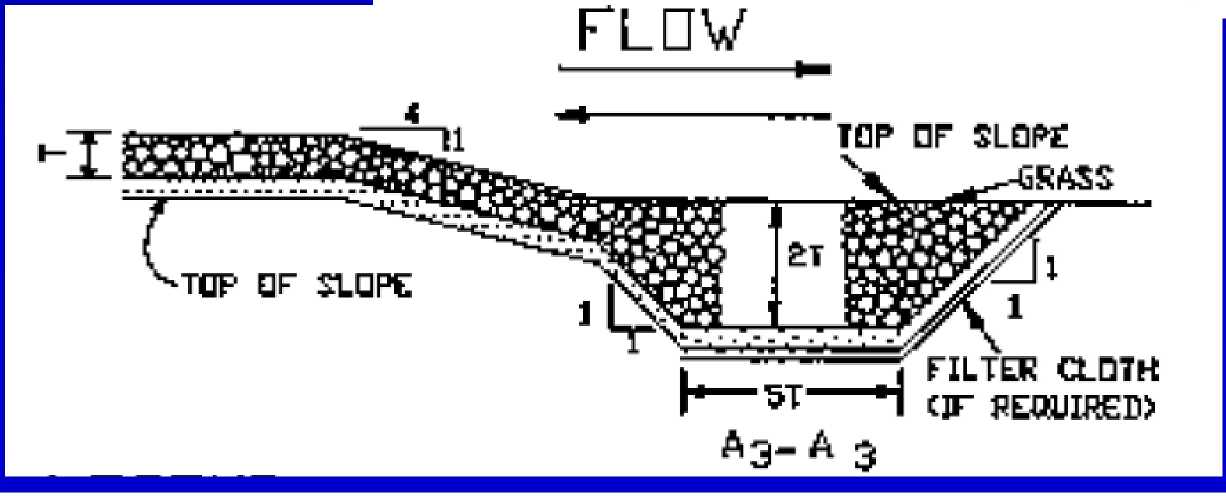




Revetment End Protection

- Method C
  - For revetments not terminating in non-eroding velocities
  - a = min of 3 times layer thickness
  - b = 2 times layer thickness





Length of Revetment

- Typically placed too far upstream and not far enough downstream of bends
- Should determine where flow crosses back across channel from site visit
- Rule of thumb
  - 1.5 channel widths downstream of bend

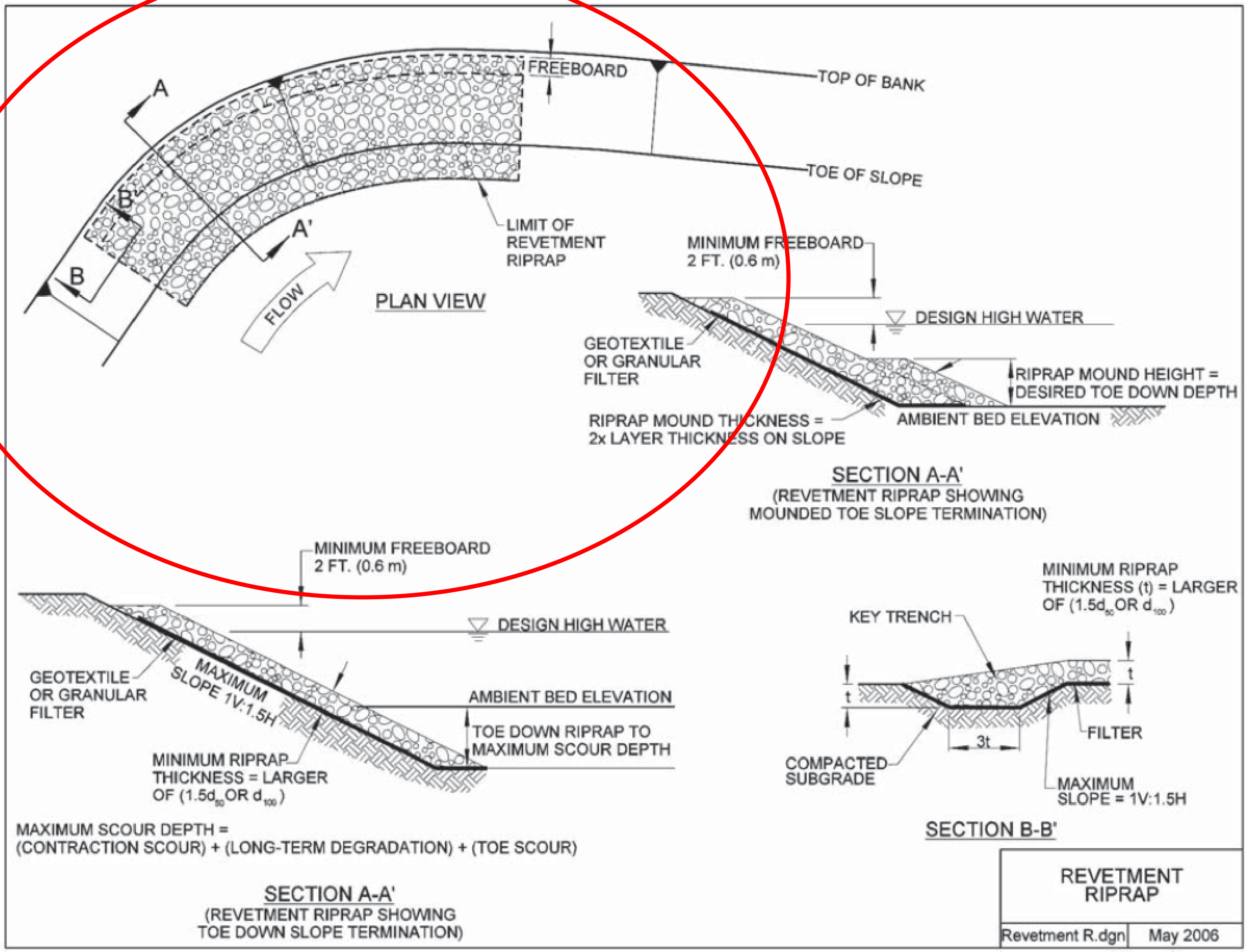


Figure C2.3. Revetment riprap details.

Riprap Protection

- Section 1 – Introduction to Riprap
- Section 2 – Channel Characteristics
- Section 3 – Design Guidance for Stone Size
- Section 4 – Revetment Toe Scour Estimation and Protection
- Section 5 – Ice, Debris and Vegetation
- Section 6 – Quality Control

Revetment Toe Scour Estimation and Protection

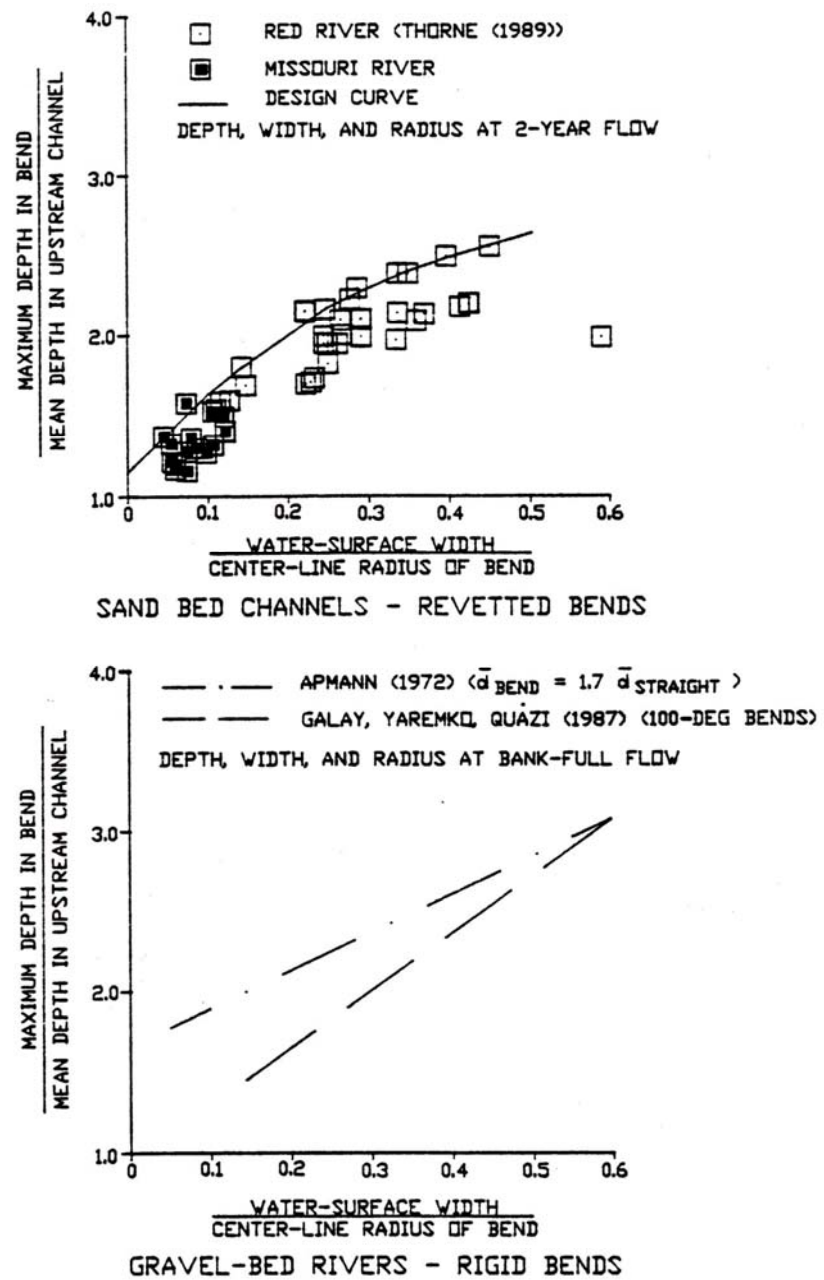
- Revetment Methods
- Revetment Design
- Delivery and Placement

Toe Scour Estimation and Protection

- Most frequent cause of revetment failure
- Result of several factors
  - Meandering channels
    - Change in section after bank is protected
    - Scour at high flows
  - Braided channels
    - Scour at intermediate flows due to angle of attack

Toe Scour Estimation and Protection

- Need to account for both components of scour
  - Local scour
  - Degradation
- Plate 42



