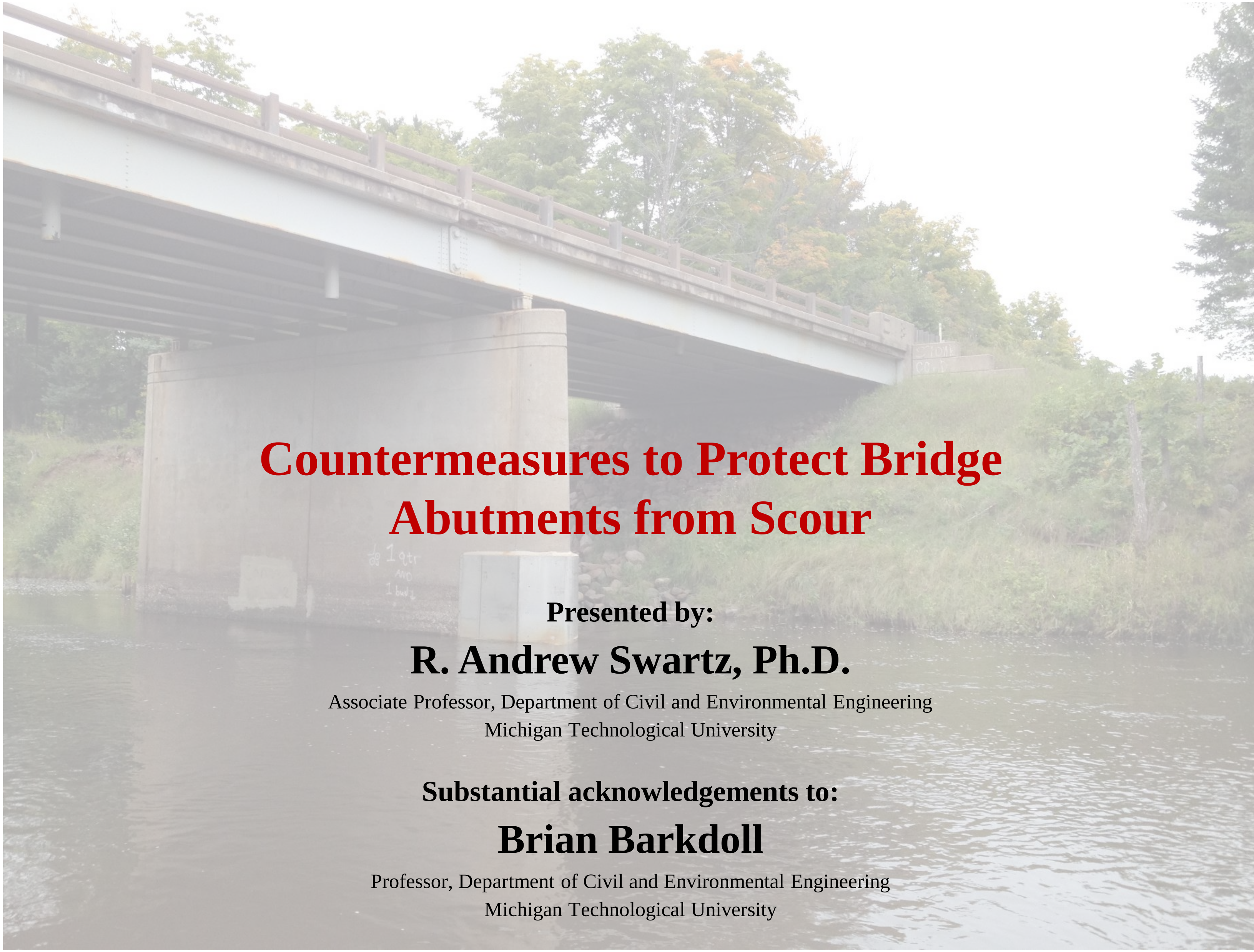

Countermeasures to Protect Bridge Abutments from Scour

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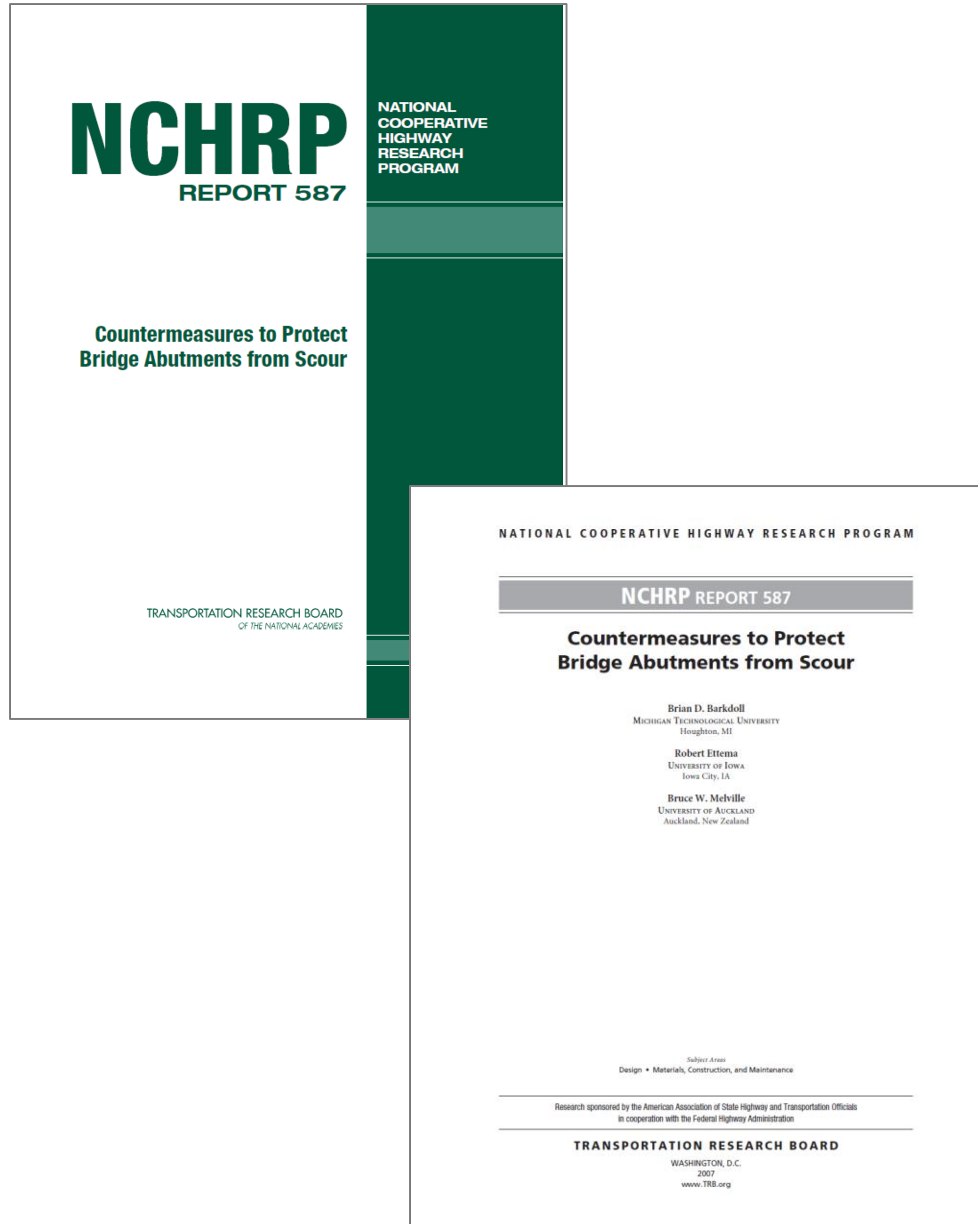
- Motivation.
- Presentation scope.
- Abutment forms and scour.
- Countermeasure Concepts.
- Recommendations.

