U.S. Department of Transportation
Federal Highway Administration

Strategies to Mitigate Scour Critical Structures

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Support Material

HEC 23, Bridge Scour and Stream Instability Countermeasures, Volumes 1 & 2

NCHRP 135048, Countermeasure Design for Bridge Scour and Stream Instability

NCHRP Report 568, Riprap Design Criteria, Recommended Specifications, and Quality Control

NCHRP Report 593, Countermeasures to Protect Bridge Piers from Scour

HEC 18, Evaluating Scour at Bridges

Design Frequency

Risk Based Design

HEC 18 Tables 2.1 & 2.3 combined

Design Flood Frequencies			
Hydraulic Design Flood Frequency, Q_D	Scour Design Flood Frequency, Q_S	Scour Design Check Flood Frequency, Q_C	Countermeasure Design Flood Frequency, Q_{CM}
Q_{10}	Q_{25}	Q_{50}	Q_{50}
Q_{25}	Q_{50}	Q_{100}	Q_{100}
Q_{50}	Q_{100}	Q_{200}	Q_{200}
Q_{100}	Q_{200}	Q_{500}	Q_{500}

Probability of Exceedance Example

Bridge Design Life – 75 Years

- Hydraulic Design Flood Frequency – Q_{50}
- Probability of Exceedance – **78%**
- Scour Design Flood Frequency – Q_{100}
- Probability of Exceedance – **59.2%**
- Scour Check Flood Frequency – Q_{200}
- Probability of Exceedance - **31.3%**

Flood Exceedance Probability
HEC 18, Appendix B

Table B.1. Probability of Flood Exceedance of Various Flood Levels.							
Flood Frequency	Probability of Exceedance in N Years (or Assumed Bridge Design Life)						
Years	N = 1	N = 5	N = 10	N = 25	N = 50	N = 75	N = 100
10	10.0%	41.0%	65.1%	92.8%	99.5%	100.0%	100.0%
25	4.0%	18.5%	33.5%	64.0%	87.0%	95.3%	98.3%
50	2.0%	9.6%	18.3%	39.7%	63.6%	78.0%	86.7%
100	1.0%	4.9%	9.6%	22.2%	39.5%	52.9%	63.4%
200	0.5%	2.5%	4.9%	11.8%	22.2%	31.3%	39.4%
500	0.2%	1.0%	2.0%	4.9%	9.5%	13.9%	18.1%

Hydraulic Countermeasure Types

- Riprap
- Partially Grouted Riprap
- Articulated Concrete Blocks
- Gabions & Gabion Mattresses
- Concrete Armor Units (Toskanes, A-Jacks, etc.)
- Spurs
- Bendway Weirs
- Guide Banks
- Longitudinal Peaked Stone Toe Protection

Riprap Countermeasures

- **Riprap Revetment – channel bank**
- **Riprap Embankment Overtopping**
- **Riprap at Bridge Piers**
- **Riprap at Abutments**
- **Riprap for Bottomless Culverts**

Similarities

- Stone quality specification
- Gradation specifications
- Filter requirements

Differences

- Equations for sizing
- Layer thickness
- Toe detail
- Lateral extent
- Filter extent

HEC 23 Riprap Equations

Revetment (DG 4)

$$D_{30} = y\,(SfCsCvCT)\left[\frac{V}{(K(Sg-1)gy)^{1/2}}\right]^{2.5}$$

Bridge Piers (DG 11)