SCOUR DEPTH IN BENDS

Plate 42

Toe Protection Methods

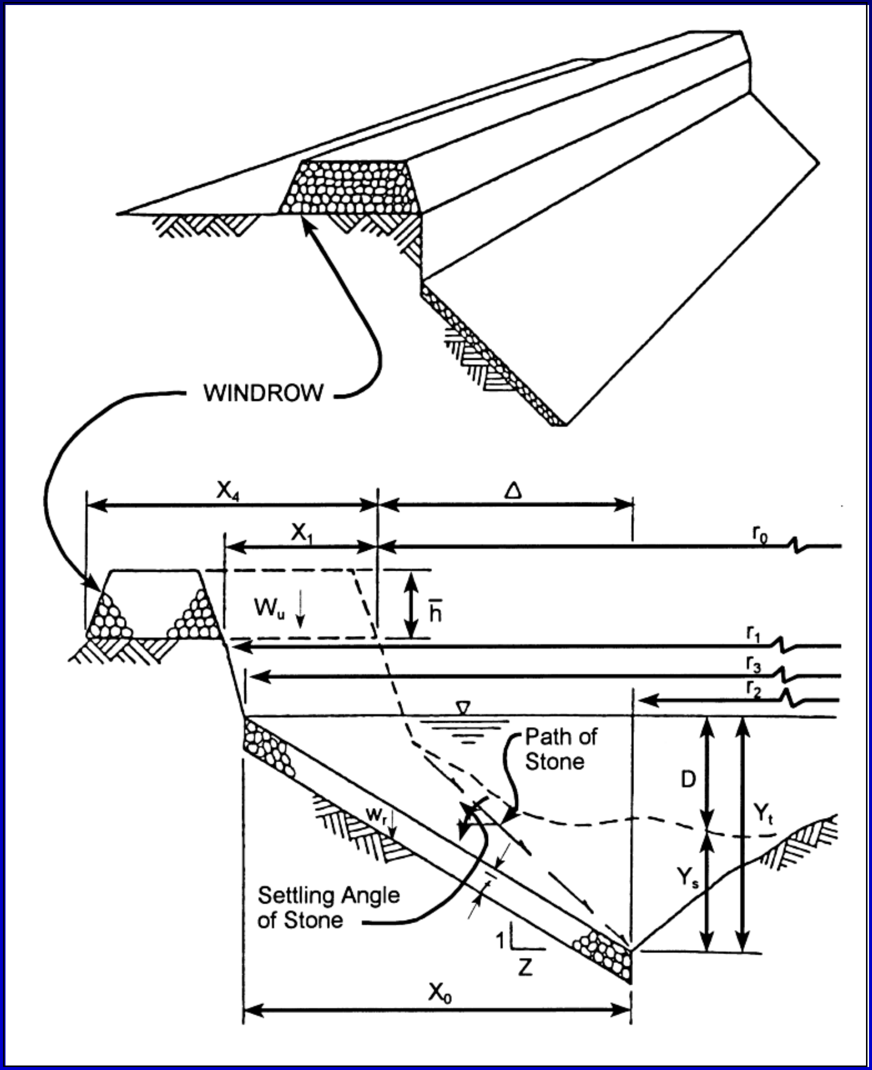
- Two methods to provide protection
  - Extend protection to maximum scour depth
    - Preferred method
    - Can utilize bedrock
    - Can be difficult and/or expensive for underwater placement
    - Must be able to accurately determine scour depth

Toe Protection Methods

- Two methods to provide protection
  - Launchable stone
    - Used extensively on sand bed streams
    - Stone placed longitudinally above the expected scour area
    - As scour progresses, stone slides into scour hole and halts progression
    - Three main types

