ARMORING

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OVERVIEW

Types of Armoring

Natural Armoring

Riprap Design

Bank Armoring Failure Mechanisms

Survey Methods

(Photo from Merrick)

(Photo from Ayres)

PURPOSE OF ARMORING

- Stabilization of Channel Bank and Bed
  - Shear stress and velocity from river flows cause degradation/scour along the channel cross-section.
  - Armoring, whether naturally formed or engineered, protects the streambanks and bed from scour by being large enough in size to resist incipient motion.
  - Armoring also protects infrastructure such as bridge piers and roads from undermining due to bank failure.
- Habitat
  - Armoring along the beds can create spawning grounds for fish to lay eggs.
  - Armoring along the banks can create habitats for small fish, macroinvertebrates, etc.

TYPES OF ARMORING

- Natural Channel Armoring
- Engineered Bank/Bed Armoring
  - Rigid
  - Flexible
  - Biotechnical
  - Grade Control Structures

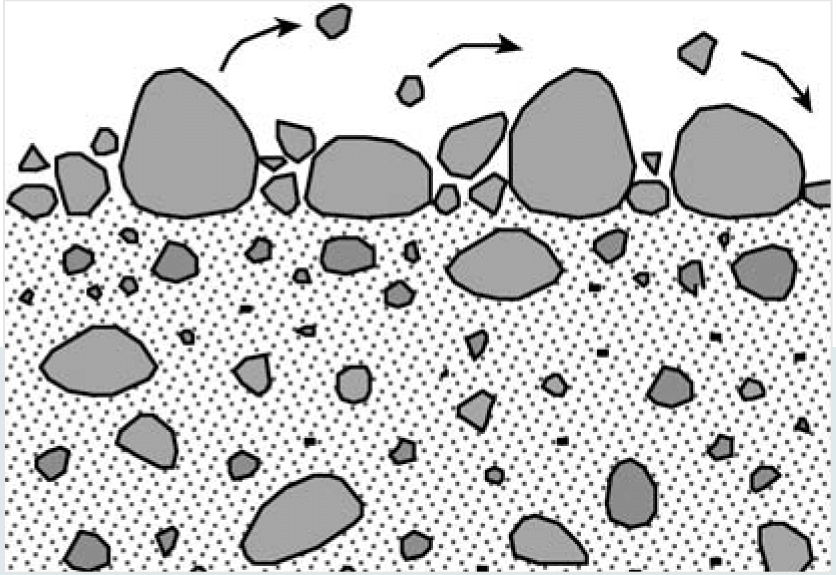
(Photo from Merrick)

(Photo from Merrick)

NATURAL CHANNEL ARMORING

To naturally form armor layers, three conditions must be met: (Julien, 2018)