$$D_{50} = \frac{0.692\,V^2}{(Sg-1)2g}$$

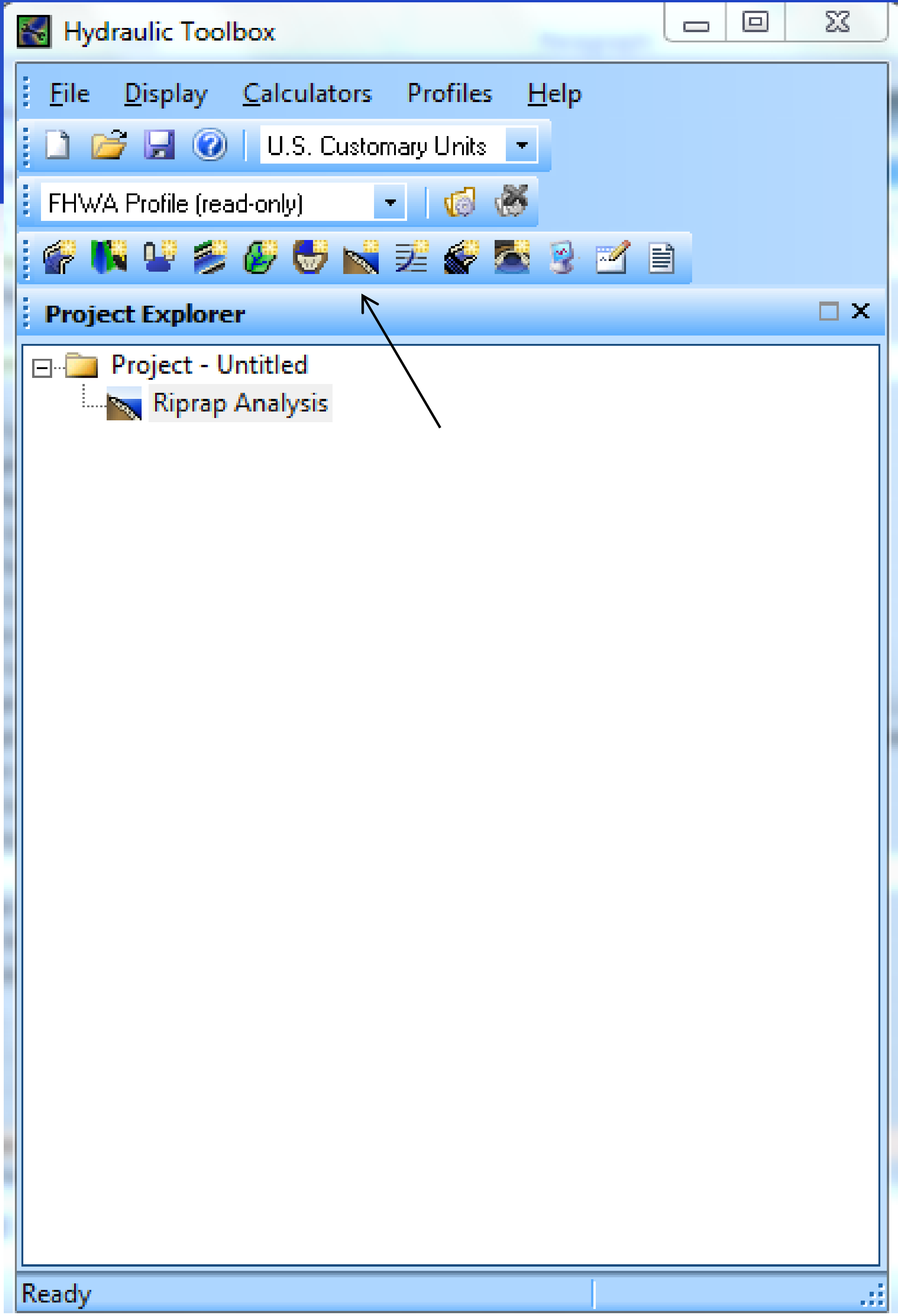
Abutments (DG 14)

$$D_{50} = \frac{ky}{(Sg-1)} \times \frac{V^2}{gy} \qquad \text{for } F_R \leq 0.8$$

$$D_{50} = \frac{ky}{(Sg-1)} \times \left[\frac{V^2}{gy}\right]^{0.14} \qquad \text{for } F_R > 0.8$$

Riprap Calculator

- Revetment
- Pier
- Abutment/Guide Bank
- Spur
- Embankment Overtopping
- Culvert Outlet
- Open Bottom Culvert
- Wave Attack



Riprap Analysis

Structure type: Pier

Geotextile/Granular Filter Des

Parameter	Value	Units	Notes
Channel Parameters			
Select Channel	<Create New>		
	Channel Calculator...		
Input Parameters			
	Transfer Values From Channel Calculator		
Velocity Input Type	average velocity at the bridge		
Channel Average Velocity (at the bridge)	6.600	ft/s	
Velocity Adjustment Factor for location in the channel	1.300		Ranges from 0.9 for a pier near the bank in a straight reach to 1.7 for a
Pier Shape Factor	round-nose pier		
Pier Width (normal to flow)	2.500	ft	
Contraction Scour Depth	3.000	ft	
Bed Form Depth	0.000	ft	
Specific Gravity of Riprap	2.650		
Results			
Design Velocity	12.870	ft/s	
D50	12.955	in	
D50	1.080	ft	
Riprap Shape	Riprap shape should be angular		
Riprap Class			
Riprap Class Name	CLASS IV		
Riprap Class Order	4		
D15	10.50	in	This value is an 'average' of the size fraction range for the selected ripra
D50	15.50	in	This value is an 'average' of the size fraction range for the selected ripra
D85	21.00	in	This value is an 'average' of the size fraction range for the selected ripra
D100	30.00	in	This value is an 'average' of the size fraction range for the selected ripra
Layout			
Depth of Riprap below Streambed	46.500	in	Design thickness of riprap below streambed is greatest of Contraction Sc
Minimum Riprap Extent	5.000	ft	See HEC 23, Figure 11.15
Filter Placement Extent	3.333	ft	See HEC 23, Figure 11.15

OK

Riprap Analysis

Structure type: Abutment/Guide Bank

Geotextile/Granular Filter Design...