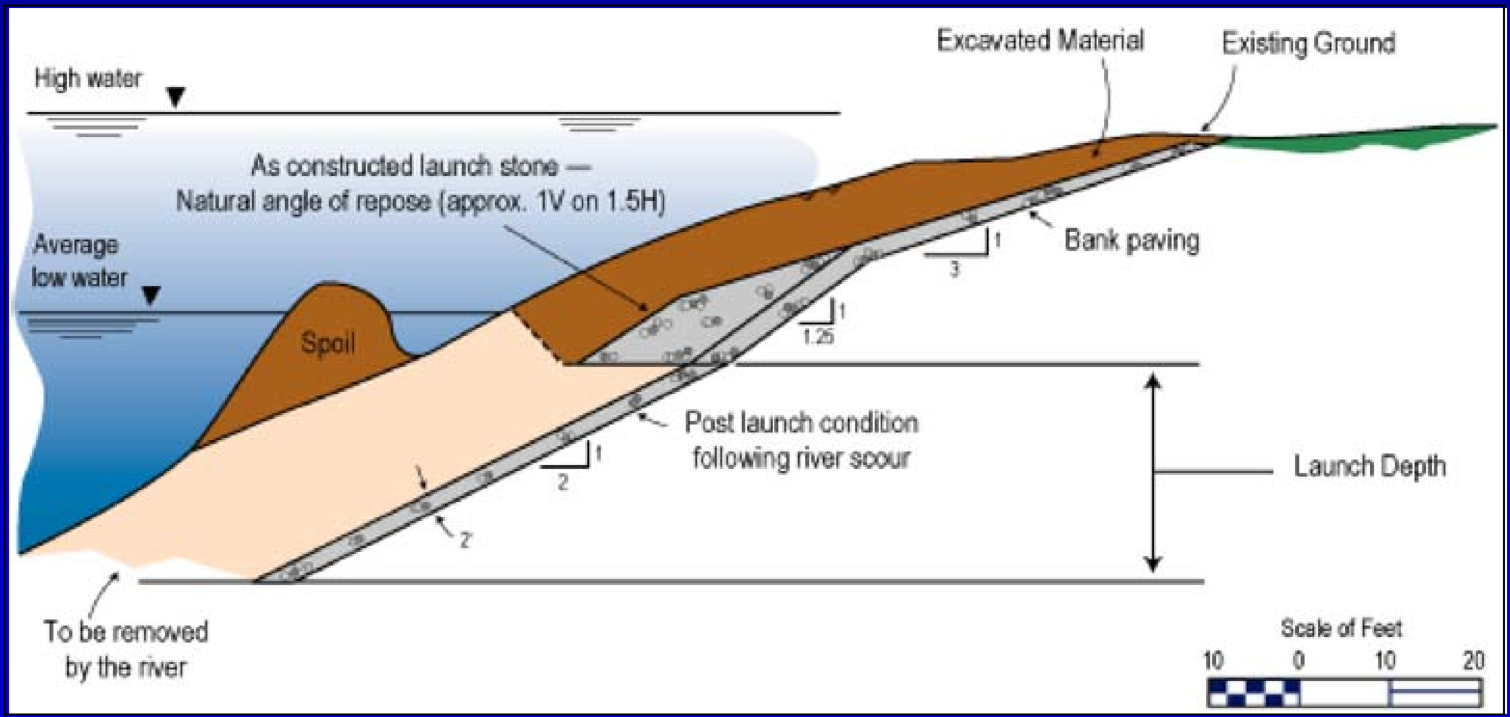
Toe Protection Methods

- Launchable stone
  - Windrow revetments



Toe Protection Methods

- Launchable stone
  - Trench-fill revetments

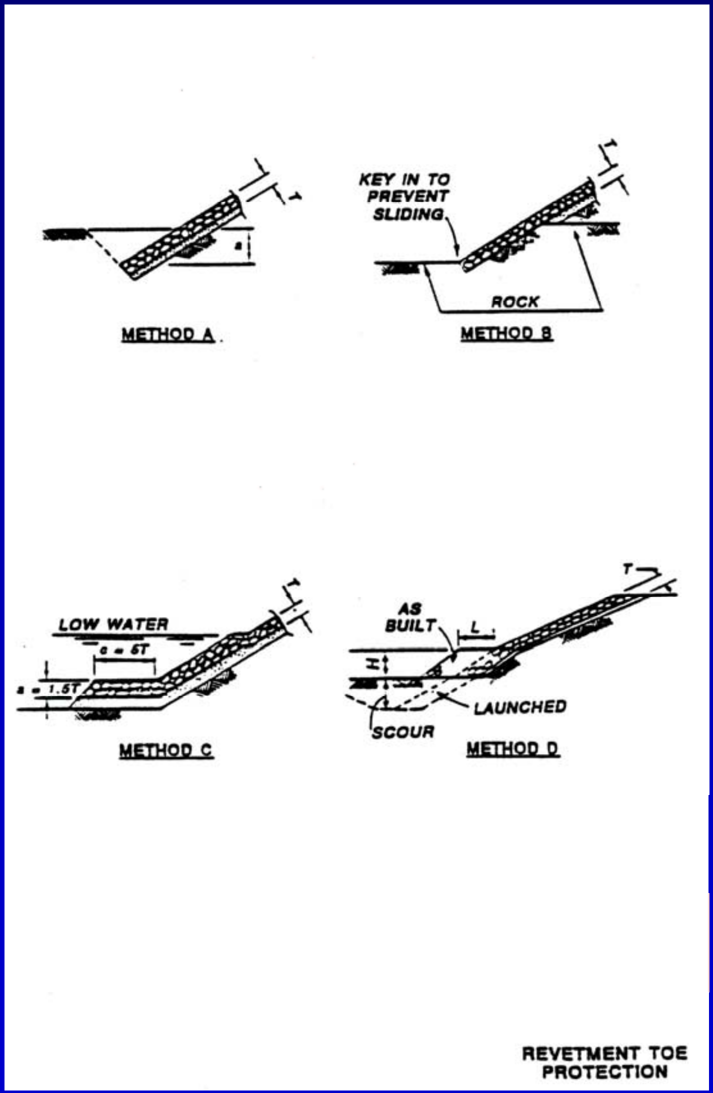


Toe Protection Methods

- Launchable stone
  - Weighted riprap toes

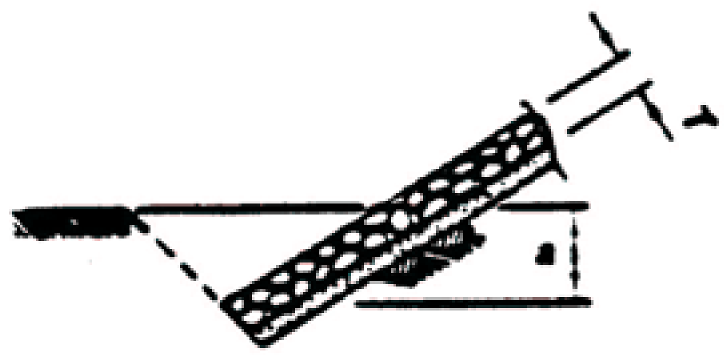
Toe Protection Design

- Plate 43 gives guidance for 4 of the most common approaches



Toe Protection Design

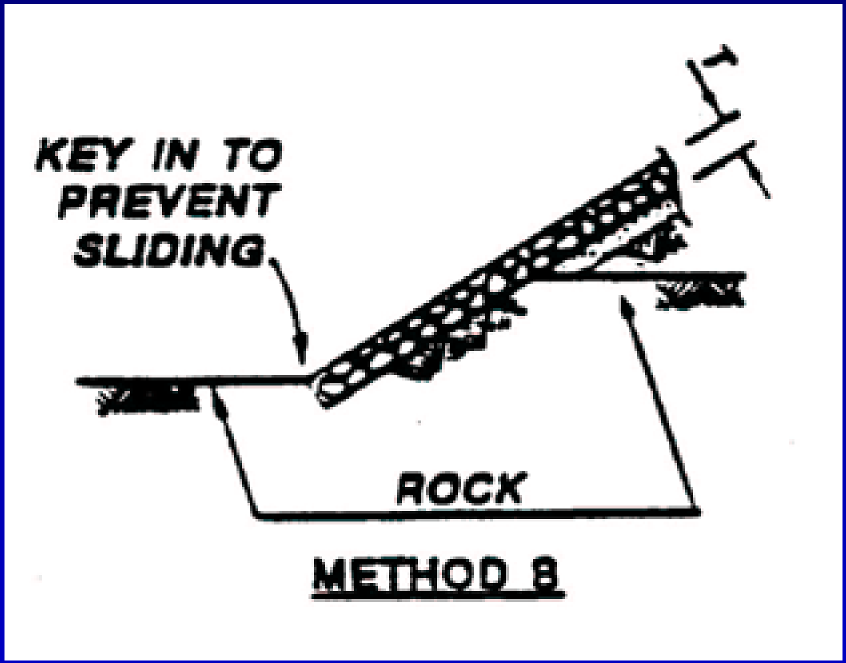
- Method A
  - Excavation in the dry
  - Extend riprap layer below existing invert a distance greater than the anticipated depth of scour



METHOD A

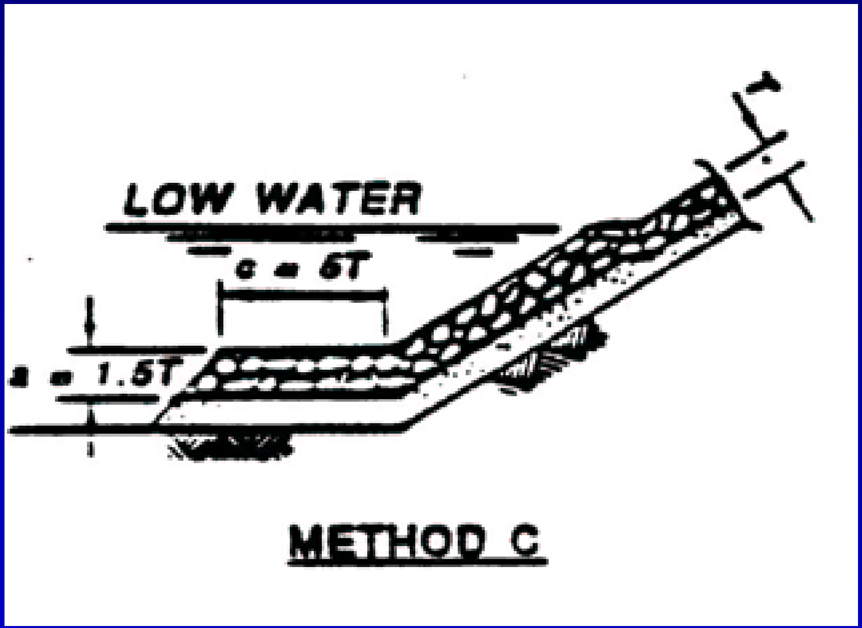
Toe Protection Design

- Method B
  - If channel bottom is nonerodible, riprap is keyed in at streambed level



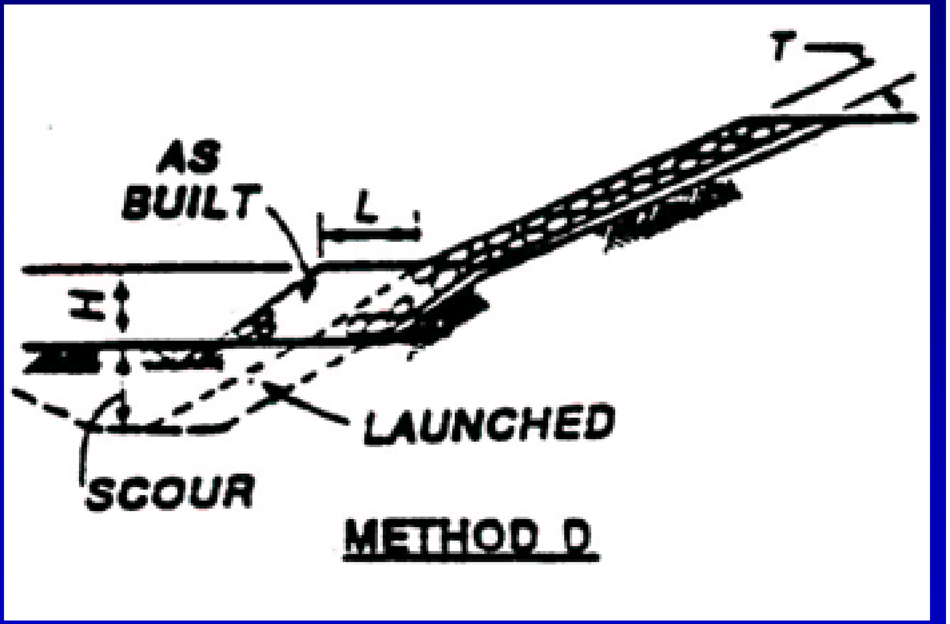
Toe Protection Design

- Method C
  - Underwater placement
  - Little or no toe scour
  - Extend rock across bottom of channel a height “a” and length “c”
  - a = 1.5 times layer thickness
  - c = 5 times layer thickness



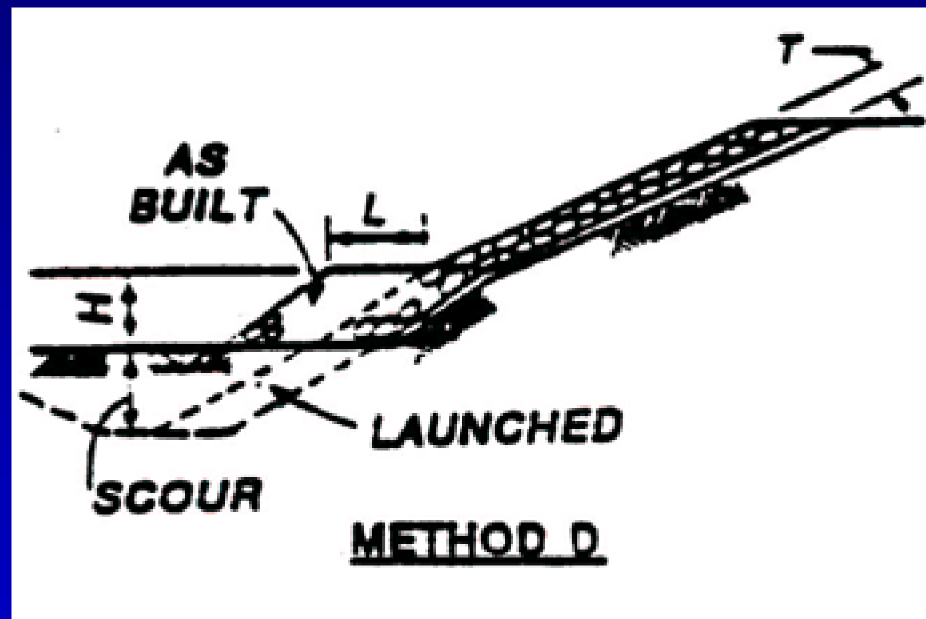
Toe Protection Design

- Method D
  - Used when water levels prohibit toe excavation or stone is less expensive than excavation
  - Useful technique for emergency protection
  - Launched thickness should be 1.5 times the thickness (1.75 for underwater and long launch distance)



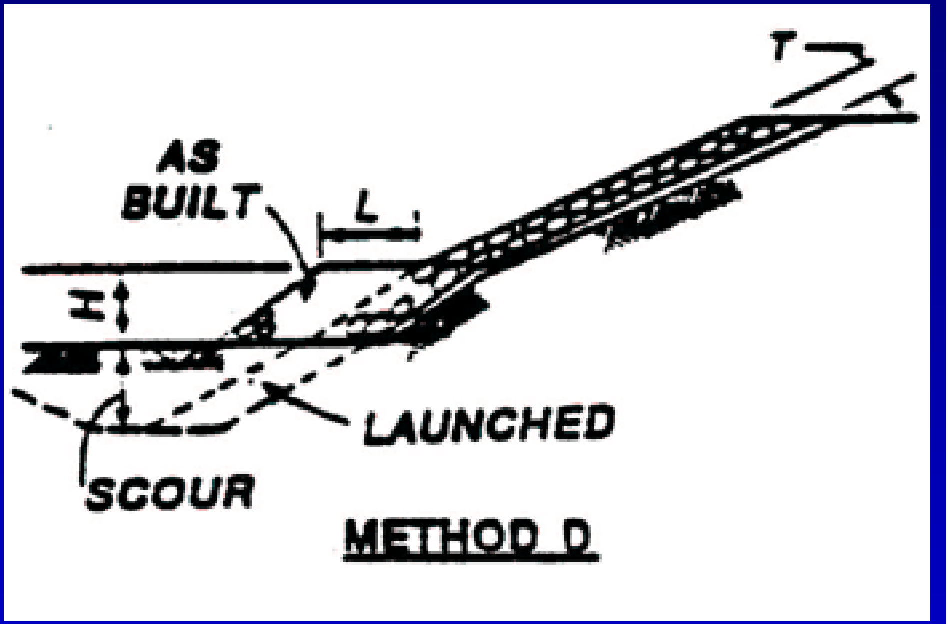
Toe Protection Design

- Method D
  - For gradual scour the height should be 2.5-4.0 times the thickness T
  - For rapid scour the stone height should be 2.5-3.0 T
  - D85/D15 ≥ 2