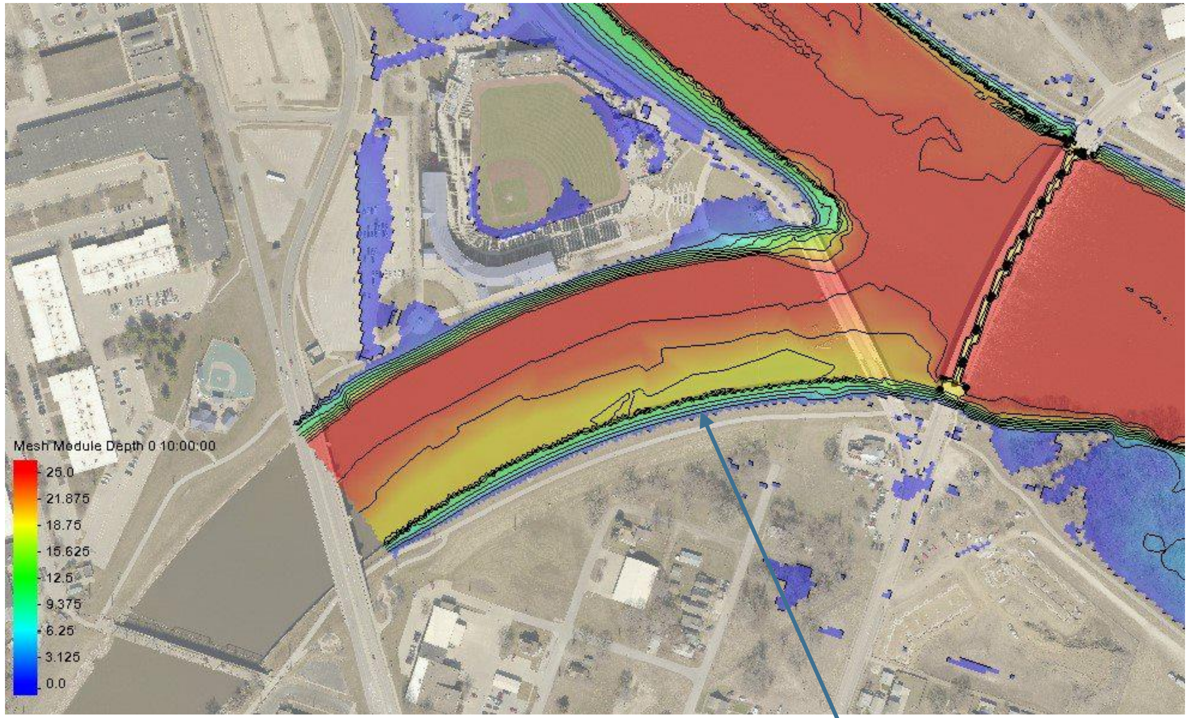
1. Stream must be degrading
   - Sediment transport capacity must exceed sediment supply.
2. Bed material must be sufficiently coarse to resist incipient motion at common flows.
   - $h \cong d_{sc}/(10S)$ (approx. incipient motion given $\tau_{*c} \cong 0.05$)
   - Most likely gravel-bed streams
   - Too coarse of material would be considered "paved".
3. There must be a sufficient quantity of coarse bed material.



(Photo from Pitlick et al., 2009)

(Photo from Merrick)

NATURAL CHANNEL ARMORING



(Model from Merrick)

2D Hydraulic Model Depth Results (More shear stress on outside of bend, results in deeper thalweg on outside bend and sand bar on inside of bend)

Armoring of the Bed Layer (Julien, 2018)

- At lower flows, the finer sediment in the well-graded bed material erodes, while the coarser sediment remains in place.
- As the bed continues to degrade, the bed material layer begins to be only made up of the coarse material until is reaches a thickness where no more degradation occurs.
  - Can occur at bends and create gravel/point bars
  - Thickness ≈ $2*d_s$ (d_s at incipient motion)
  - Results in bed material being coarser than subsurface material.
- Represents a stable bed condition and will only be mobilized during large floods.

ENGINEERED ARMORING

Rigid

Armoring that is unable to adjust to changes in the bed and bank

- Paved Channels
- Grouted Boulder Walls
- Fully-Grouted Riprap
- Faux Rock
- Grout-Filled Mattresses

(Photo from Merrick)

(Photo from FHWA HEC-23)

(Photo from Merrick)

ENGINEERED ARMORING

Flexible

Armoring that can “flex” and adjust to minor changes to the bed and bank without failing

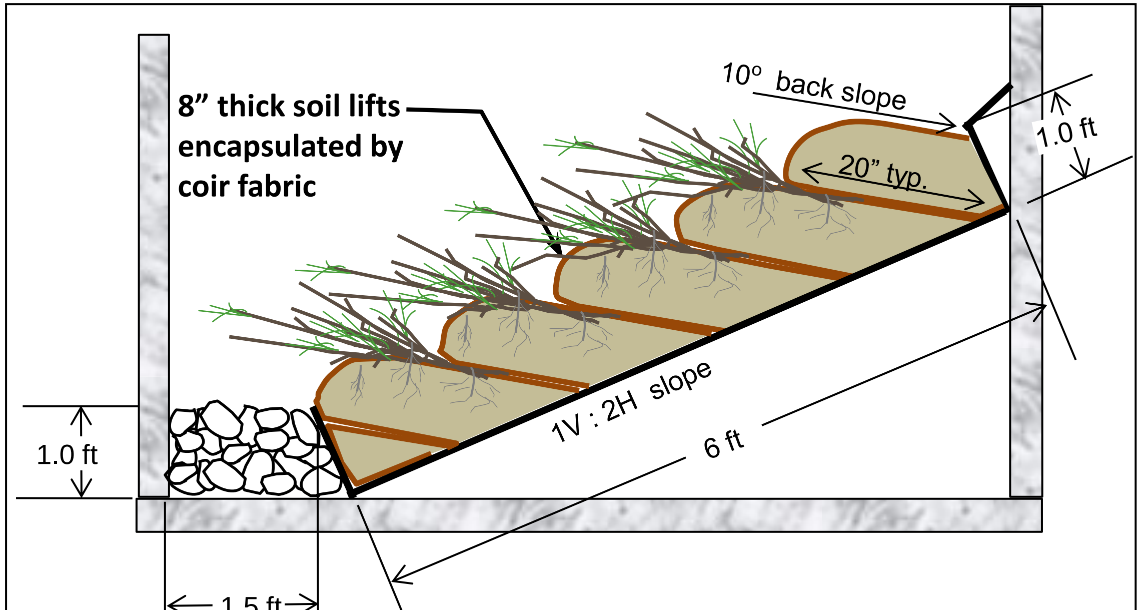
- Riprap
- Matrix Riprap (Partially-Grouted)
- Articulated Concrete Blocks (ACBs)
- Wire-Enclosed Mattresses
- Concrete Armor Units