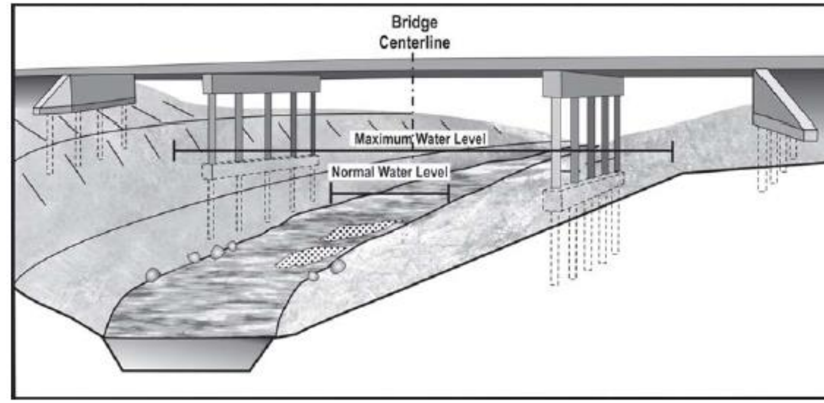
Motivation

- Scour countermeasures provide good protection for bridge abutments when applied correctly.

- Correct use of countermeasures is application specific:
  - ❑ Channel size.
  - ❑ Abutment placement.
  - ❑ Soil conditions.
  - ❑ Channel morphology.
  - ❑ Vegetation.

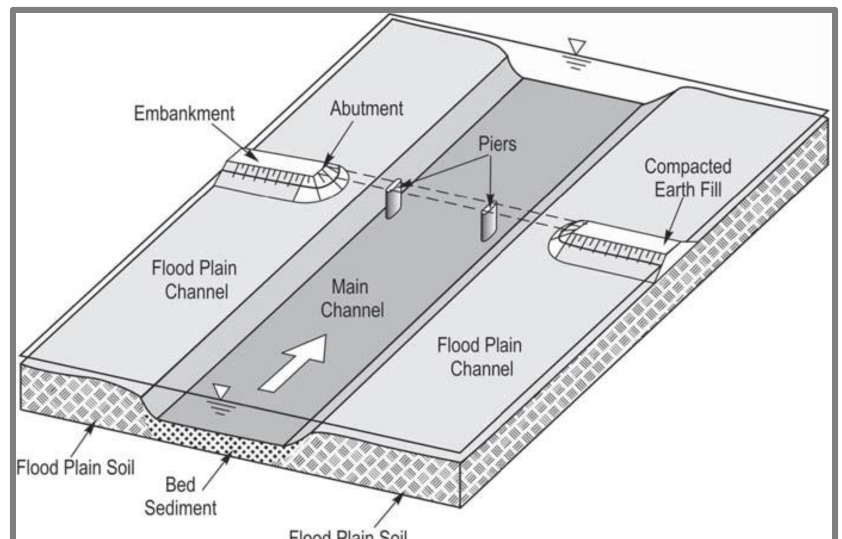


- Presentation will focus on use of countermeasures for protection of abutments.
  - ❑ Wing-wall – small channels.
  - ❑ Spill through – large channels.



Typical small-channel bridge features

- Countermeasures considered include:
  - ❑ Approach-channel control.
  - ❑ Downstream-channel control.
  - ❑ Armoring of bridge opening.
  - ❑ Bridge modifications.
  - ❑ Drainage control.