Parameter	Value	Units	Notes
Channel Parameters			
Select Channel	<Create New>		
	Channel Calculator...		
Input Parameters			
	Transfer Values From Channel Calculator		
Structure Type	abutment		
Abutment Type	spill-through abutment		
Set-back Length	50.000	ft	The set-back length is the distance from the
Main Channel Average Flow Depth	15.000	ft	
Flow Depth at Toe of Abutment	6.000	ft	
Total Discharge	**12000.000**	cfs	Calculations will use either total or overbank
Overbank Discharge	4000.000	cfs	
Total Bridge Area	**2000.000**	ft^2	
Setback Area	300.000	ft^2	
Maximum Channel Velocity	**6.600**	ft/s	
Specific Gravity of Riprap	2.650		
Results			
Set-back ratio	3.333		
Characteristic Velocity	6.000	ft/s	
Froude Number at the Abutment Toe	0.432		
Abutment Coefficient	0.890		
D50	7.242	in	
D50	0.604	ft	
Riprap Shape	Riprap shape should be angular		
Riprap Class			
Riprap Class Name	CLASS II		
Riprap Class Order	2		
D15	7.00	in	This value is an 'average' of the size fraction
D50	9.50	in	This value is an 'average' of the size fraction
D85	13.00	in	This value is an 'average' of the size fraction
D100	18.00	in	This value is an 'average' of the size fraction
Layout			
Riprap Thickness	18.000	in	
Minimum Horizontal Extent of the Toe Apron from the Abutment Toe	12.000	ft	
Minimum Extent of "Wrap Around" beyond the Abutment Radius, along the Approach Embankment	25.000	ft	See HEC 23, Figure 14.7

OK Cancel

Layer Thickness

- Abutments: Not less than 1.5 D_{50} or D_{100}
- Channel Lining: Not less than 1.5 D_{50} or D_{100}
- Piers: $3D_{50}$ or depth of contraction scour. When placed under water increase thickness by 50 %.

Lateral Extent

HEC 23 recommends twice pier width.

I recommend a minimum of 10 ft. to account for effects of debris or changes in skew over time.

Note: filter extends only 2/3 riprap extent at piers.

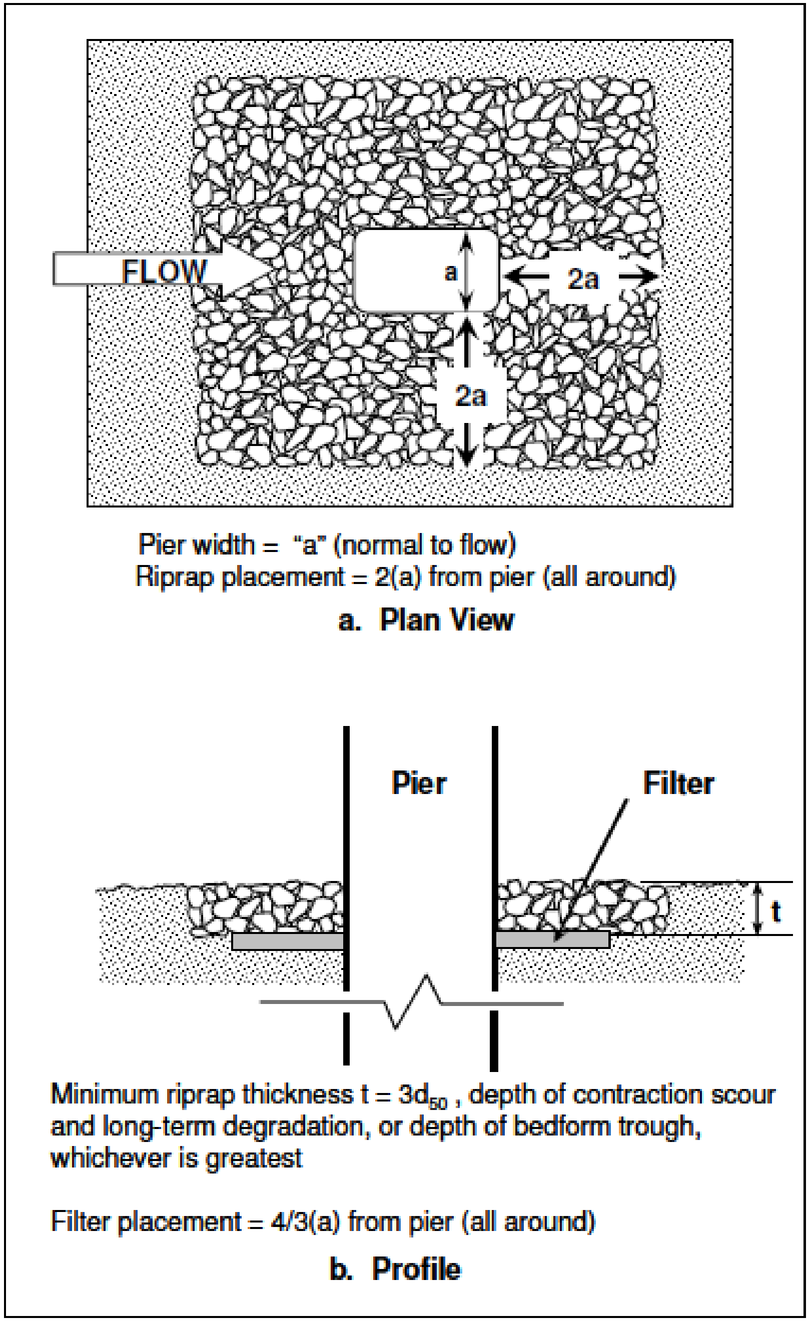
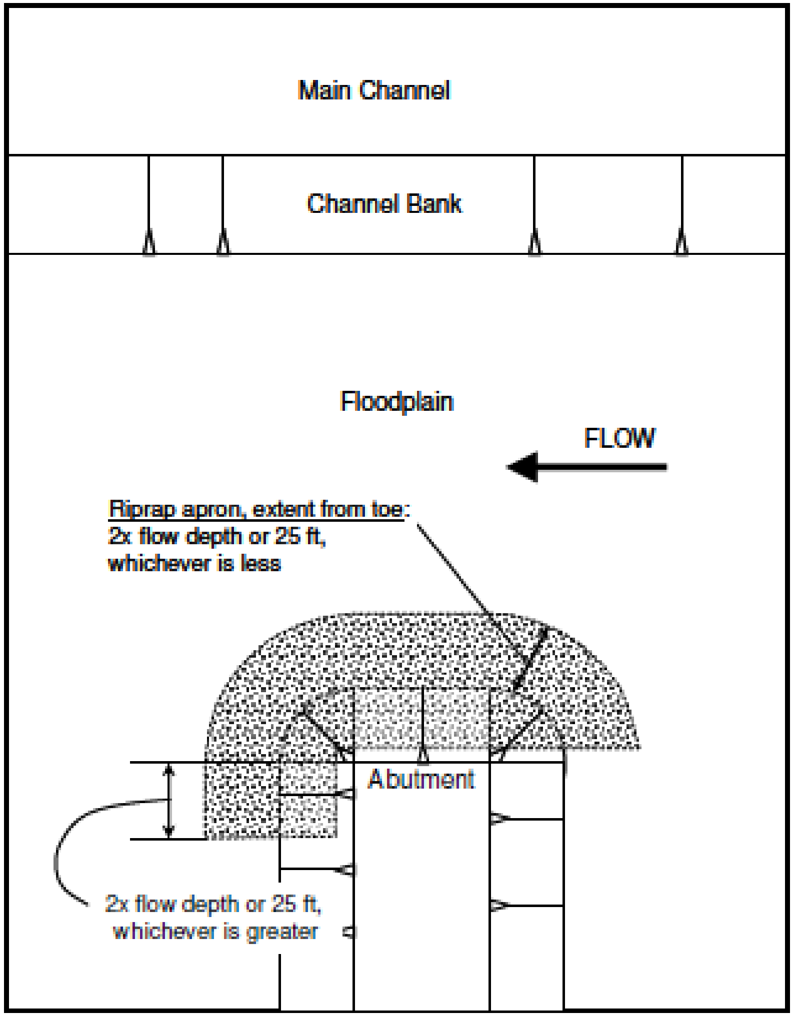