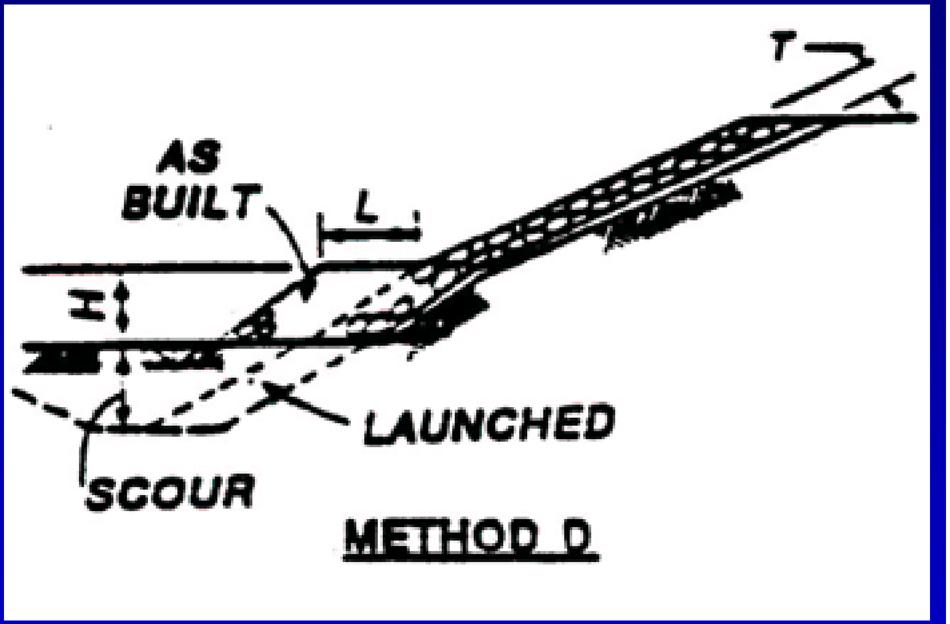
Toe Protection Design

- Method D
  - Proper volume of stone is crucial to success
  - Assume
    - Launch slope = 2:1
    - Maximum scour depth
    - Thickness after launching is 1.5 times bank layer thickness



Toe Protection Design

- Method D
  - Incorporating these assumptions and solving for the volume of rock gives:



Volume = 1.5*T*launch slope length (<15 ft)

Volume = 1.5*T*scour depth*$\sqrt{5}$

Volume = 3.35*T*scour depth

Toe Protection Design

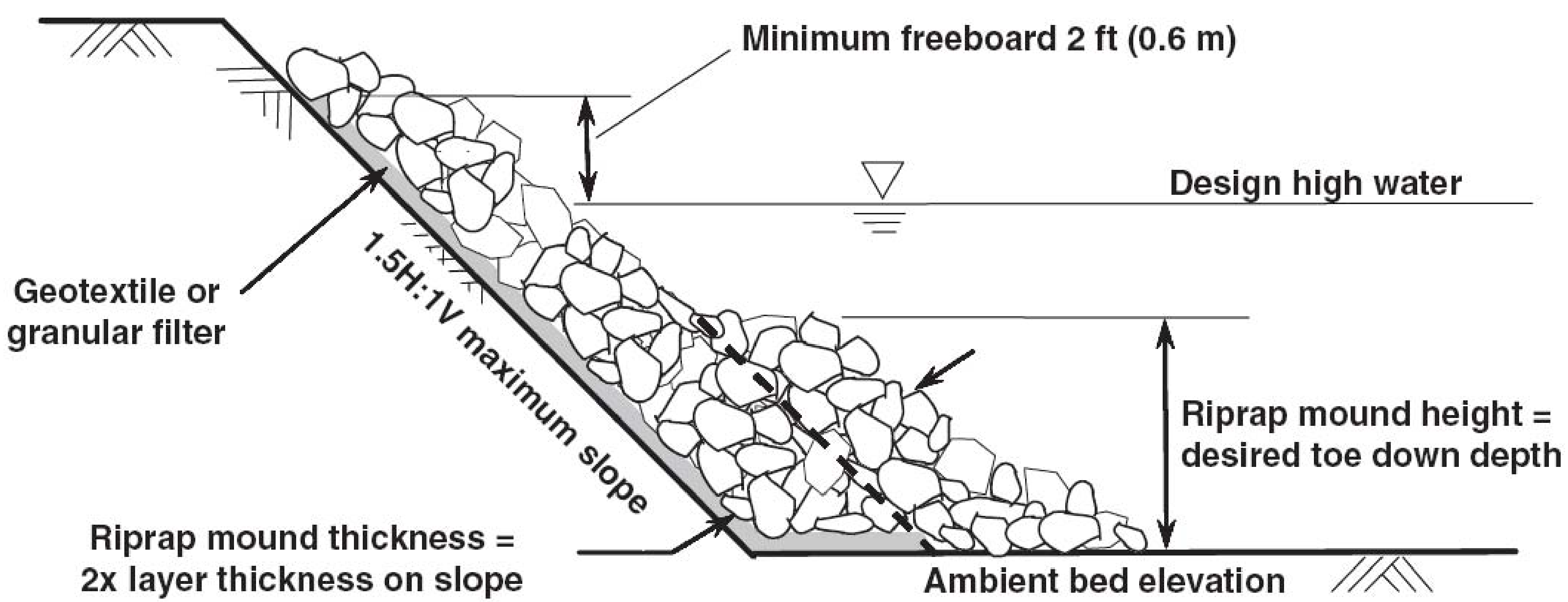


Figure C2.2. Revetment riprap with mounded toe.

Summary

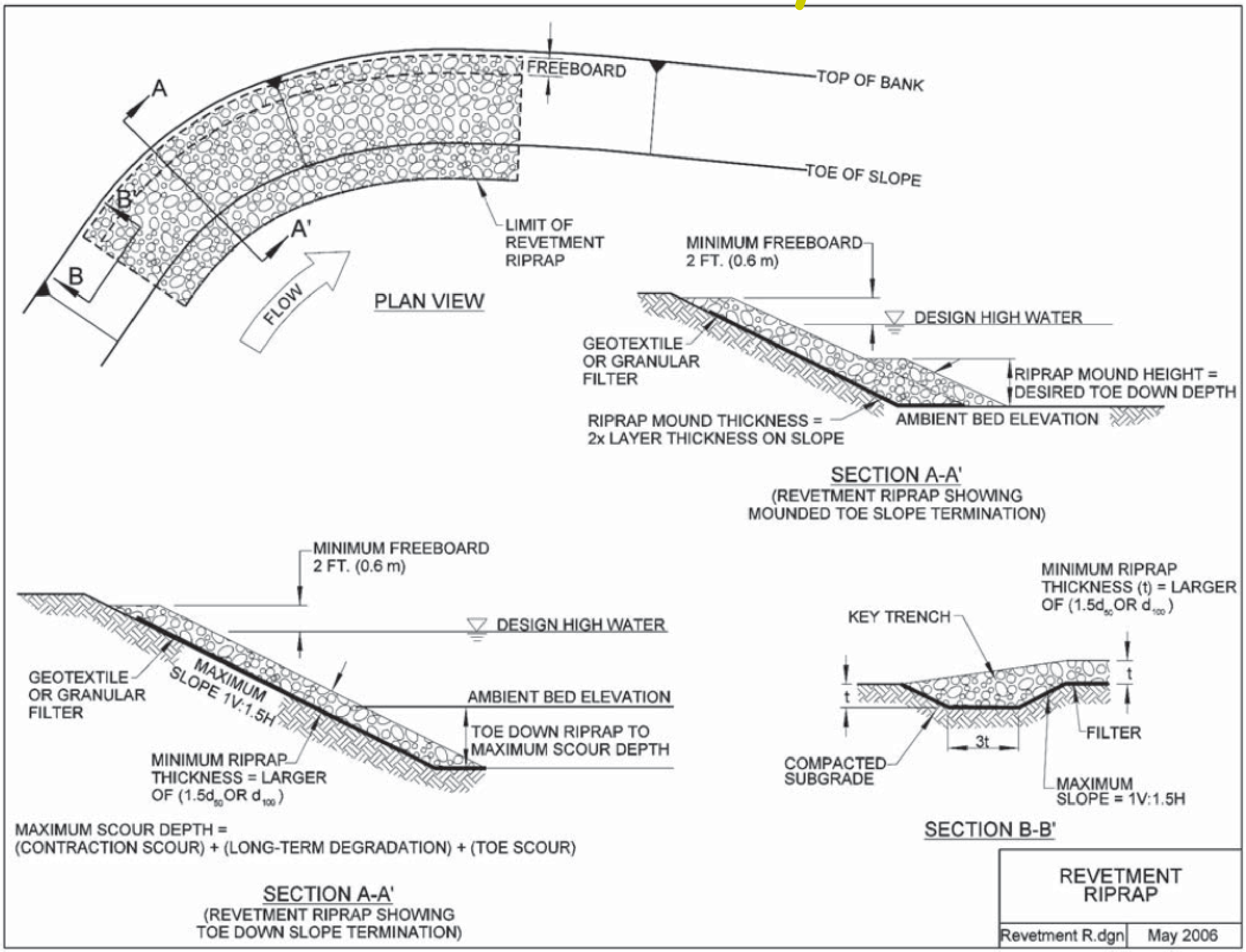
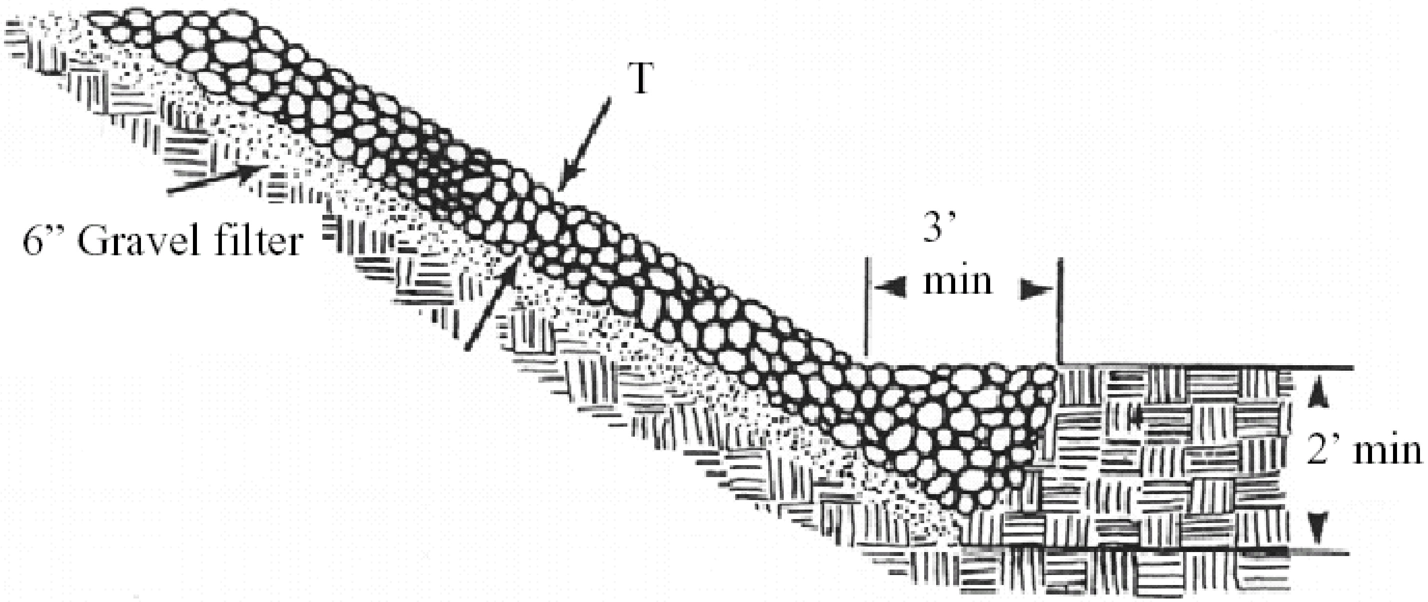


Figure C2.3. Revetment riprap details.