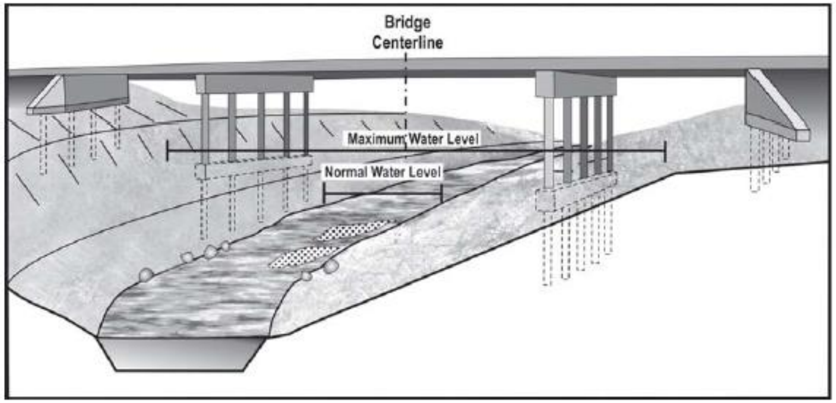
Typical large-channel bridge features

Abutment Forms

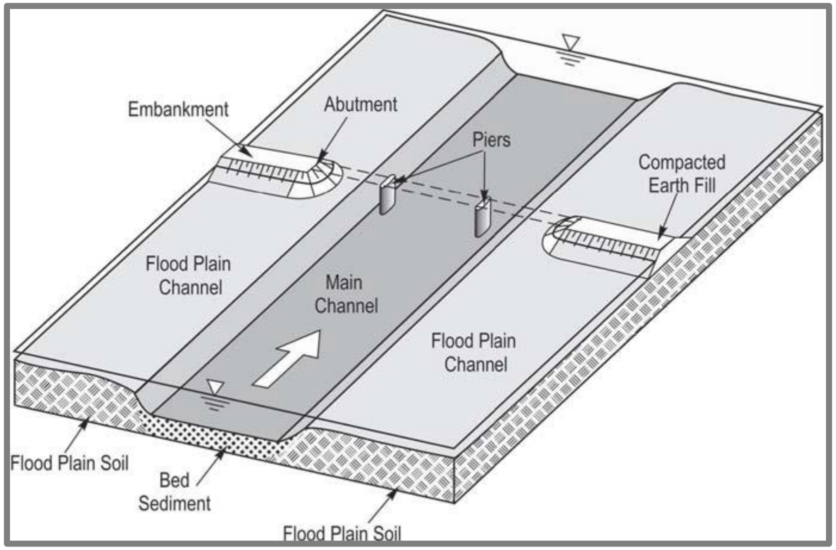
Wing-wall abutment

Pier very close to abutment

Spill-through abutment

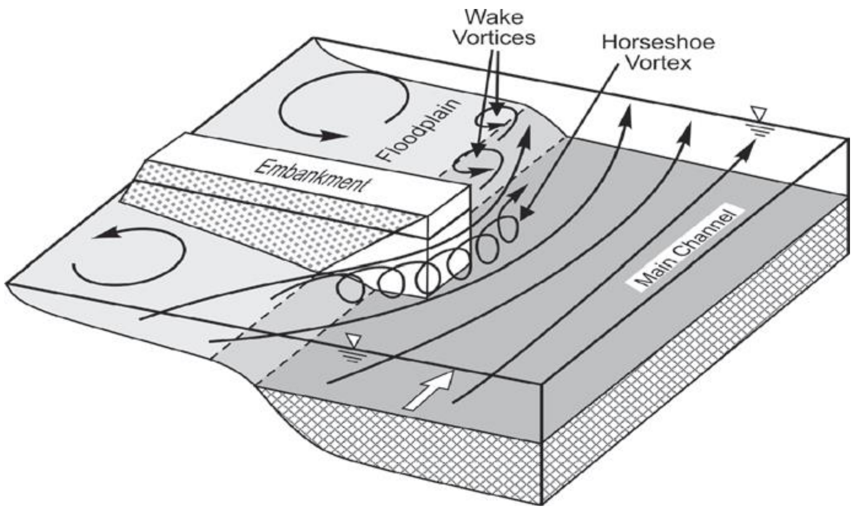


Typical small-channel bridge features

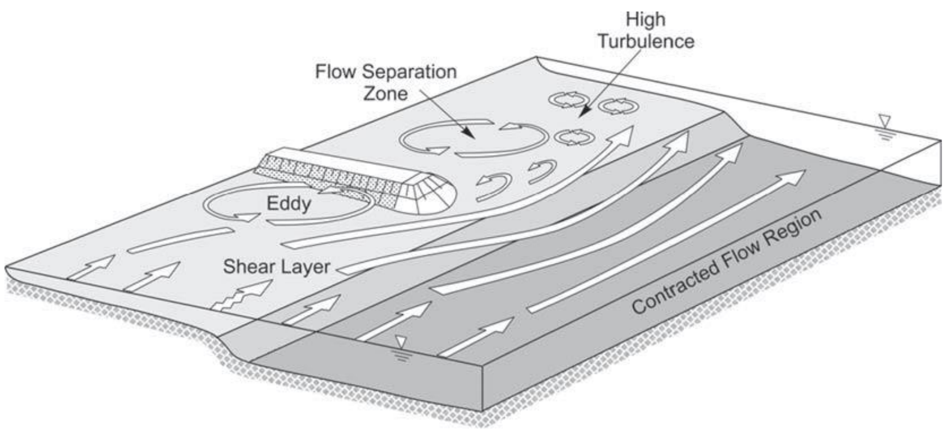


Typical large-channel bridge features

- **Flow field.**
  - Flow contraction.
  - Turbulence caused through boundary interactions.