ENGINEERED ARMORING

BIOTECHNICAL (ENVIRONMENTALLY SENSITIVE)

STREAMBANK ARMORING THAT INCORPORATES VEGETATION

- Live Siltation
- Brush Mattresses
- VMSE
- Vegetated Riprap
- Engineered Wood



(Photo from NCHRP Report 882 Lagasse et al. 2016)

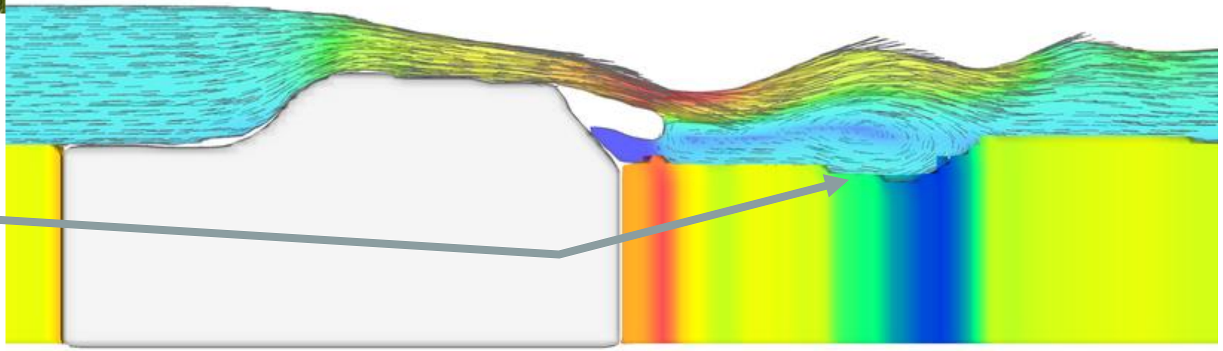
ENGINEERED ARMORING

Grade Control Structures

- Also called Gradient Restoration Facilities (GRF)
- Reduce channel slope and velocities
- Stabilize channel bed
- Scour downstream of drop structures is important to consider and needs additional armoring to protect structure.

(Photo from Merrick)

Scour Hole Below Grade Control Structure



(Model from Merrick)

RIPRAP DESIGN CONSIDERATIONS

- Particle Size/Weight – to withstand hydraulic forces without mobilizing
- Gradation, Blanket Thickness, & Rock Angularity – help to minimize hydraulic forces on the underlying soil and facilitate interlocking between rocks
- Filter – permeable layer that prevents loss of fine material below riprap
- End Treatments - to prevent undermining, flanking, and other failures along edges

Photos from Ayres

RIPRAP DESIGN

Rock Sizing

(Using Shear Stress)

$$d_m \cong \frac{K_b \tau_0}{0.047 * \gamma * (G-1) * \sqrt{1 - \frac{\sin^2 \theta_1}{\sin^2 \phi}}}$$

Where: $d_m = 1.25 d_{50}$

(Using Velocity)