Figure 11.15. Riprap layout diagram for pier scour protection.

Lateral Extent at Abutment (minimum)

- **Upstream - cover abutment spill thru cone.**
- **Downstream – 2 times flow depth or 25 ft. past cone.**
- **Toe (apron) – 2 times flow depth or 25 ft.**



Abutment Toe Details

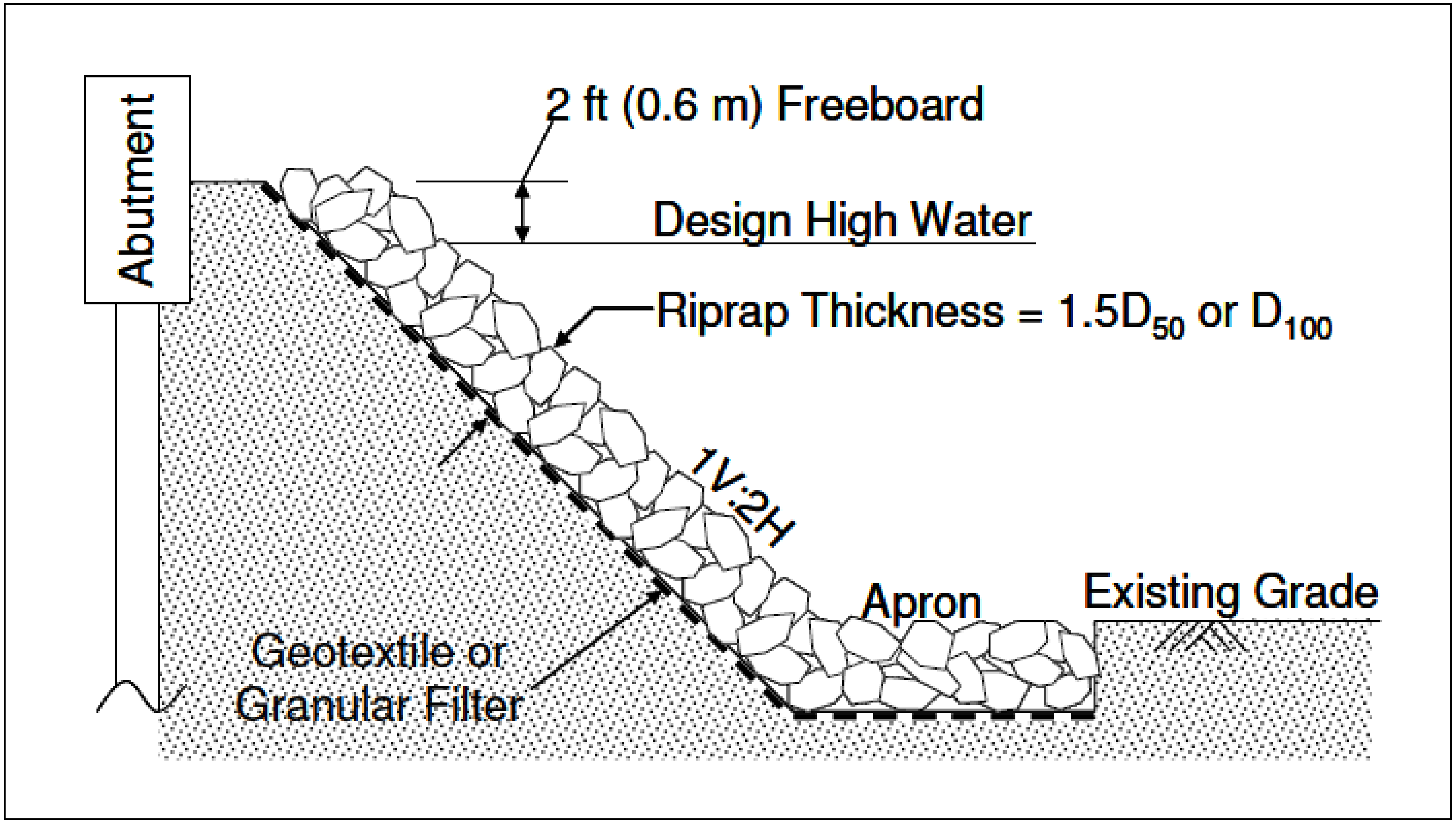


Figure 14.8. Typical cross section for abutment riprap (Lagasse et al. 2006).

Keys to Successful Riprap Installations

- Stone Quality

  Need strong quality spec and material inspection procedures.

- Excavation for placement

  Excavate to plan depth and finish surface for uniform placement depth.

- No mounding at piers or for toe protection.
- Install and anchor filters underwater

  Filter controls the movement of soil particles. Riprap holds filter in place.

Filter Systems

- Granular
- Geotextile
- Combined – Geotextile with granular cover

  Granular cover provides a layer of protection from puncturing by riprap placement.

Installations Underwater

DOTs report that few riprap installations in water

have filters placed during construction.

Why?

Contractors say it’s too difficult and they don’t know how.


KOMATSU
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PC 300 LC


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250

Environmental Concerns

- Increased water surface caused by obstructions
- Maintaining natural river bed
- Obstruction to fish passage
- Length of loss of native stream bed and banks

What's wrong with this installation?

Construction Supervision

Verify

- **Excavation and surface preparation**
- **Placement of filter**
- **Stone size gradation & quality (check before installation)**
- **Thickness of layer**
- **Lateral Extent**
- **Elevation of finished surface (Not to create mounding on streambed)**

Maintenance Inspection

<u>**Changed appearance**</u>

- **Lose of stones**
- **Reduced stone size (freeze thaw or abrasion)**
- **Filter is visible through voids**
- **Lateral extent**
- **Sloughing or sliding down bank**

Document findings (text description and photos)

Poor Quality Stone

Essentials for a Durable lasting Riprap Countermeasure

- “A” Quality Stone
- Proper size and gradation of stone
- Filter under countermeasure
- Layer thickness
- Maintenance inspection and repair

Alternatives to Riprap

Articulated Concrete Blocks (Allows some flexibility)

- Interlocking geometries
- Cable tied blocks
- Interlocking or cabled and vegetated

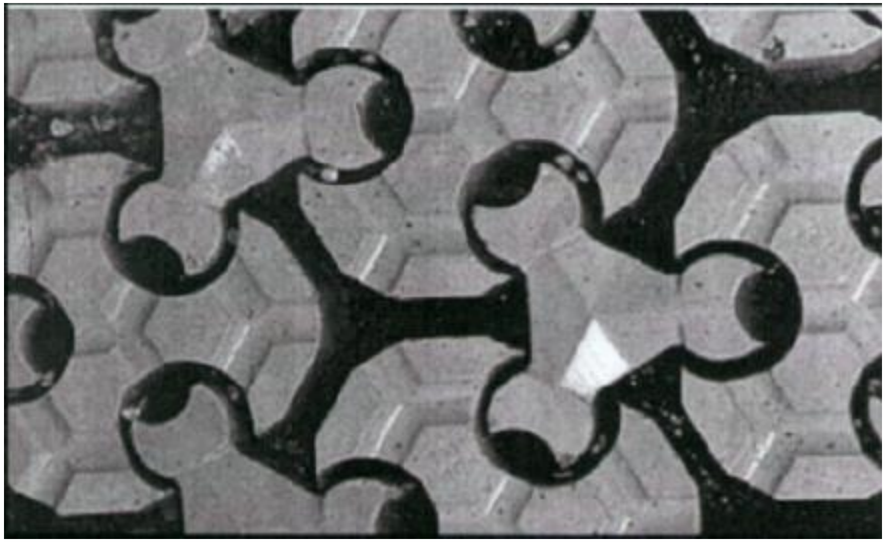
Applications for Articulated Blocks

- **Insufficient vertical clearance for equipment for riprap installation.**
- **Necessary riprap stone size not available.**
- **Necessary stone quality not available.**