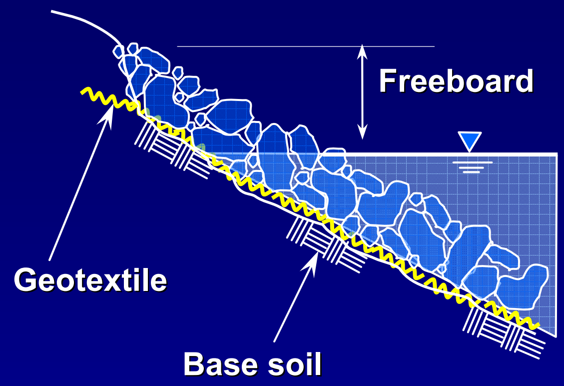
Filter Design

Granular filter beneath riprap

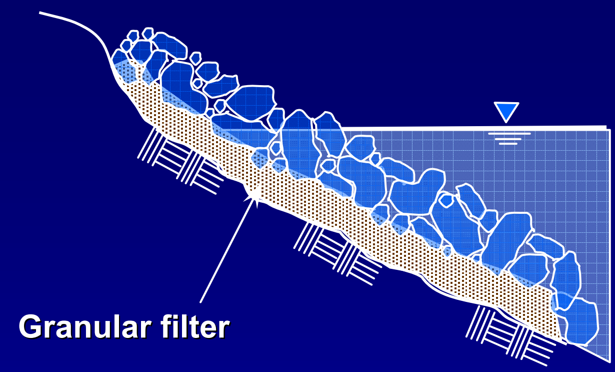
Typical Riprap Slope Protection Detail



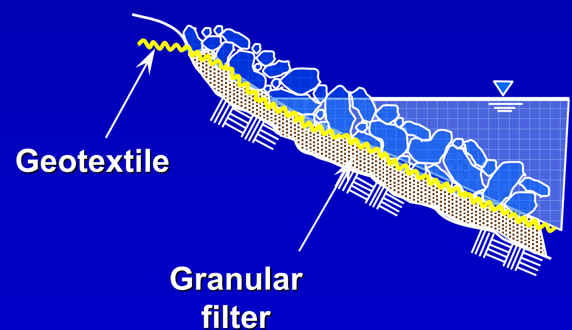
Geotextile beneath armor layer



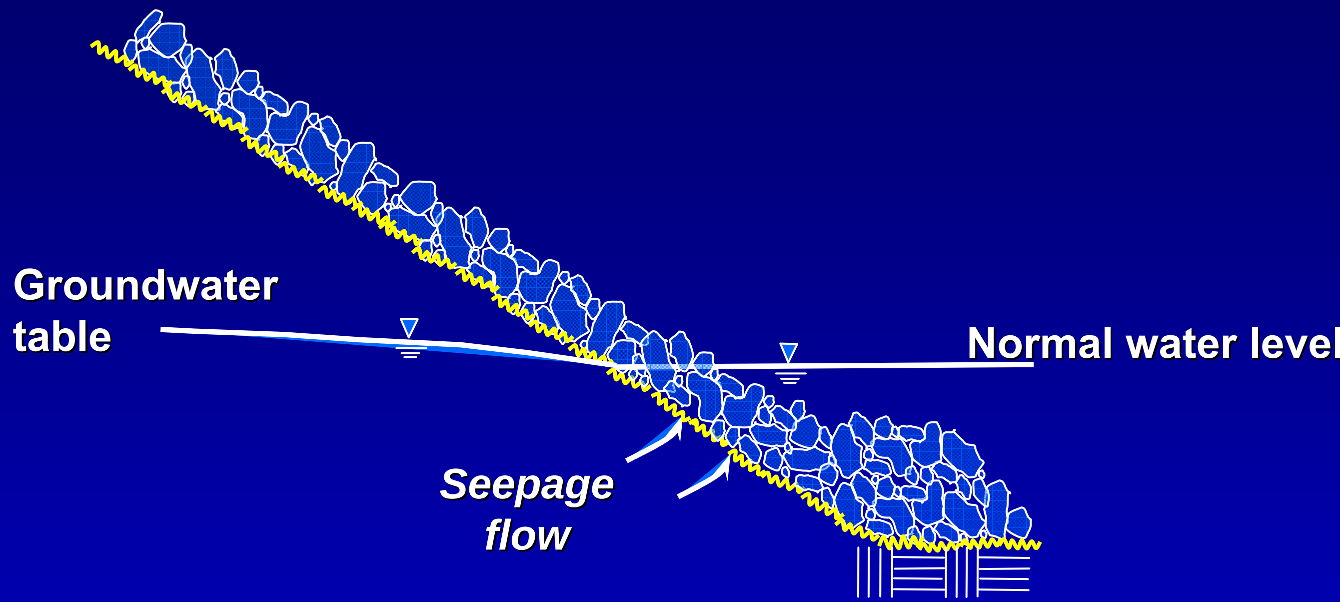
a) Geotextile filter



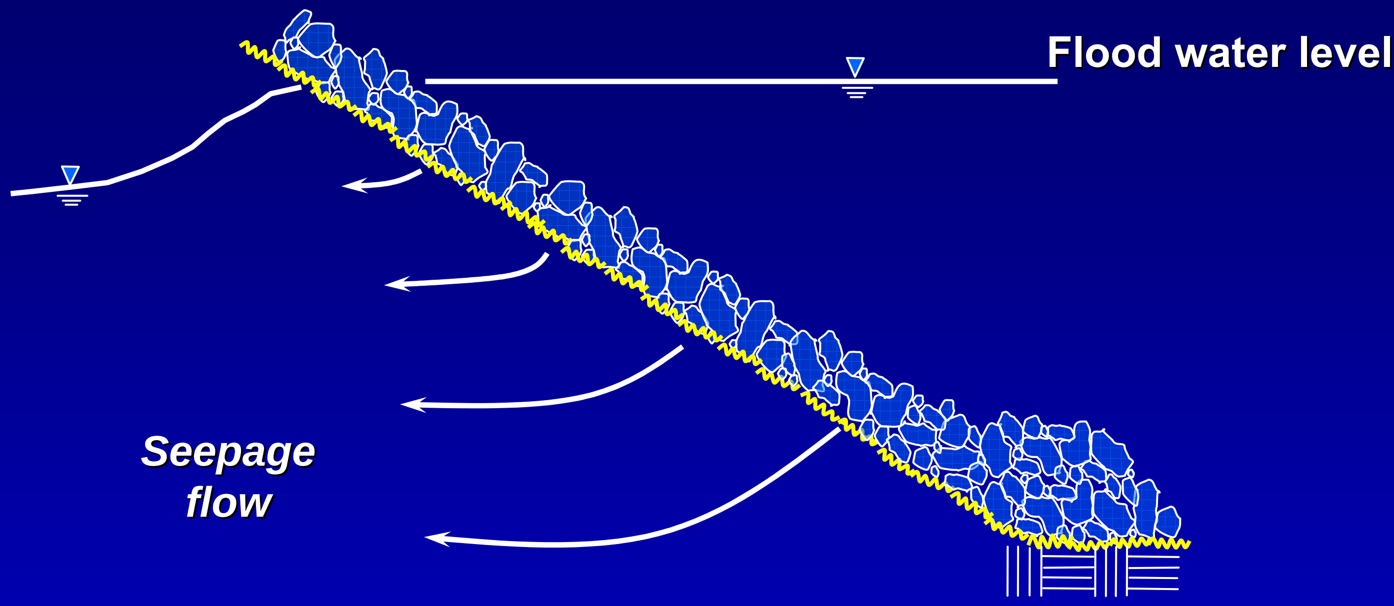
b) Granular filter



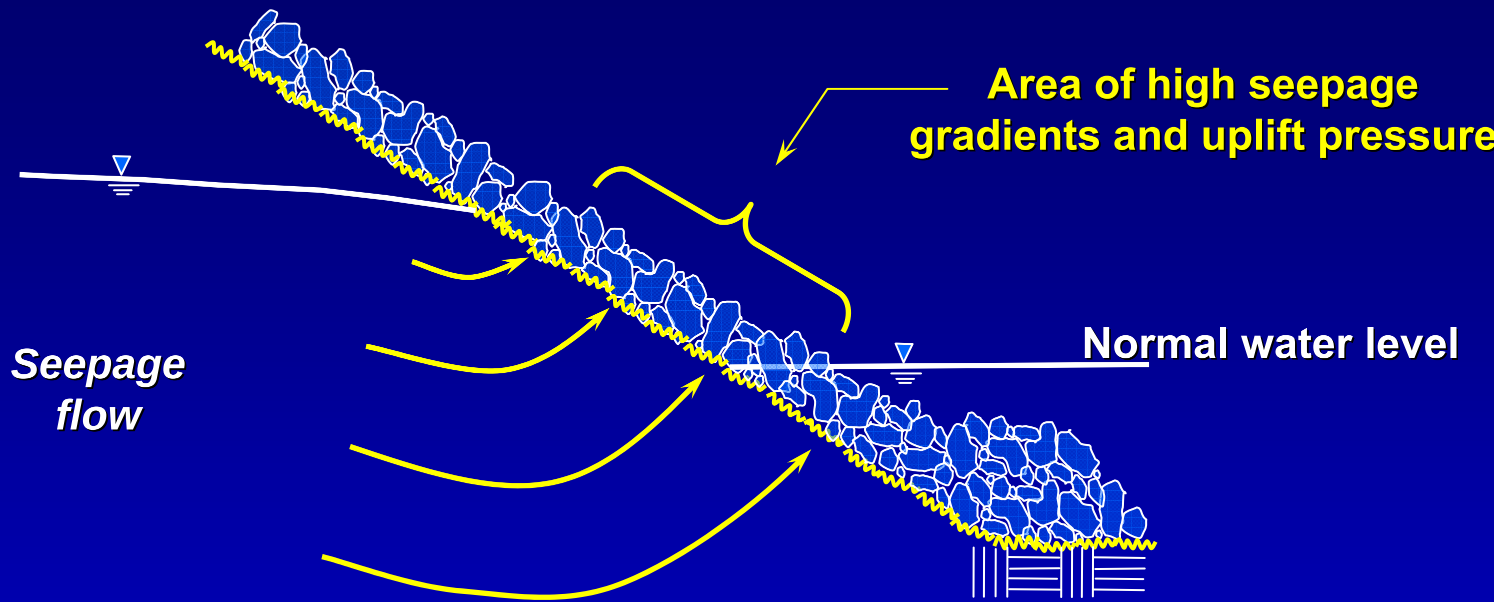
c) Granular transition layer with geotextile (composite filter)