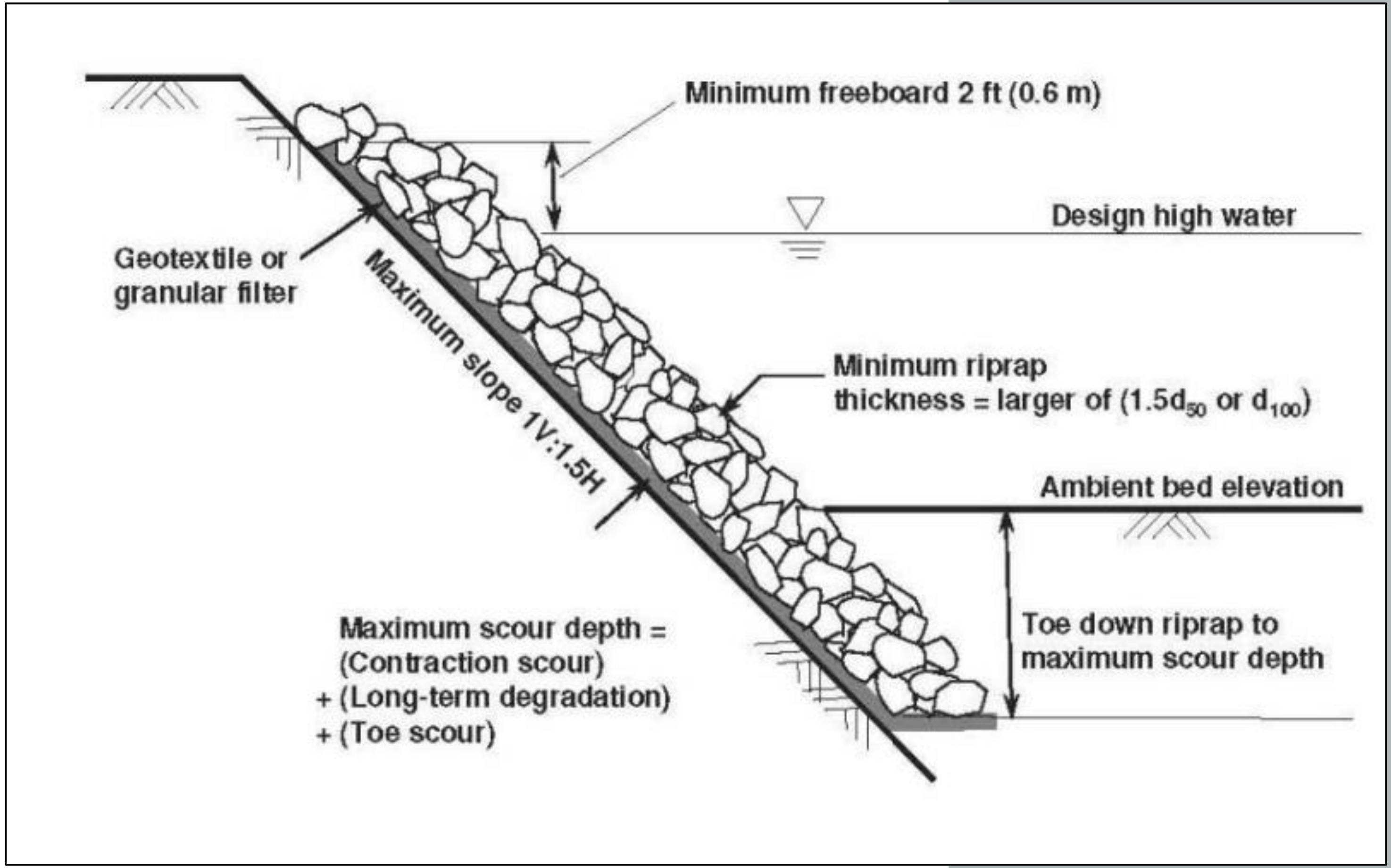
$$d_s \cong \frac{V_c^2}{K_c^2} * \frac{\sin \phi}{2 * (G-1) * g * (\sin^2 \phi - \sin^2 \theta_1)^{1/2}}$$

Filter

Granular or fabric filter required when d_{15} of riprap exceeds 5xd_{85} of bank material

Scour

Toe riprap down below long-term degradation, contraction scour, and local (i.e. bendway) scour



(Figure from FHWA HEC-23 2009)

2013 Post-Flood Assessments

US 34 Canyon

ARMORING FAILURES

US 34 Canyon

US 34 Canyon

(Photos from Ayres)