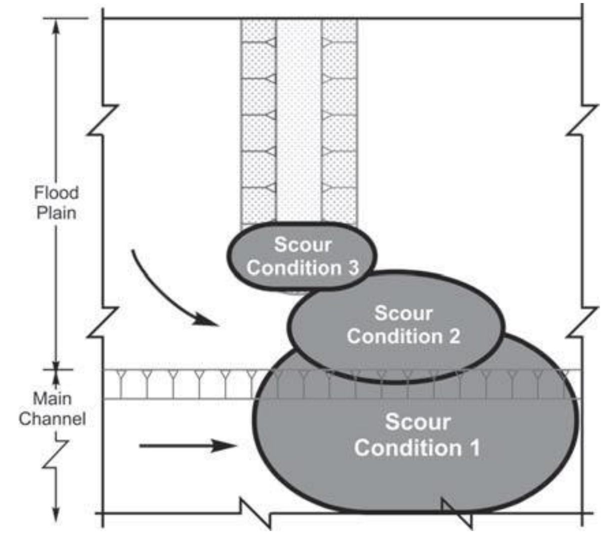


Flow field past wing-wall abutment

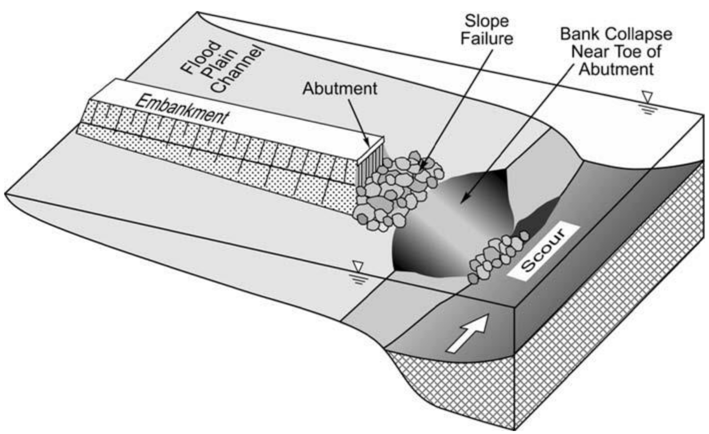


Near-field flow around spill-through abutment

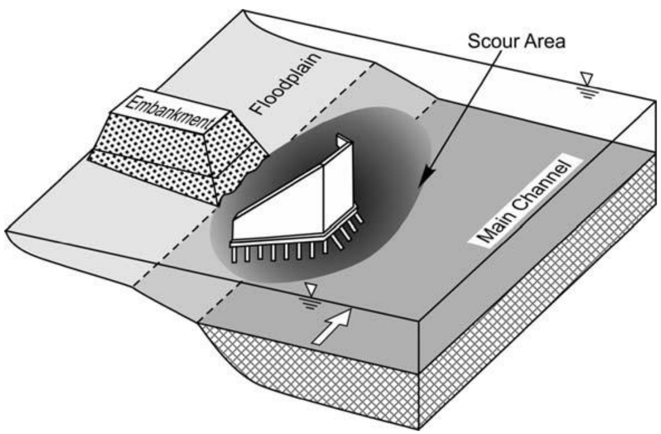
- Scour condition 1:
  - Scour destabilization of the main-channel bank near the abutment.
  - Several-stage failure process.
  - Loss of soil and even riprap into scour hole.
  - Exposure of piles and pile cap problematic.



Regions of abutment scour



Advanced progress of scour condition 1 at spill-through abutment



Very advanced progress of scour condition 1 at wing-wall abutment (abutment collapse)

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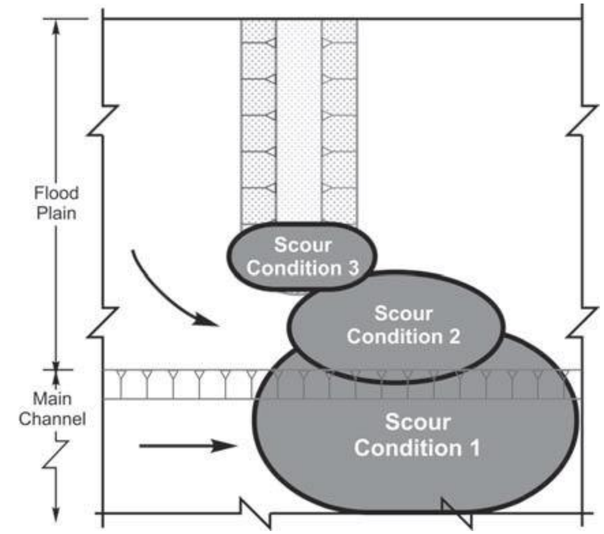
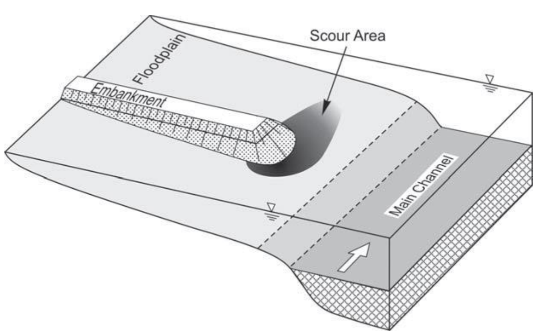
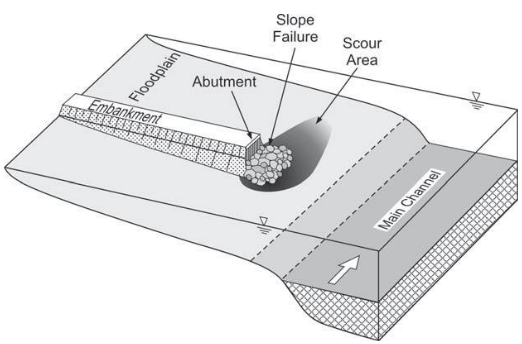
- Scour condition 2:
  - Scour of the floodplain around an abutment set back from main channel.
  - Scour hole forms slightly downstream from abutment.
  - Loss of soil and even riprap into scour hole.
- Scour condition 3:
  - Conditions 1 or 2 progress to allow washout of the embankment around the abutment.



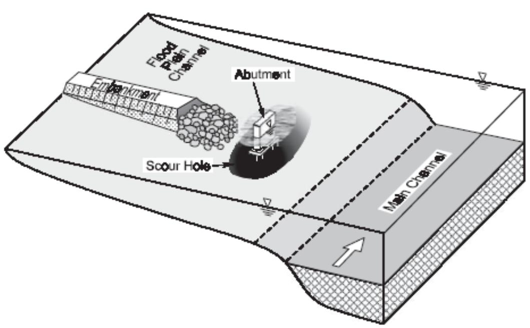
Regions of abutment scour



Initial progress of scour condition 2

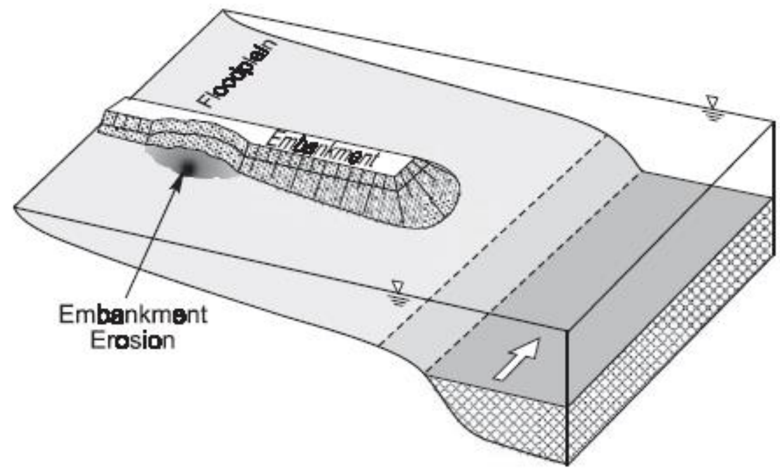


Advanced progress of scour condition 2



Scour condition 3

- Scour condition 4:
  - Scouring of the embankment some distance away from the abutment.
  - Does not occur at bridge opening.
  - Armoring of the bridge opening not effective.