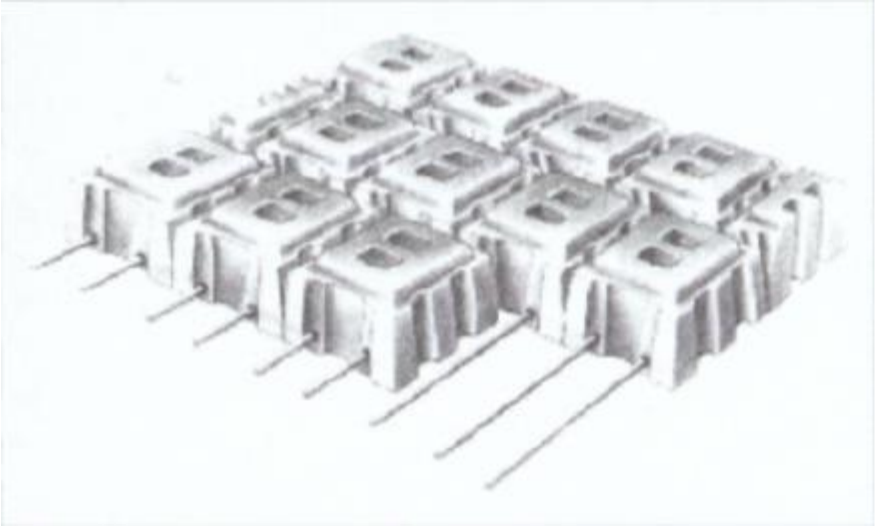
Requires well prepared uniform surface for installation.