FAILURE MECHANISMS

- Particle Erosion
  - Particle size too small
  - Bank slope too steep
  - Gradation too uniform

- Translational Slide
  - Bank slope too steep
  - Excess hydrostatic (pore) pressure – (filter)
  - Loss of support at toe

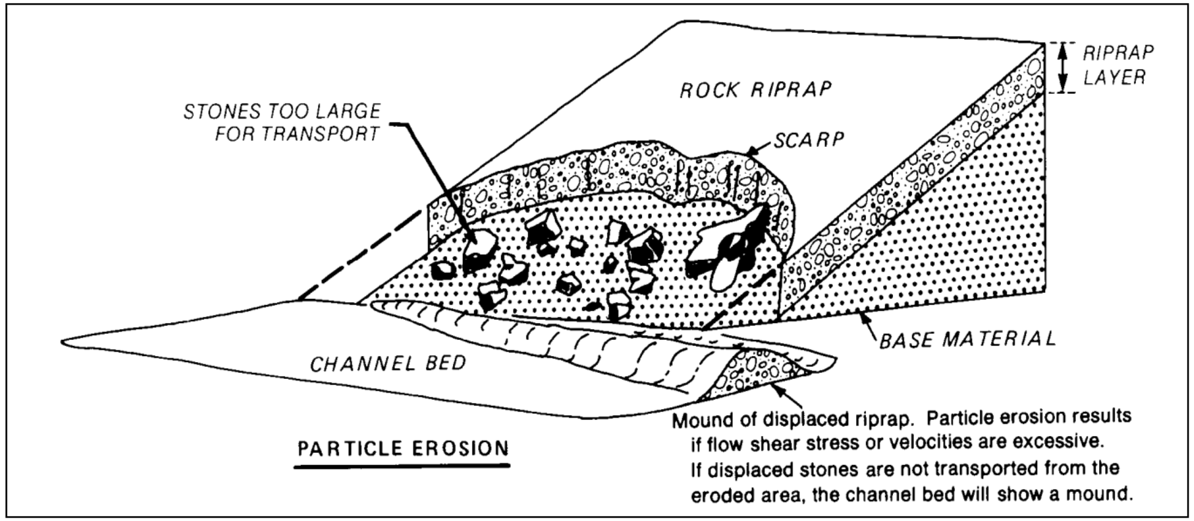


Figure 5.8. Riprap failure by particle erosion (Blodgett and McConaughy 1986).

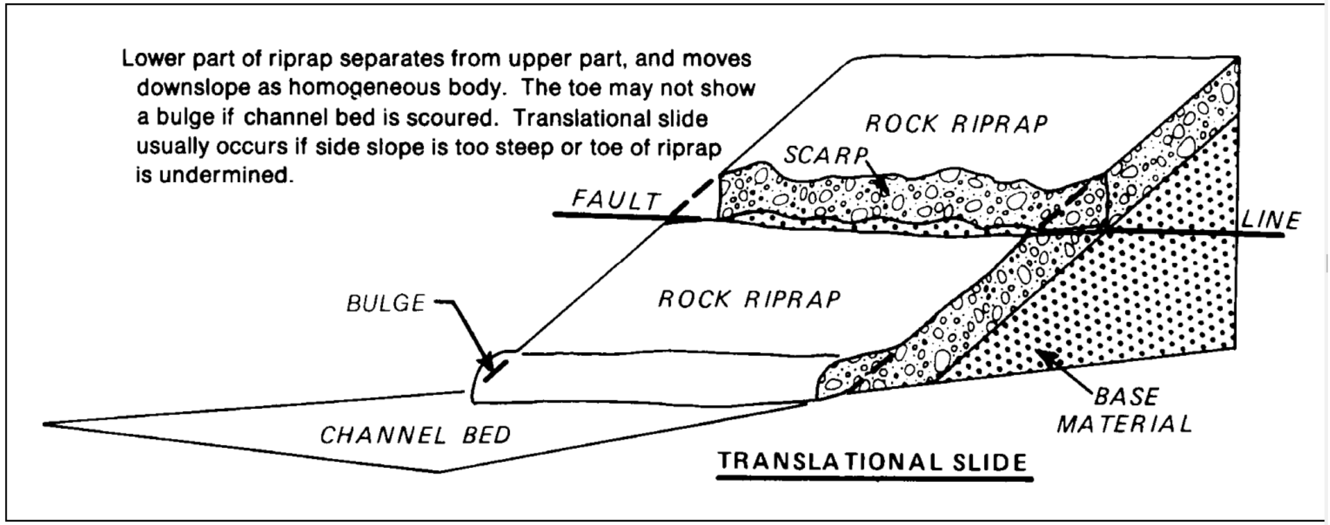


Figure 5.10 . Riprap failure by translational slide (Blodgett and McConaughy 1986).