Scour condition 4 – scouring of embankment away from the bridge opening

- Scour condition 5:
  - Scouring during overtopping event.

Bridge scour after overtopping event (image source: CODOT, 2017)

- Other scour processes of note:
  - General scour.
  - Head-cut migration along a channel.
  - Channel (thalweg) alignment shift.
  - Erosion of drainage channels along flanks of abutment.

Upstream progression of head cut through waterway exposes pier supports and destabilizes abutments

Erosion of side drainage in embankment close to abutment exposes it to scour

- General bed degradation or overall scour:
  - Results from reduction in the bed-load supply of sediment to the bridge site (*i.e.*, degradation progressing from upstream to downstream).
  - Or from a steepening of channel slope owing to head-cutting of the channel bed (*i.e.*, degradation progressing from downstream to upstream).
- Approach-flow scour:
  - Results from channel shifting or thalweg shifting.
- Localized scour at the abutment:
  - Results from localized vortices.

- Suggested countermeasure design criteria:
  1. Technical effectiveness (including no substantial adverse effects).
  2. Constructability.
  3. Durability and maintainability.
  4. Aesthetics and environmental issues.
  5. Cost.

- Recommended steps for countermeasure design:
  1. Identify the process causing the scour concern.
  2. Select a countermeasure concept.
  3. Select a construction method for the countermeasure concept.
  4. Design the countermeasure.
  5. Review the design in terms of Criteria 1 through 5 above.

Countermeasure Concepts

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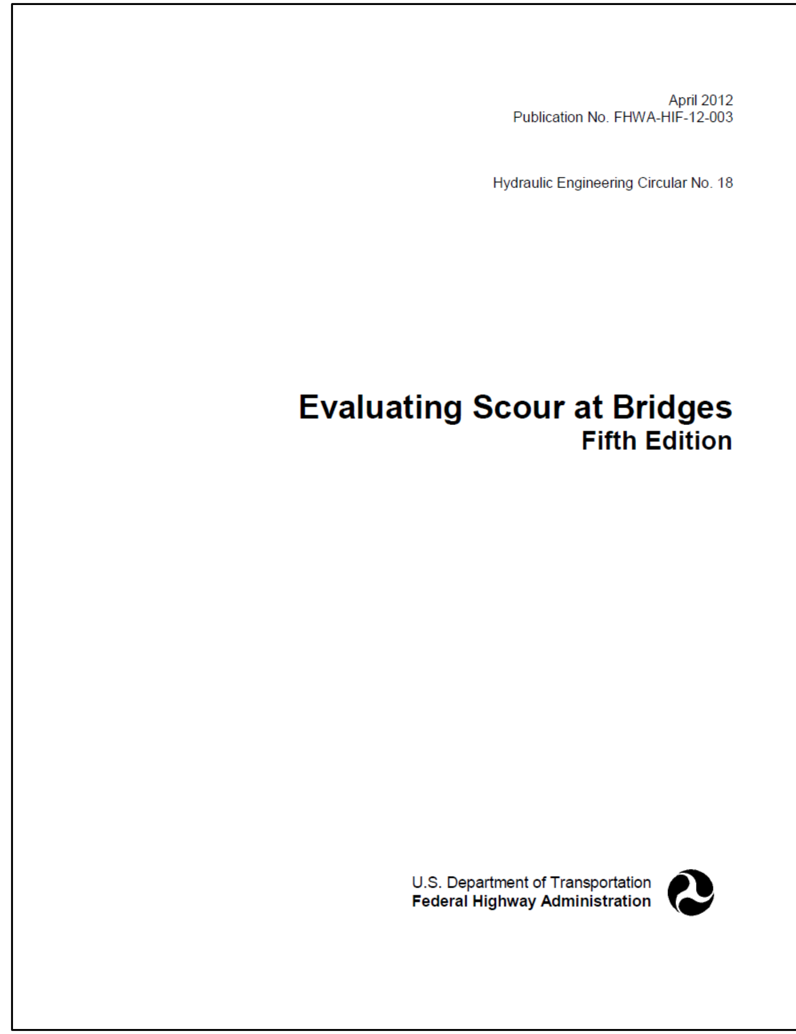
- Scour countermeasures should not be used alone:
  - Maintenance and repair of waterway.
  - Regular monitoring.
- Countermeasure approaches.
  - Approach-channel control.
  - Downstream-channel control.
  - Armoring of the bridge opening.
  - Bridge modification.
  - Drainage control.
- Most commonly used countermeasures:
  - Armoring (mostly riprap) most commonly used technology.
  - HEC 18 and HEC 20 circulars most commonly cited standard for countermeasure design.
    - MI: HEC 18, HEC23.



April 2012
Publication No. FHWA-HIF-12-003

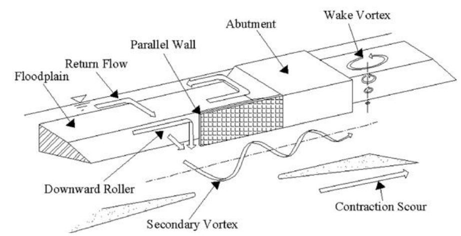
Hydraulic Engineering Circular No. 18

Evaluating Scour at Bridges
Fifth Edition

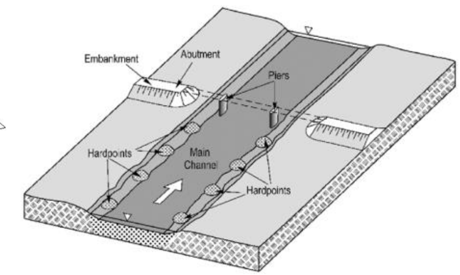
U.S. Department of Transportation
Federal Highway Administration

HEC 18 (Hydraulic Engineering Circular No. 18)
Evaluating Scour at Bridges

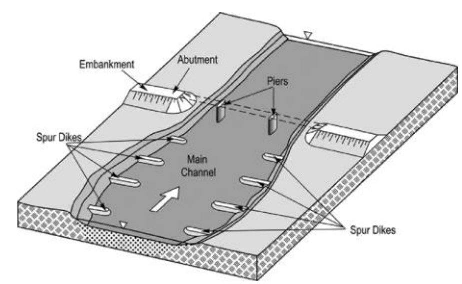
- **Approach-channel/flow control:**
  - Guide approach flow directly through bridge opening:
    - Most useful for approach-flow scour.
    - Streamline flow to minimize the bridge's obstruction to flow.
    - Usually this means to minimize angle between approach flow and major horizontal axis of pier or abutment face.
  - Site-specific analysis is typically required for effective use of flow control:
    - Laboratory testing.
    - Numerical modeling.
- Upstream flow control structures:
  - Guidebanks.
  - Hardpoints.
  - Spur dikes.
  - Bendway weirs and barbs.
  - Vanes.
- Additional upstream channel-control methods:
  - Removal of vegetation and sloughed riverbank material.
  - Bridge widening or shifting:
    - Most attractive is an existing abutment is already damaged or washed out.



