Briefing Document

Topic XV — Bridge Scour Prediction and Protection

Executive Summary

Bridge scour—the erosion and removal of sediment around bridge foundations due to flowing water—is the leading cause of bridge failure in the United States. Modern understanding recognizes that scour is driven by complex **flow–sediment–structure interactions**, rather than by mean flow alone. Effective prediction and protection therefore require the integration of:

- Hydraulics
- Sediment transport theory
- River morphodynamics
- Engineering judgment

Bridge safety evaluation commonly relies on the concept of **Total Scour**, which combines long-term channel change, contraction scour, and local scour. Although empirical methods such as the **FHWA HEC-18 CSU equation** remain the standard design approach, they often produce conservative estimates and may overpredict field scour by approximately **50–100%**.

Modern bridge-scour assessment increasingly incorporates:

- Numerical modeling (HEC-RAS, SRH-2D, Delft3D)
- Real-time monitoring systems
- Climate-change considerations
- Data-driven and AI approaches

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1. Introduction and Fundamentals

Definition and Significance

Bridge scour is defined as:

The erosion and removal of bed material surrounding bridge piers or abutments due to flowing water.

Bridge scour is particularly important because:

Leading Cause of Bridge Failure

FHWA statistics identify scour as the primary cause of bridge collapses in the United States.

Hidden Nature

Scour frequently develops during flood events and may partially refill after flows recede, making the maximum scour depth difficult to identify after an event.

Economic and Safety Consequences

Potential impacts include:

- Foundation instability
- Structural failure
- Traffic disruption
- Expensive retrofitting and repairs

Total Scour Concept

Bridge design generally assumes:

$$\text{Total Scour} = \text{Long-term Scour} + \text{Contraction Scour} + \text{Local Scour}$$

This represents a conservative simplification because the maximum values of the three components may not occur simultaneously.

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2. Taxonomy and Physical Mechanisms

Long-Term Aggradation and Degradation

Long-term changes involve basin-scale modifications of bed elevation over years to decades.

Degradation

Progressive lowering of the river bed:

$$z_b \downarrow$$

Aggradation

Progressive deposition and rising bed elevation:

$$z_b \uparrow$$

Typical causes include:

- Watershed land-use changes
- Reservoir operations
- Sediment supply imbalance
- River training structures

Contraction Scour

Contraction scour occurs when a bridge opening or channel constriction reduces the effective flow area.

Hydraulic Mechanism

Continuity requires:

$$Q = VA$$

For steady flow:

$$Q_1 = Q_2 = Q$$

Therefore:

$$A \downarrow \Rightarrow V \uparrow \Rightarrow \tau_b \uparrow \Rightarrow \text{Scour} \uparrow$$

Bed shear stress:

$$\tau_b = \rho g R S$$

For a wide channel:

$$\tau_b \approx \rho g y S$$

Scour occurs when:

$$\tau_b > \tau_c$$

where:

$$\tau_c$$

is the critical shear stress for sediment motion.

Local Scour

Local scour develops because of complex vortex systems generated around structural obstructions.

Downflow

Flow striking the pier nose is redirected downward:

- Acts like a vertical jet
- Increases local erosion

Horseshoe Vortex

Forms around the upstream pier base:

- Wraps around the foundation
- Removes sediment efficiently

Wake Vortices

Develop behind the pier due to flow separation:

- Lift sediment
- Transport material downstream

3. Scour Prediction Methods

Clear-Water vs. Live-Bed Scour

Feature	Clear-Water Scour	Live-Bed Scour
Sediment Supply	No upstream transport	Incoming transport present
Initial Bed Condition	Stable bed	Bed already mobile
Equilibrium	Static equilibrium	Dynamic equilibrium
Ultimate Depth	Often deeper	Often shallower

HEC-18 (CSU) Pier Scour Equation

The CSU equation used in HEC-18 predicts local pier scour:

$$\frac{y_s}{y} = 2.0 K_1 K_2 K_3 K_4 \left(\frac{a}{y}\right)^{0.65} Fr^{0.43}$$

where:

y_s = scour depth
y = approach flow depth
a = pier width

Froude number:

$$Fr = \frac{V}{\sqrt{gy}}$$

Correction factors:

K_1 = pier shape factor
K_2 = angle of attack factor
K_3 = bed condition factor
K_4 = armoring factor

Abutment Scour

Abutment scour is frequently estimated using the Froehlich equation.

Important variables include:

- Effective embankment length:

$$L'$$

- Average floodplain depth:

$$y_a$$

These equations are known to be conservative.

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4. Time Evolution and Uncertainty

Temporal Evolution of Scour

Scour development generally follows:

$$y_s(t) = y_{s,\infty}\left(1 - e^{-t/T}\right)$$

where:

$y_{s,\infty}$ = equilibrium scour depth
T = characteristic time scale

Characteristics:

Rapid Initial Development

- High erosion rates occur early

Equilibrium Behavior

- Scour growth slows with increasing hole depth

Live-Bed Fluctuations

- Sediment pulses and migrating bedforms produce fluctuating scour depth

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Predictability and Limitations

Scour prediction remains uncertain because of:

Sensitivity to Variables

Small changes in:

- Velocity
- Sediment size D_{50}
- Bedforms

may substantially alter results.

Laboratory vs Field Differences

Many equations originate from laboratory experiments that may not fully scale to natural systems.

Scatter in Empirical Data

HEC-18 equations frequently overpredict field scour by approximately:

$$50\% - 100\%$$

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5. Engineering Design and Protection

Design Philosophy

Bridge foundations are commonly designed using conservative assumptions:

Worst-Case Flow Conditions

Design typically considers:

- 100-year flood
- 500-year flood

Total Scour Approach

$$\text{Total Scour} = \text{Long-term} + \text{Contraction} + \text{Local}$$

Safety Factors

Additional embedment depth is commonly added.

Scour Protection Methods

Standard FHWA Protection Methods

- Riprap
- Gabions
- Articulated Concrete Block (ACB) systems
- Guide banks

Structural and Experimental Approaches

- Collars
- Slots
- Sacrificial piles

Riprap Design

Riprap sizing often follows a Shields-type relationship:

$$D_{50} \propto \frac{V^2}{(s-1)g}$$

Important design considerations:

- Stone size
- Layer thickness
- Filter layer design
- Edge stability

6. Emerging Challenges: Climate Change

Climate change introduces increasing uncertainty into bridge design.

Observed and anticipated impacts include:

Increased Flood Magnitude

Higher peak discharges:

$$Q_p \uparrow$$

leading to:

$$V \uparrow$$

and:

$$\text{Scour Risk} \uparrow$$

Altered Flood Frequency

Traditional design floods:

- 100-year events
- 500-year events

may no longer accurately represent future risk.

Increased Channel Instability

Possible consequences include:

- Channel migration
- Thalweg movement
- Exposure of overbank piers
- Increased local scour potential

Key Takeaways

- Bridge scour is controlled by **flow–sediment–structure interaction**.
- Total scour consists of **long-term + contraction + local scour**.
- Local scour is dominated by **horseshoe and wake vortices**.
- HEC-18 equations remain the engineering standard but contain substantial uncertainty.
- Scour protection measures and conservative design remain essential.
- Climate change may significantly increase future scour risk.