Articulating Block Systems

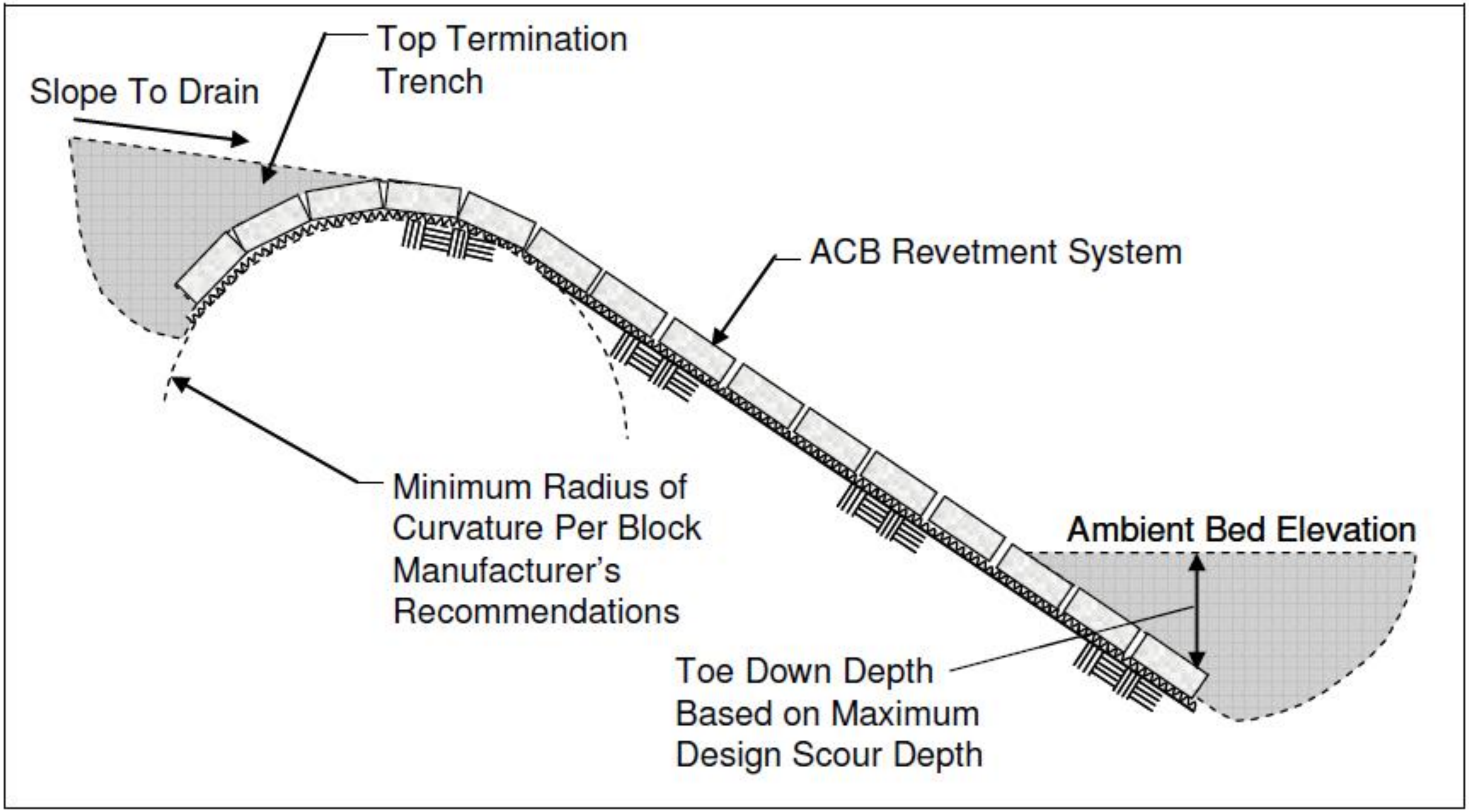
Interlocking



Cable Tied



Layout Detail



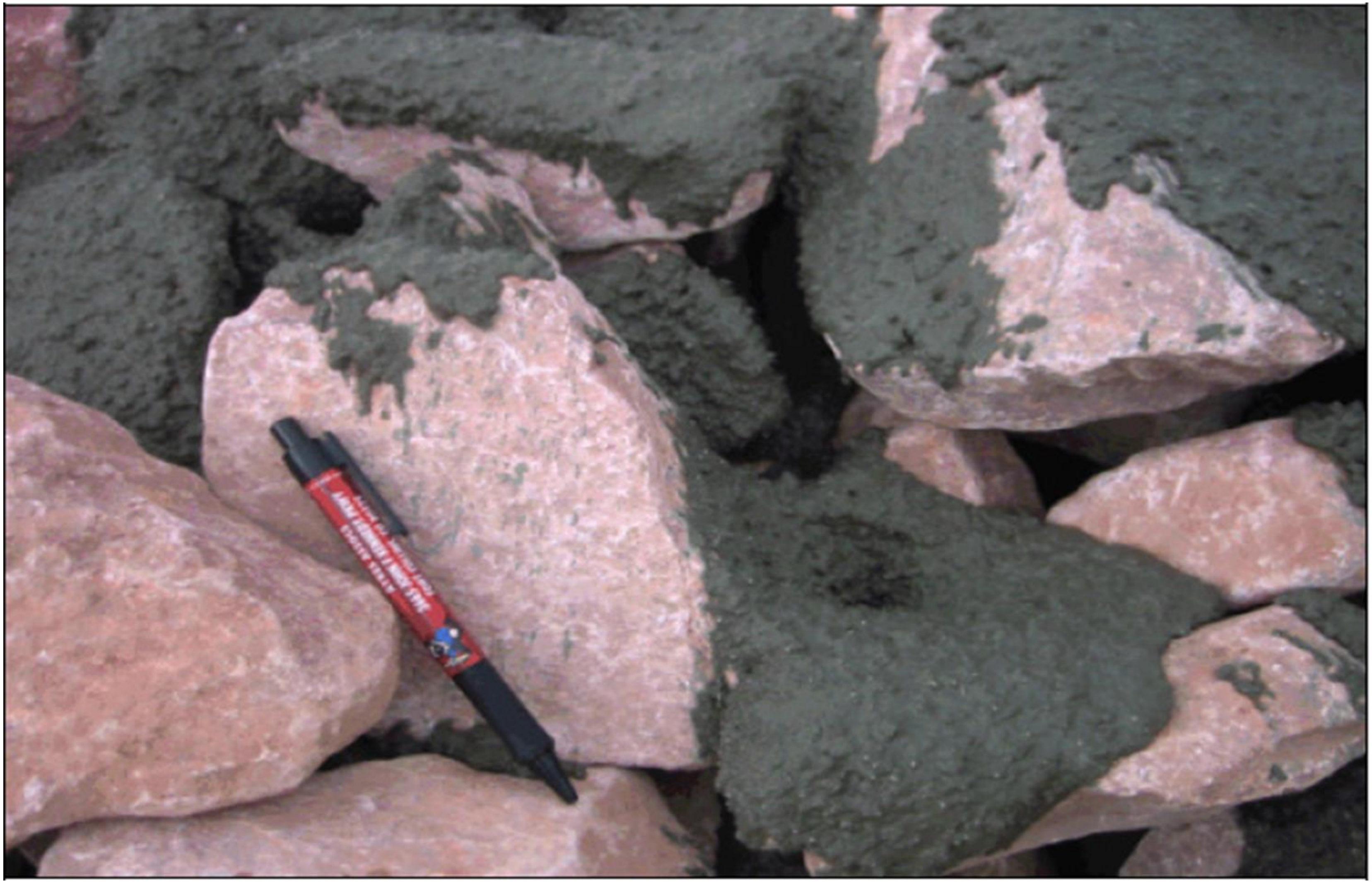
Alternatives to Riprap

- **Gabions and Gabion Mattresses**

Applications for Gabions and Mattresses

- **Required riprap size not available.**
- **High velocity and limited space for placing large size stone.**
- **Can serve as retaining wall as well as scour countermeasure.**