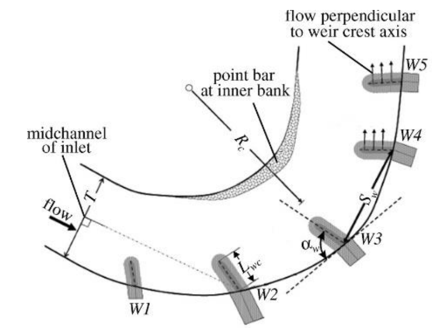
Guidebanks



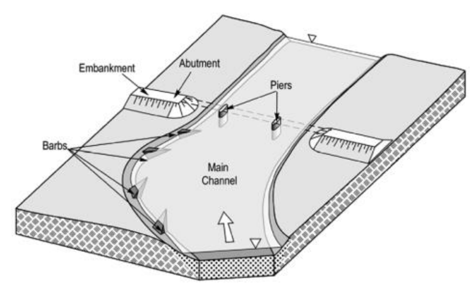
Hardpoints



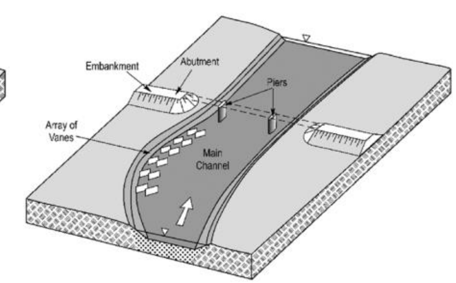
Spur dikes



Bendway weirs[1]



Barbs



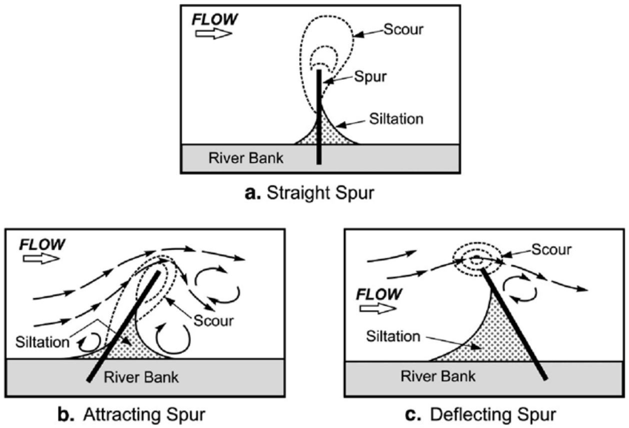
Vanes

Flow control structures

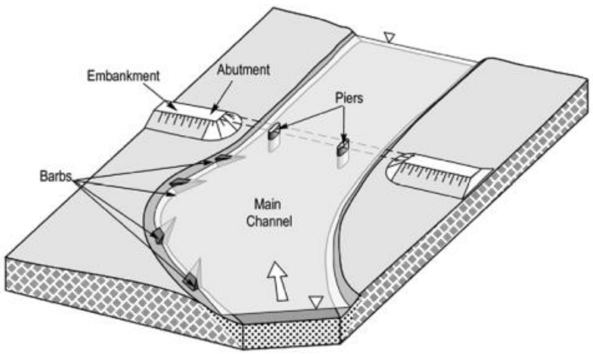
[1] Image source: Cunningham, R.S. and Lyn, D.A., "Laboratory Study of Bendway Weirs as a Bank Erosion Countermeasure," Journal of Hydraulic Engineering, 142(6), 04016004 (2016).

Approach-channel/flow control:

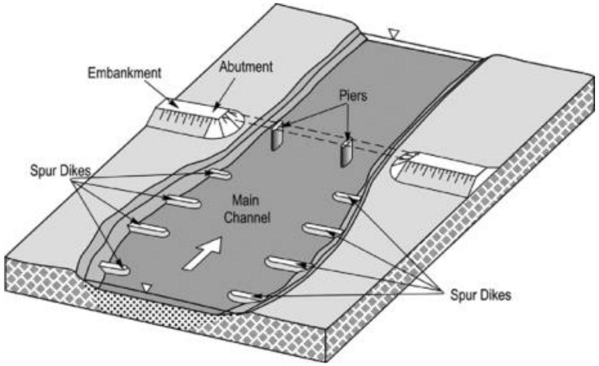
- Spur details:
  - Redirect flow at bend in channel.
  - Halt channel migration.
  - Orient flow more optimally to bridge opening.



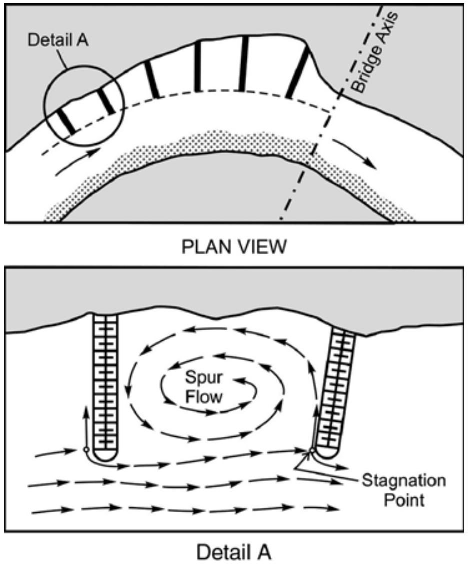
Flow scour and siltation features for spurs (including spur dikes, groins, exposed barbs, and bendway weirs)