(Figures from FHWA HEC-23 2009)

FAILURE MECHANISMS

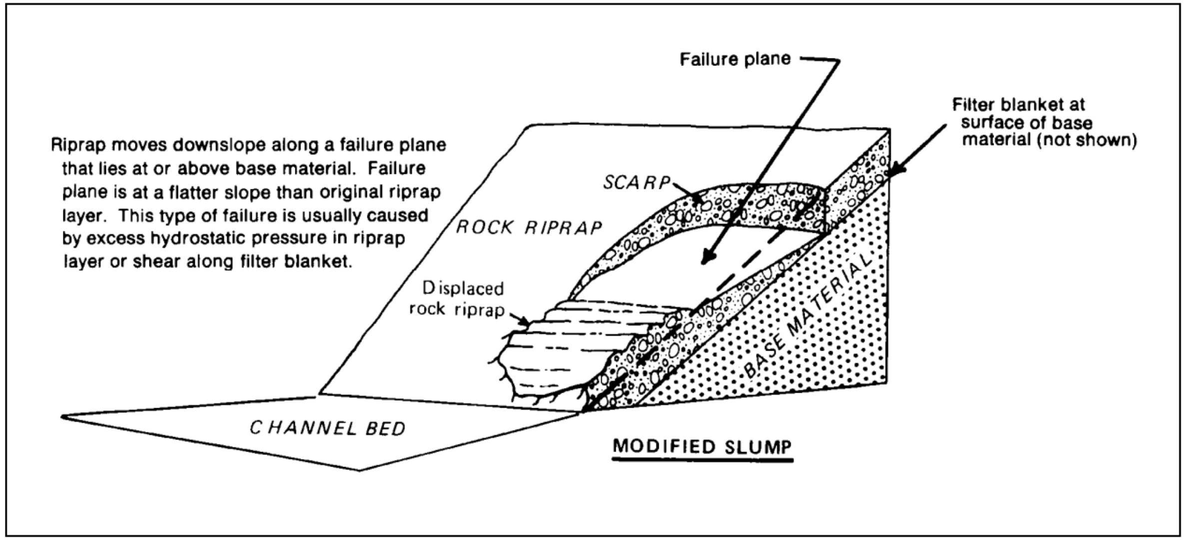


Figure 5.12. Riprap failure by modified slump (Blodgett and McConaughy 1986).