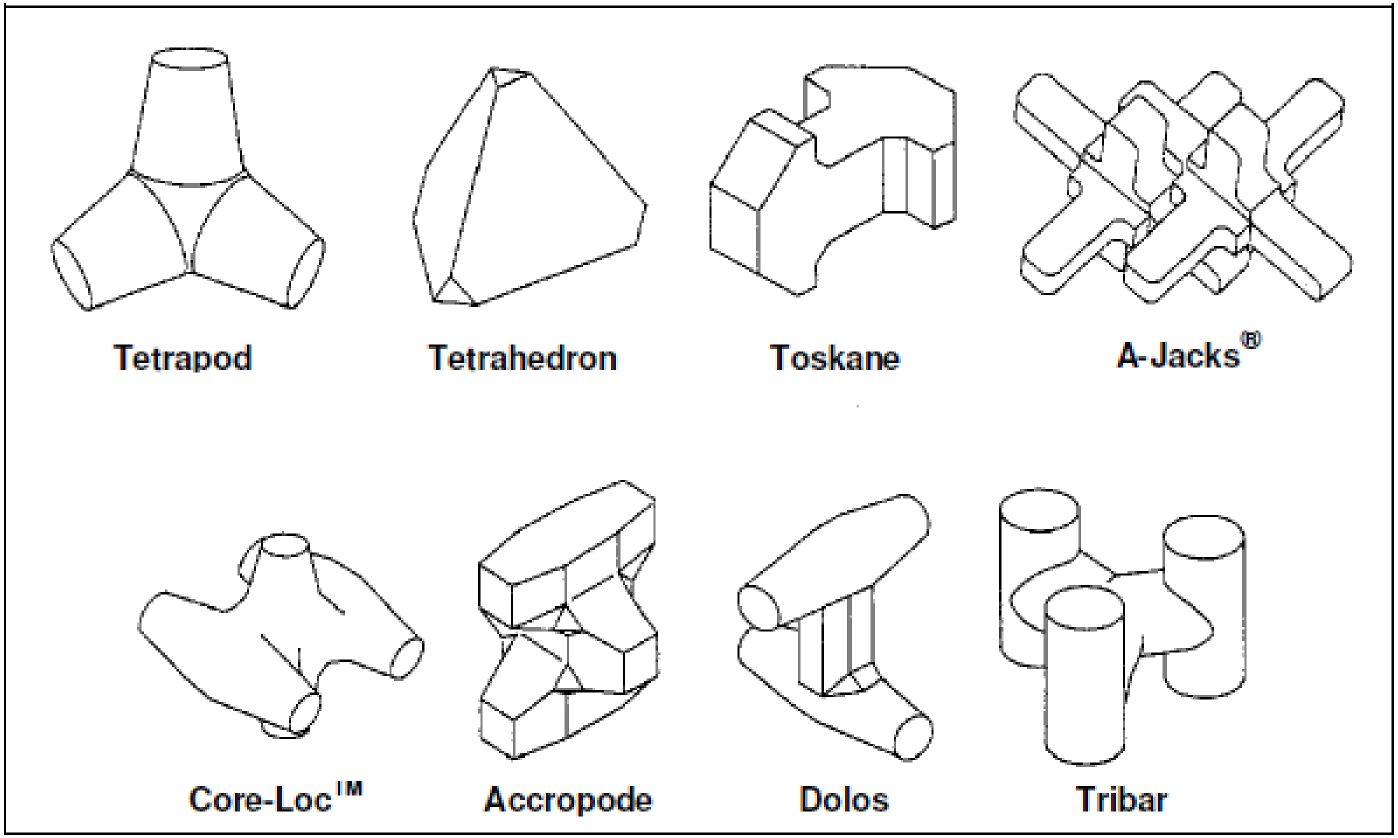
Partially Grouted Riprap



Avoid Fully Grouted Riprap

Alternatives to Riprap

- **Concrete Armor Units (Toskanes, A-Jacks, etc.)**



Toskanes placed like Riprap

Figure 5.23. Laboratory study of Toskanes for pier scour protection.

A-Jacks Installed as a Unit

Concrete Armor Units: A-Jacks

Hard Points – Similar to Bend Way Weirs

Current Countermeasure Research

- NCHRP 24-42, Techniques for Installation of Filters Underwater. (2-yr. project just getting started)

- FHWA - USGS Interagency Project. Performance Evaluation of Existing Countermeasures. (Feb. 2016)

  Objective: Inspect and evaluate the effectiveness of existing policies, design procedures, and installation of scour countermeasures.

Interest in Countermeasure Webinar

Provide comments on evaluation sheet if interested in webinar.

Identify specific coverage areas of interest.

Questions

FHWA Hydraulics Website:

www.fhwa.dot.gov/engineering/hydraulics

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