Barbs



Spur dikes

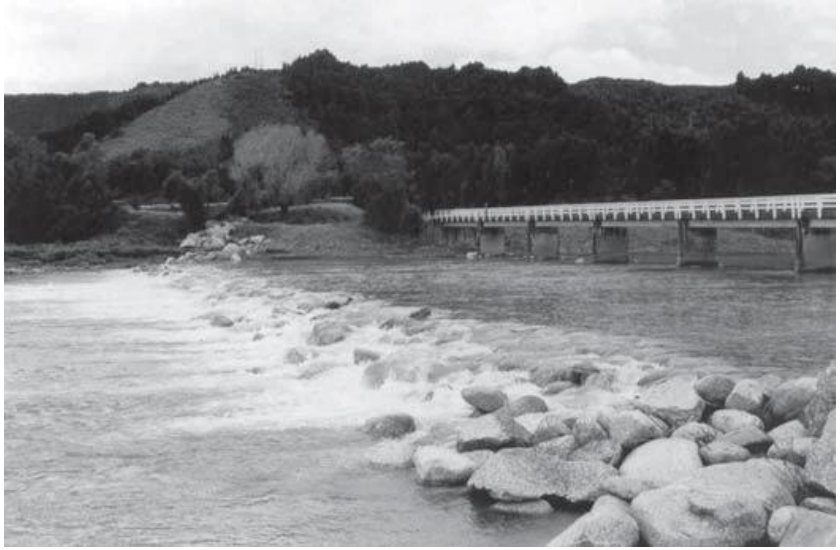


Typical spur dike layout

- **Downstream-channel control:**
  - ❑ Prevention of channel bed degradation:
    - Degradation progressing from downstream typically due to head-cutting:
      - Use of check dam or low weir can be effective.
      - Placement of sheet piling around abutment can also be useful.
      - Lining the channel with riprap or concrete has been observed not to be effective.
  - ❑ Low weirs also useful for upstream channel bed degradation issues.

Sheet pile weir (with fish ladder)

Concrete weir



Downstream weir to arrest head-cutting

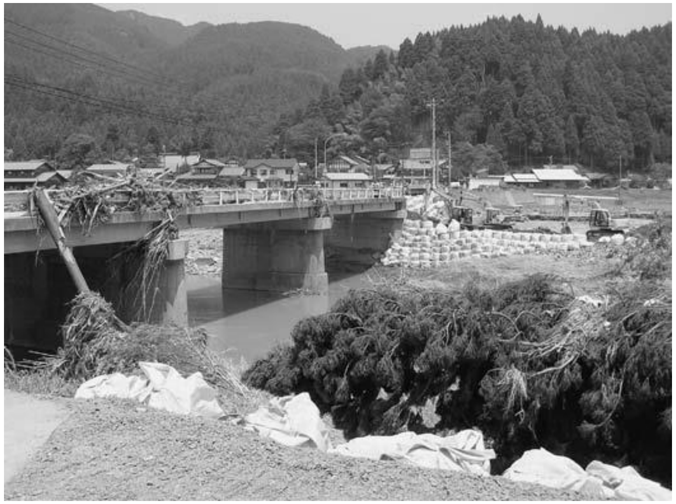
Sheet pile skirt

- Commonly used armoring technologies:
  - Riprap.
  - Cable-tied blocks.
  - Geobags.
- Choice of technology largely up to designer:
  - Consider life-cycle costs.
  - Might also consider aesthetics.

Riprap (Photo source WISDOT)

Cable-tied blocks

Cable-tied blocks (Photo source Contech Company)



Geobags used to form and protect recently damaged abutment.

Figure 10-11. Spur dike installation along the outside bank upstream of an approach channel to a bridge.

2. **Hardpoints.** Place resistant nodes along the bank to make sure that the bank holds its alignment in situations where the approach flow may otherwise tend to shift the channel laterally. The nodes, commonly called hardpoints, are usually formed from rock placed in relatively close spacing. Sometimes, hardpoints are formed from a combination of timber posts and rock. Figure 10-12 illustrates this option, and Figure 10-13 illustrates a typical application.

10.5 Design Guidelines for Localized Abutment Armoring

The construction choice between riprap, cable-tied blocks, or geobags is largely up to the designer and should be based on a life-cycle cost assessment of the structure and/or countermeasure. One exception is that some designers find geobags not particularly pleasing aesthetically and may, therefore, consider geobags a temporary countermeasure.

10.5.1 Wing-Wall Abutments

Riprap

The design parameters for riprap as an abutment scour countermeasure at wing-wall abutments are riprap size and size gradation, riprap layer thickness, filter requirements, and riprap layer extent. Figure 10-14 shows the pertinent parameters.

Riprap size, d_{50}. Riprap size selection can be based on stability against shear and edge failure if the other possible modes of failure are also addressed appropriately.

Either of the following Pagan-Ortiz (1991) and Lagasse et al. (2001) equations, with appropriate factors of safety, are suitable for predicting riprap stone sizes that are resistant to shear failure at wing-wall abutments.

Pagan-Ortiz (1991):

$$d_{50} = \left(\frac{1.064U^2 y^{0.23}}{(S_s - 1)g} \right)^{0.81} \qquad (10\text{-}1)$$

Lagasse et al. (2001):

$$\frac{d_{50}}{y} = \frac{K_s}{(S_s - 1)} Fr^2 \qquad Fr \le 0.8$$

$$\frac{d_{50}}{y} = \frac{K_s}{(S_s - 1)} Fr^{0.28} \qquad Fr > 0.8 \qquad (10\text{-}2)$$

Where:

d_{50} = median size of the riprap stones,
U = mean velocity in the contracted bridge section,

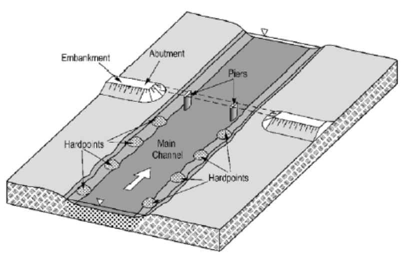


Figure 10-12. Hardpoints placed to keep an approach channel from eroding its banks.

Figure 10-13. Rock hardpoints placed along a bank approach to a bridge.

y = depth of flow in the contracted bridge section,
Fr = Froude number in the contracted bridge section,
S_s = specific gravity of the riprap material,
g = gravitational acceleration, and
K_s = shape factor.

Riprap size selection is appropriately based on stability against shear and edge failure, although consideration of the possibility of winnowing or bed-form undermining is also important in design.