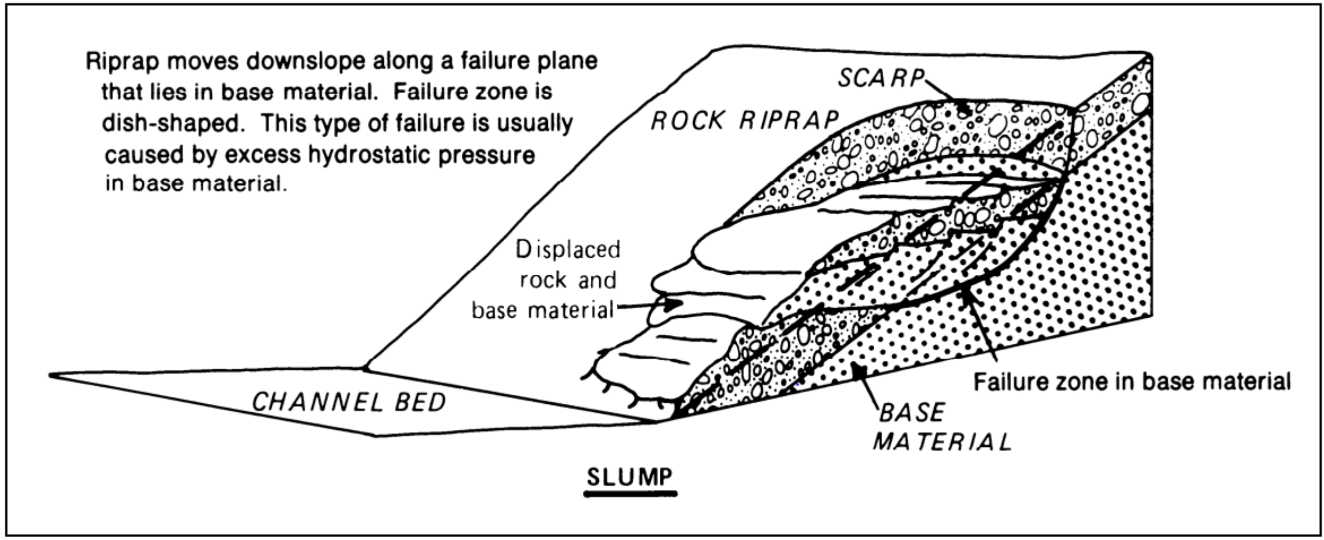


Figure 5.14. Riprap failure due to slump (Blodgett and McConaughy 1986).

(Figures from FHWA HEC-23 2009)

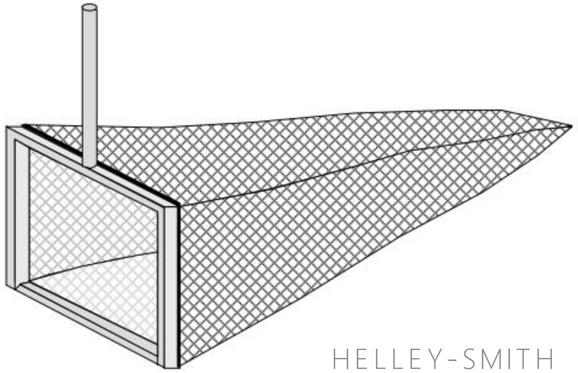
- Modified Slump
  - Base soil does not fail
  - Bank slope too steep

- Slump
  - Excess pore pressure
  - Layers of impermeable material
  - Bank slope too steep
  - Too much overburden on slope

MATERIAL SURVEY METHODS

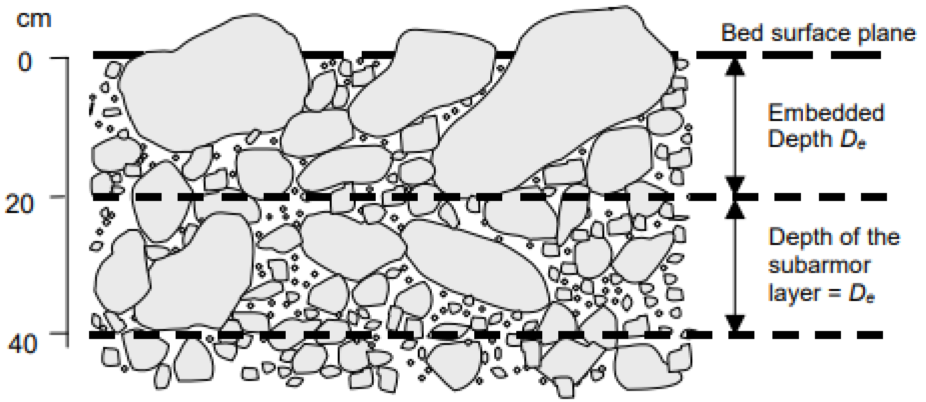
Surveying Bed Material versus Subsurface Material (Bunte, K., &; Abt, S. R. (2001))

- Surface Sampling (Most likely armor layer in gravel/cobble bed streams)
    - Pebble Counts
    - Grid Sampling
    - Areal Sampling
- Volumetric Sampling
    - Armor Layer
    - Subsurface Bed Material
    - Helley-Smith Sampler
        - First armor layer and then subsurface
        - Works well for fine gravel beds



HELLEY-SMITH

GRAVELOMETER



Figures from Bunte, K., &; Abt, S. R. (2001)

CONCLUSION

- Armoring, whether naturally formed or engineered, protects the streambanks and bed from scour by being large enough in size to resist incipient motion.

- Engineered Armoring can be used to protect infrastructure such as bridge piers and roads from undermining and channel bank migration

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