a) Normal (baseflow) conditions



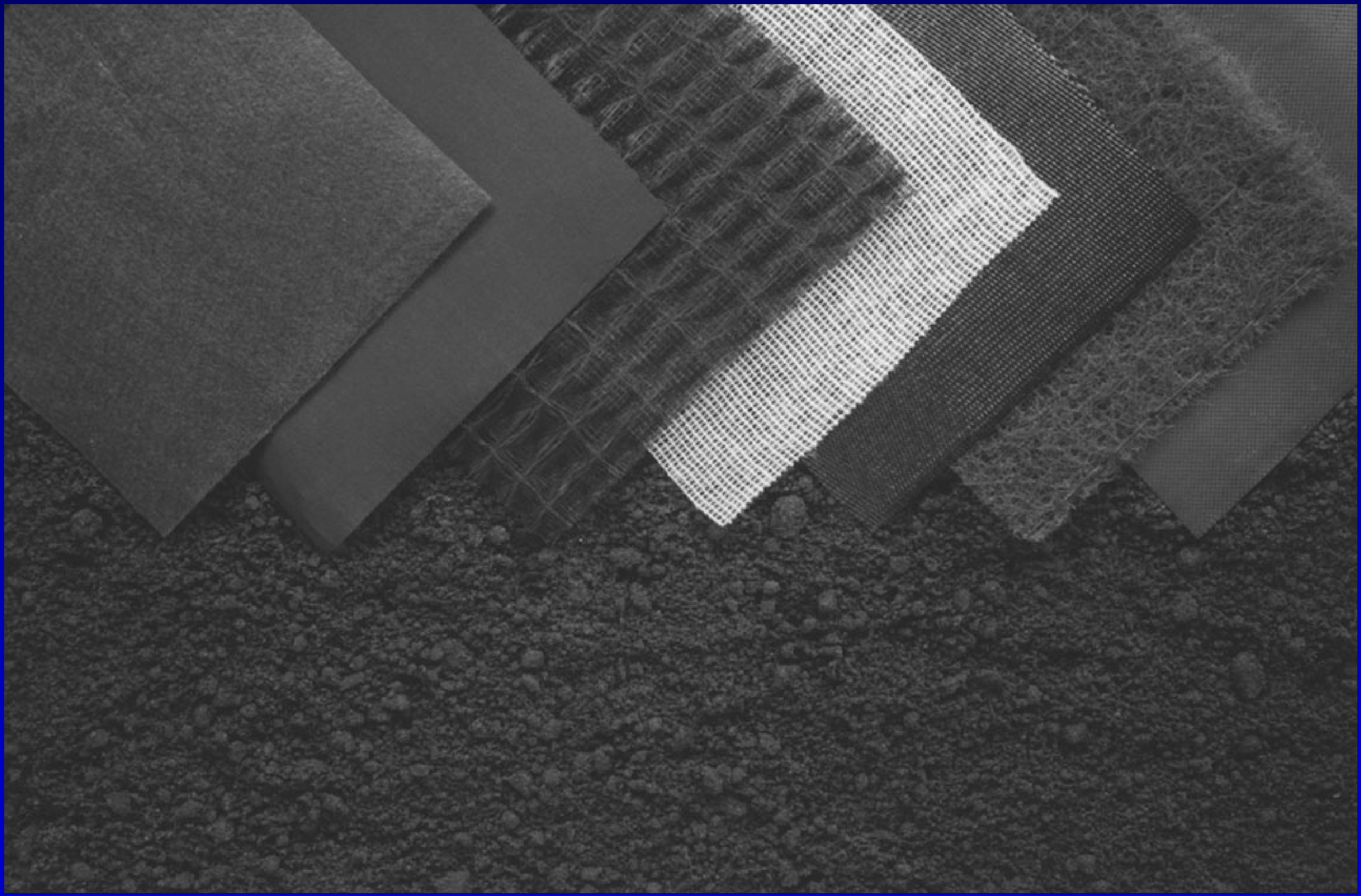
b) During flood peak



c) After flood recession

Types of Geosynthetics

- Geotextiles
- Geogrids
- Geomembranes
- Geosynthetic Clay Liners
- Rolled Erosion Control Products
- Geonets/Drainage Composites
- Geofoam, Geotextile Tubes and Soil Fibers



OK for filters under armor layer:

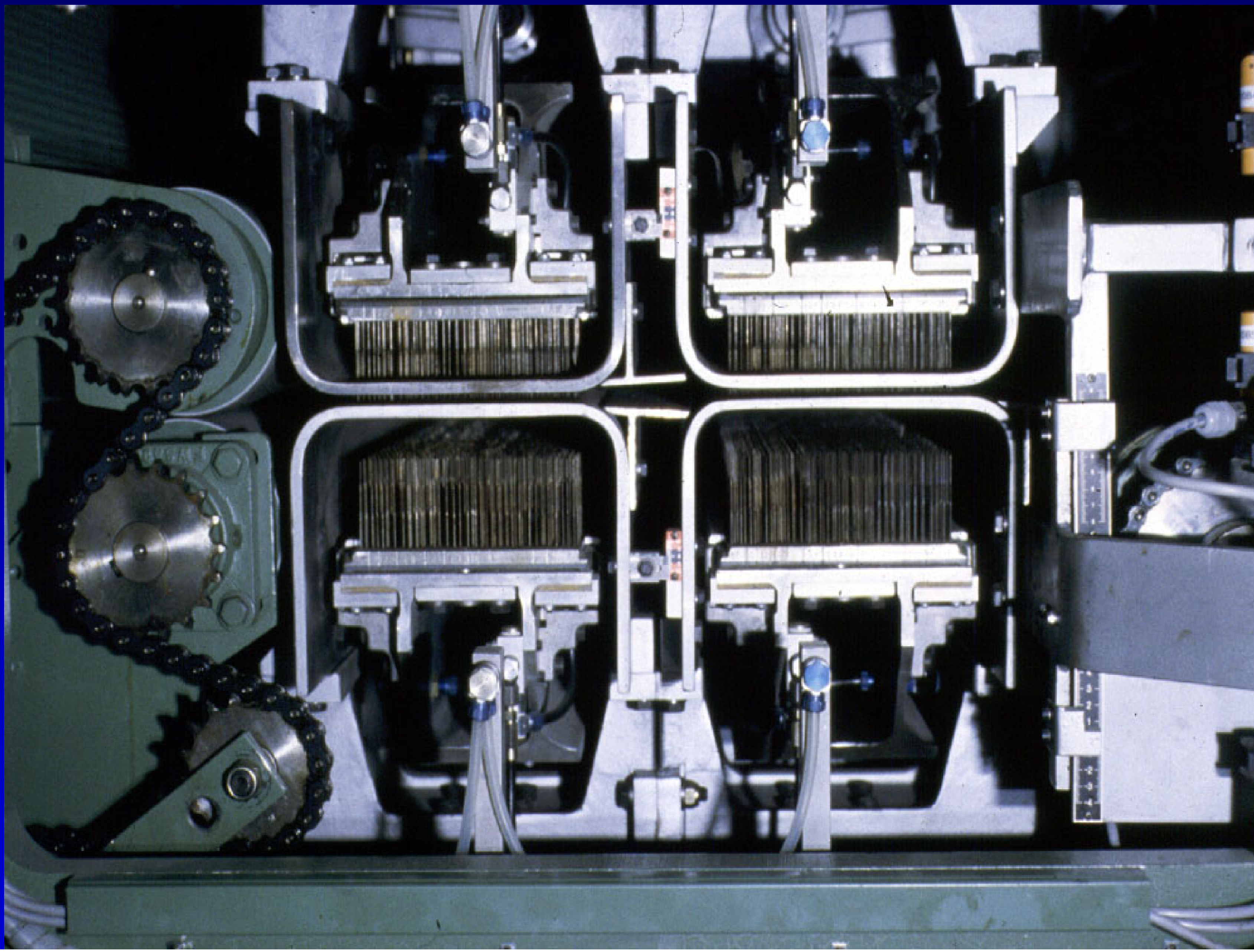
- Woven monofilament fabric
- Non-woven needle punched fabric

Not OK:

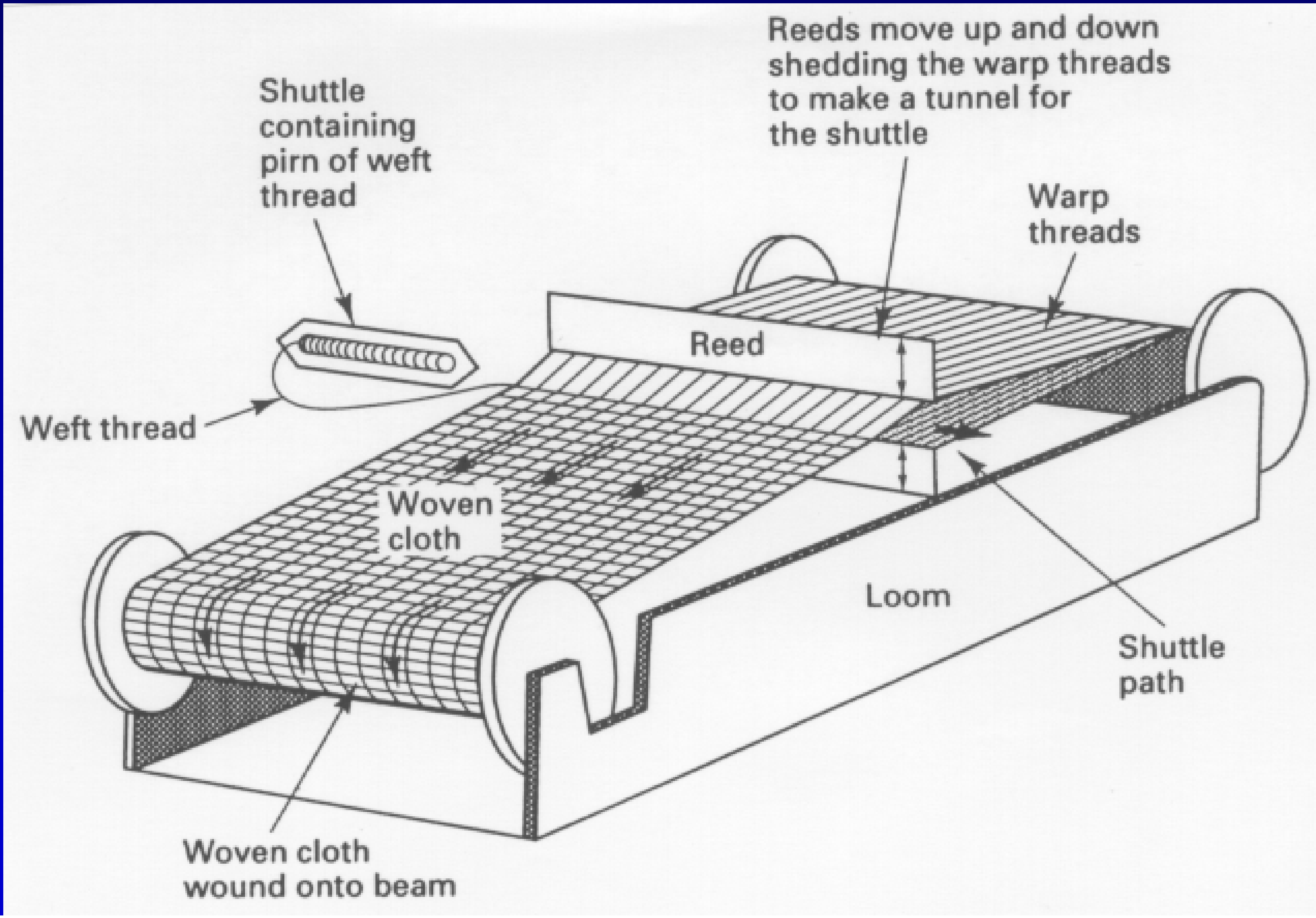
- Slit film fabrics (e.g., silt fence)
- Spun-bonded fabrics

Non-woven needle punched

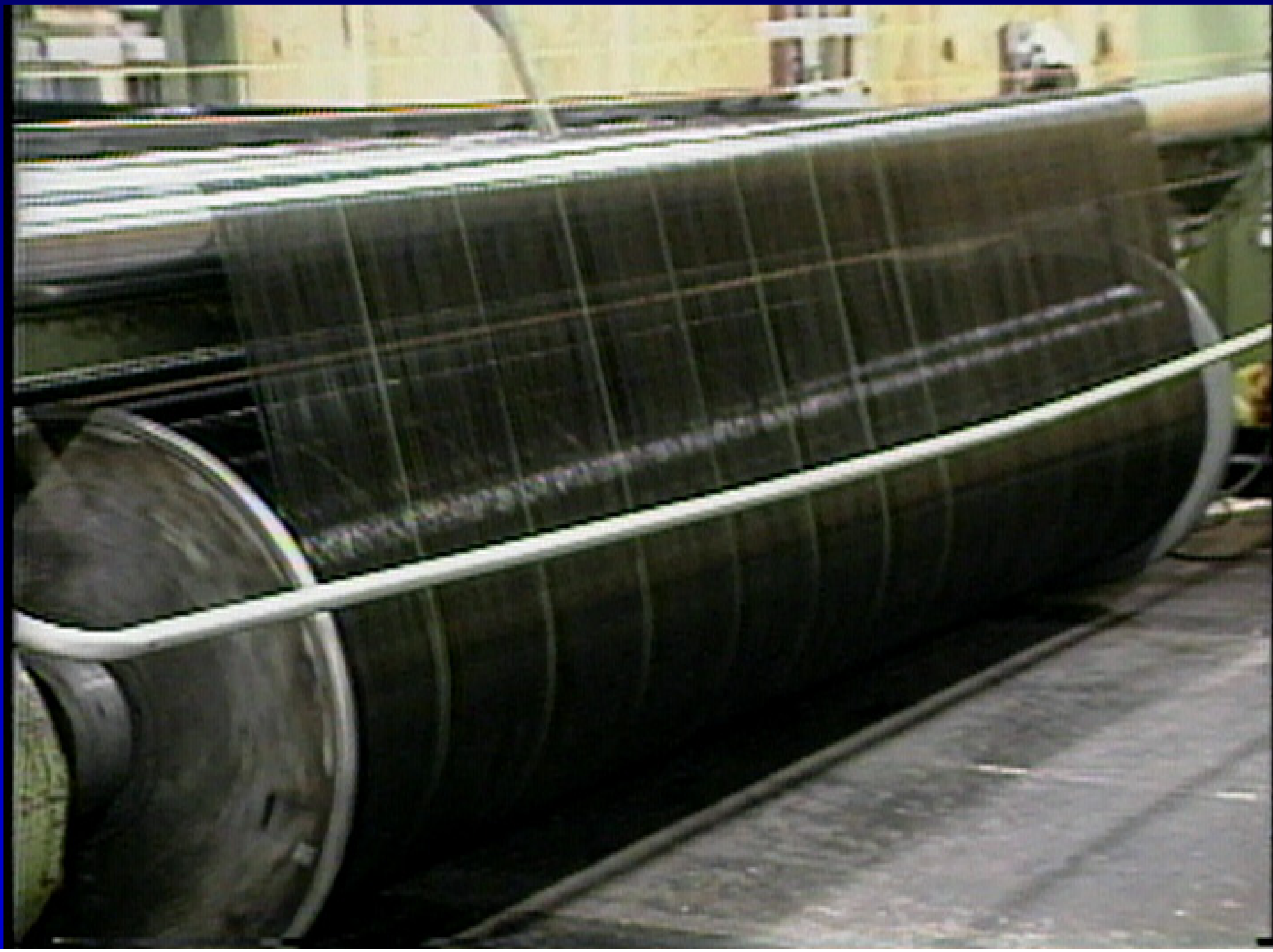
Non-woven needle punched



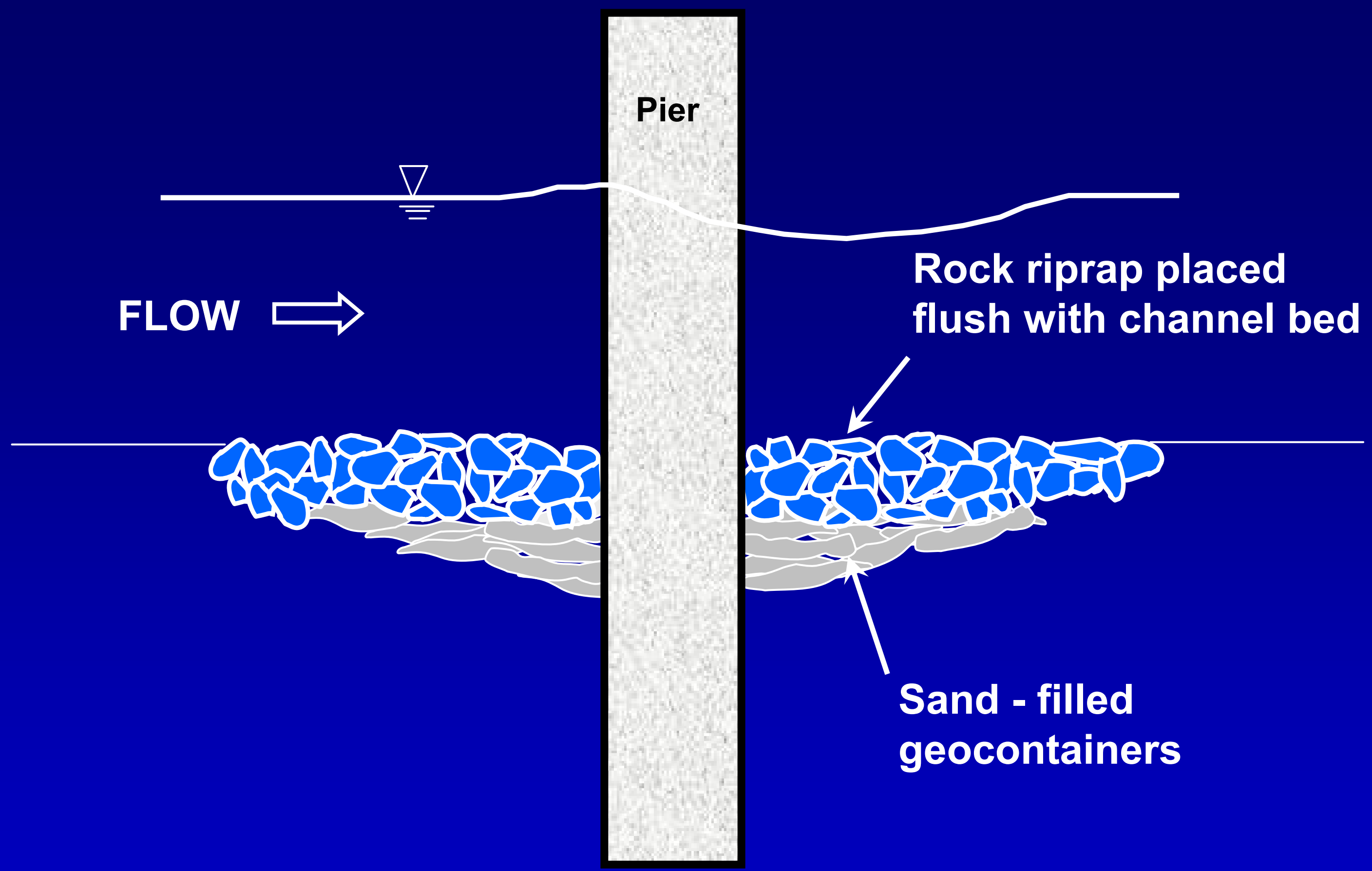
Woven monofilament



Woven monofilament



Placement under water



Minimum riprap thickness $t = 3d_{50}$, depth of contraction scour, or depth of bedform trough, whichever is greatest