Riprap layer thickness. The criterion given by Lagasse et al. (2001) (discussed in Section 5.6.3) is recommended—that is, the riprap layer thickness should be at least the larger of 1.5 times d_{50} or d_{100}.

Riprap gradation. The Brown and Clyde (1989) criteria (discussed in Section 5.6.3) for correctly grading riprap for bridge abutment protection are recommended. The criteria were shown in Table 5-7 and are shown again here in Table 10-2.

Filter Requirements. As discussed in Section 5.6.3, filters are used to prevent winnowing of bed sediment from between the riprap voids. Filters can be granular (which use the filtering effect of graded sediments) or synthetic (commonly known as geotextiles). Filters are placed beneath riprap layers to meet the following objectives:

- To prevent the groundwater seepage behind the riprap from transporting the underlying sediment through the riprap, commonly known as piping failure. The filter should be fine enough to prevent the base sediment from passing through it, but more permeable than the base sediment being protected to prevent build-up of any excess pore-water pressures.
- To prevent the high level of turbulence in front of the riprap layer from winnowing the underlying material through the riprap.

It is recommended that filters be placed beneath riprap at wing-wall abutments whenever practicable.

Riprap layer extent. Under mobile-bed conditions, riprap aprons placed at wing-wall bridge abutments are subject to undermining due to localized scour and bed-form propagation through the bridge section. Typically, the riprap apron settles (i.e., the outer edge of the riprap layer tends to settle most). If appropriately designed, the riprap layer will remain intact as it settles. The limiting condition for design is when W_{min} is zero. For this situation, the following expression was developed in Section 7.2.4:

$$W = C_1(d_{s2} - d_b + d_{50}) \qquad (10\text{-}3)$$

Where:

W = apron width;
d_{s2} = scour depth (i.e., layer settlement depth) at the outer edge of the riprap;
d_b = placement (i.e., burial) depth of the riprap;
d_{50} = median size of the riprap stones; and
C_1 = 1.68 and 1.19 at the upstream and downstream corners of the riprap layer, respectively.

Equation 10-3 is recommended for determination of the lateral extent of the riprap apron. Furthermore, the apron should extend at least 1.5W upstream and 1.0W downstream from the wing-walls.

Design steps. Design steps are as follows:

1. Estimate the maximum likely scour depth, d_s.
2. Select the riprap size (using Equations 10-1 or 10-2), grading, filter, and layer extent (using Equation 10-3).
3. Sketch the abutment/countermeasure/scour hole geometry (in a cross section) that is likely to appear after scour.
4. Assess the geotechnical stability of the abutment, as shown in Figure 10-15.

Cable-Tied Blocks

The design parameters for cable-tied blocks as an abutment scour countermeasure at wing-wall abutments are block size and shape, cable design, filter requirements, and cable-tied block layer extent.

Cable-tied block aprons are subject to two observed flow-induced failure modes, as described by Parker et al. (1998). The failure modes are overturning and rolling-up of the leading edge of a cable-tied block mat (which can occur in the absence of sufficient anchoring or toeing-in of the leading edge) and uplift of the inner mat (which can occur at higher flow velocities when the leading edge is sufficiently anchored).

Block size. In order to avoid failure by uplift, the weight per unit area, ζ, of the block mattress as a whole, should be greater than the value given by the following equation, which was proposed by Parker et al. (1998):

Armoring system design: please see HEC 18, HEC23, and NCHRP Report 587

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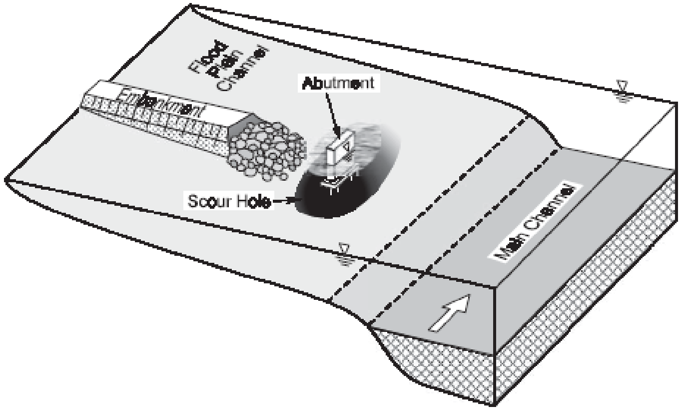
- **Increase bridge span size or add additional span(s):**
  - Very costly approach:
  - ❑ Can reduce flow reduction at bridge opening.
    - Decreases scouring effects.
    - Useful approach if the bridge opening constrains flow enough to cause upstream flooding.
  - ❑ Approach becomes more attractive when a bridge abutment has already been compromised by scour and major remediation is already required.

Bridge abutment critically compromised by scour[1]



[1]Photo source: Ettema, R., Bergendahl, B.S., Yorozuya, A. and Idil-Bektur, P., "Breaching of Bridge Abutments and Scour at Exposed Abutment Columns," Journal of Hydraulic Engineering, 142(10), 06016010 (2016).

- Poorly maintained surface drainage control systems may also threaten bridge abutments:
  - ❑ Increase the geotechnical stability at the abutment.

Erosion due to surface runoff increases scour exposure

Erosion due to surface runoff threatens roadway

Recommendations

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Abutment Scour Concern	Countermeasure Concept	Construction Option
General bed degradation	Use a bed-control structure	1. Place weir across channel to maintain bed level at bridge waterway. 2. Place sheet pile around abutment to maintain bed level at abutment.
Channel or thalweg shift	Use a channel control structure	1. Use a channel-control structure to guide flow away from a bank. 2. Use a bank-control structure to armor the bank and thereby prevent further channel shifting. 3. Shift the abutment back and add a bridge span.
Localized scour at abutment	Modify the flow field at the abutment	1. Align approach-channel banks. 2. Shift the abutment back and add a bridge span. 3. Add a relief bridge. 4. Add a parallel wall or guidebanks. 5. Place flow-deflection spur dikes or groins.
	Armor the abutment boundary	1. Place riprap or cable-tied blocks at spill-through abutments located on floodplain. 2. Place riprap, cable-tied blocks, parallel walls, or spur dikes at wing-wall abutments at main channel bank at narrow crossings. 3. Armor the outflow region of lateral drains and the adjacent channel bank.
	Increase the geotechnical stability of the abutment	1. Place sheet pile around the abutment to retain the embankment.