Filter placement = 4/3(a) from pier (all around)

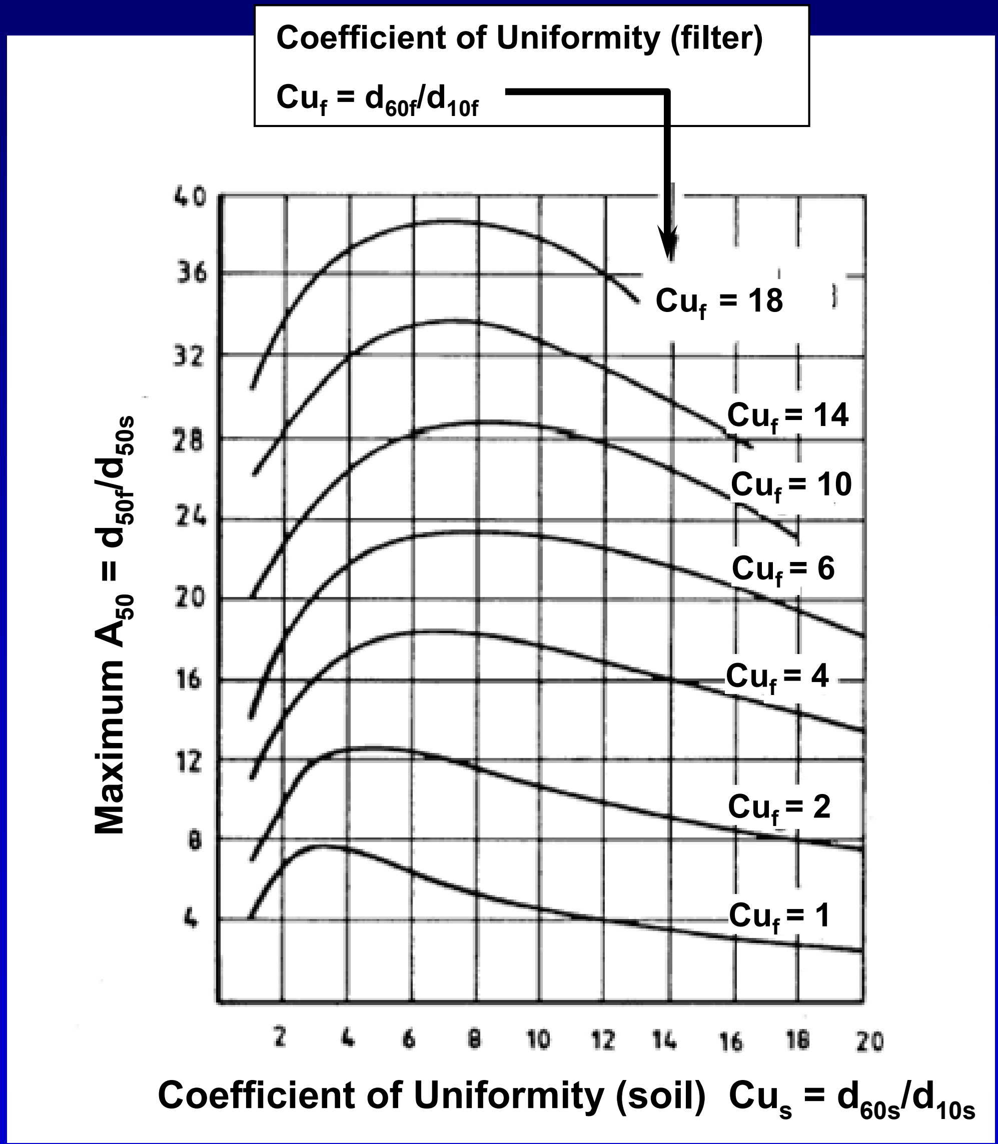
Granular Filter Design

$$\frac{D_{50}(\text{filter})}{D_{50}(\text{base})} < 40 \quad \text{and} \quad \frac{D_{50}(\text{riprap})}{D_{50}(\text{filter})} < 40$$

$$5 < \frac{D_{15}(\text{filter})}{D_{15}(\text{base})} < 40 \quad \text{and} \quad 5 < \frac{D_{15}(\text{riprap})}{D_{15}(\text{filter})} < 40$$

$$\frac{D_{15}(\text{filter})}{D_{85}(\text{base})} < 5 \quad \text{and} \quad \frac{D_{15}(\text{riprap})}{D_{85}(\text{filter})} < 5$$

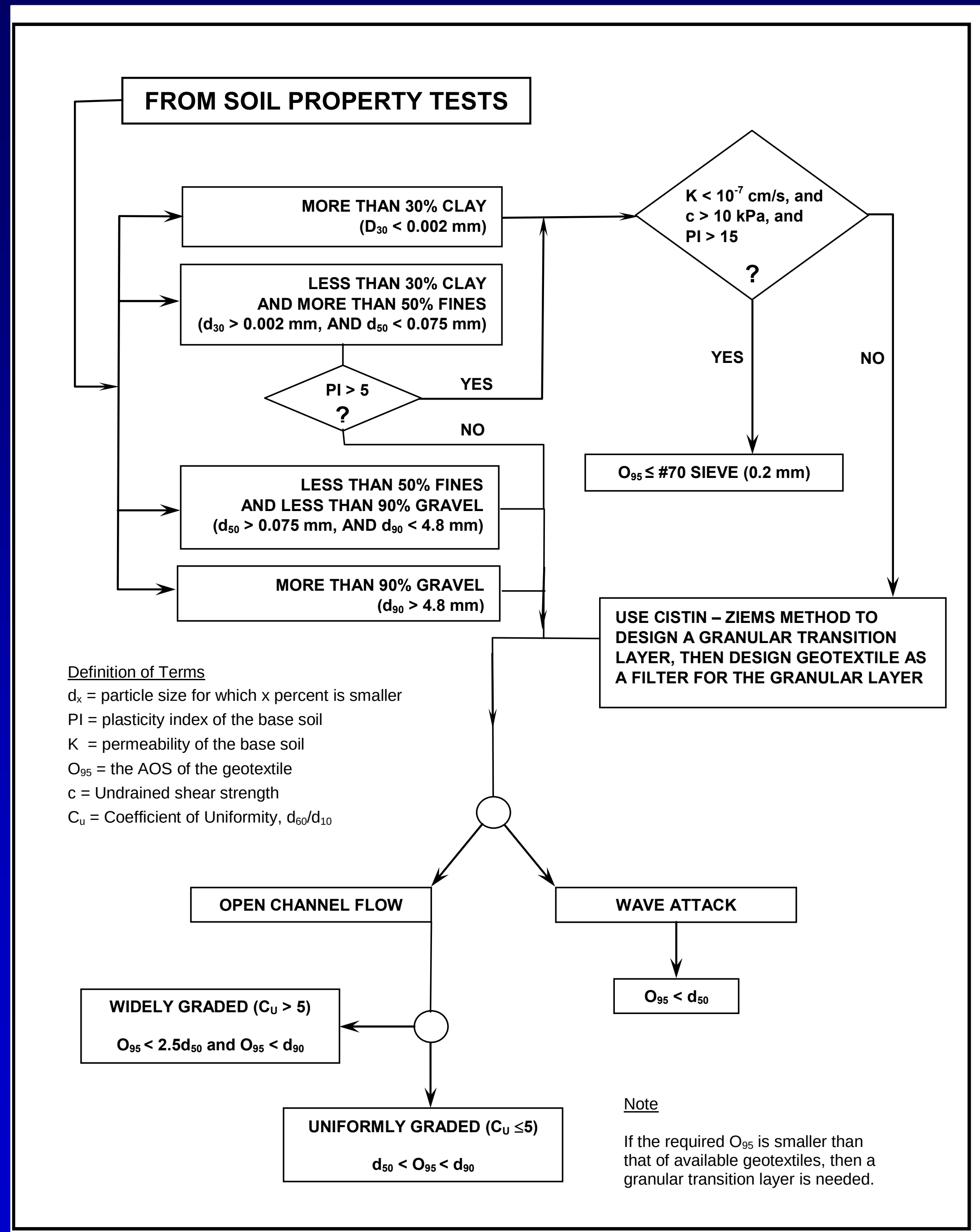
Granular filter design



IMPORTANT GEOTEXTILE PROPERTIES:

Permeability, Apparent Opening Size (AOS), Clogging potential

Geotextile filter design



Delivery and Placement

- Placement method can affect required layer thickness and total volume of rock required
  - Hand placed
    - Can incorporate steeper slopes and therefore less rock
  - Machine placed
    - Stone can be broken and therefore layer thickness may need to be increased

Ice and Debris

- Create greater stresses due to impact and flow concentration
- Ice effects..
  - Cold Regions Research Engineering Laboratory, Hanover, NH
- Debris..
  - Increase thickness, and therefore stone size, by 6-12 inches
  - Side slopes no steeper than 2:1

Quality Control

- Sampling and testing of in-place riprap should be conducted
- Deterioration can be caused by:
  - Loading
  - Transportation
  - Stockpiling
  - Placing
- EM 1110-2-2302, Construction with Large Stone, provides sampling guidance for in-place riprap

Quality Control

Test	Criteria for Evaluating Suitability
Petrography	Interlocking crystalline, no clay or soluble minerals
Unit Weight	Dry unit weight > 160 pcf
Absorption	Less than 1 %
Sulfate Soundness	Less than 5% loss
Glycol Soundness	No deterioration except for minor crumbs from surface
Abrasion	< 20% loss after 500 revolutions
Freeze-Thaw	< 10% loss after 12 cycles
Wetting-Drying	No major progressive cracking
Field Visual	Distinctions based on color and/or size
Field Index	Distinction based on scratch, ring and other characteristics
Drop Test	No breakage or cracking
Set Aside	No breakage or cracking after on season cycle

CECW-EH-D Engineer Manual 1110-2-1601	Department of the Army U.S. Army Corps of Engineers Washington, DC 20314-1000	EM 1110-2-1601 1 July 1991/ 30 June 1994
	Engineering and Design HYDRAULIC DESIGN OF FLOOD CONTROL CHANNELS	

Chapter 4

Special Features and Considerations