SCOUR AND STREAM STABILITY PROBLEMS AT HIGHWAY BRIDGES IN THE UNITED STATES

Peter F. LAGASSE
Senior Vice President
Ayres Associates, Inc.
Fort Collins, CO USA

Peter Lagasse obtained his engineering degrees from U.S. Military Academy (BS), University of California, Berkeley (MS), and Colorado State University (PhD). After 20 years with the U.S. Army Corps of Engineers, he has been involved for the last 18 years in River Engineering Consulting, including stream stability and scour at bridges.

SUMMARY
This paper provides an overview of the magnitude of the bridge scour problem in the United States. Procedures and results from the ongoing national program to evaluate all bridges over water for scour vulnerability are highlighted. Current practices for analyzing bridge scour are reviewed and sources of technology transfer are referenced and highlighted, including training courses on bridge scour and stream stability offered by the U.S. Federal Highway Administration, National Highway Institute.

Co-Authors: Dr. L.W. Zevenbergen, Senior Hydraulic Engineer, Ayres Associates, Inc.
Dr. E.V. Richardson, Senior Associate, Ayres Associates, Inc.

1. INTRODUCTION

As of February 1998, results of a national screening of bridges over water by State Highway Agencies indicate that approximately 66,000 bridges are scour susceptible and another 97,000 have unknown foundations. Of the scour susceptible bridges that have been evaluated, about 17,000 have been identified as scour critical. These bridges will require monitoring, repair, or scour protection through the installation of bridge scour and stream instability countermeasures.

Countermeasures for bridge scour and stream instability problems are defined as measures incorporated into a highway-stream crossing system to monitor, control, inhibit, change, delay, or minimize stream instability and bridge scour problems. An action plan for monitoring structures during and/or after flood events can also be considered a countermeasure. Countermeasures also include river stabilizing works over a reach of the river up- and downstream of the crossing. Countermeasures may be installed at the time of highway construction or be retrofitted to resolve stability problems as they develop at existing crossings.

While considerable research has been dedicated to design of countermeasures for scour and stream instability, many countermeasures have evolved through a trial and error process. In addition, some countermeasures have been applied successfully in one locale, state or region, but have failed when installations were attempted under different geomorphic or hydraulic conditions. In many cases, a countermeasure that has been used with success in one state or region is virtually unknown to highway design and maintenance personnel in another state or region. Thus, there is a significant need for information transfer regarding bridge scour and stream instability countermeasure design, installation, and maintenance.

This need resulted in the publication [1] of Hydraulic Engineering Circular Number 23 (HEC-23) in July 1997. HEC-23 "Bridge Scour and Stream Instability Countermeasures - Experience, Selection, and Design Guidance," represents an initial step toward sharing countermeasure experience, selection, and design guidelines among Federal, State, and local highway agency personnel. This information is intended to facilitate the selection and design of countermeasures as State Highway Agencies develop Plans of Action for bridges identified as scour critical.

2. THE COUNTERMEASURES MATRIX

A wide variety of countermeasures have been used to control scour and stream instability at highway bridges. The countermeasure matrix presented in HEC-23 is organized to highlight the various groups of countermeasures and to identify their individual characteristics. The matrix identifies most countermeasures used by State Highway Agencies and lists information on their functional applicability to a particular problem, their suitability to specific river environments, the general level of maintenance resources required, and which states have experience with specific countermeasures. Finally, a reference source for design guidance is noted, where available.

While page limitations and format restrictions preclude presenting the HEC-23 countermeasures matrix in this paper, Table 1 shows the Functional Applications section of the matrix. In Table 1 countermeasures were organized into groups based on their functionality with respect to scour and stream instability. The three main groups of countermeasures are: hydraulic countermeasures, structural counter-measures and monitoring.

Table 1. Bridge Scour and Stream Instability Countermeasures Matrix - Functional Applications

Countermeasure Group	FUNCTIONAL APPLICATIONS				
	Local scour		Contraction Scour	Stream Instability	
	Abutments	Piers	Floodplain and Channel	Vertical	Lateral
GROUP 1. HYDRAULIC COUNTERMEASURES					
GROUP 1.A. RIVER TRAINING STRUCTURES					
TRANSVERSE STRUCTURES					
Impermeable spurs (jetties, groins, wing dams)	◗	◗	○	○	●
Permeable spurs (fences, netting)	◗	◗	○	○	●
Transverse dikes	○	○	○	○	●
Bendway weirs/Stream barbs	◗	◗	○	○	●
Hardpoints	○	○	○	○	●
Drop structures (check dams, grade control)	◗	◗	◗	●	○
Embankment Spurs	◗	○	◗	○	○
LONGITUDINAL STRUCTURES					
Longitudinal dikes (crib/rock toe/embankments)	◗	○	○	○	●
Retards	◗	○	○	○	●
Bulkheads	●	○	○	○	●
Guide banks	●	◗	◗	○	◗
AREAL STRUCTURES/TREATMENTS					
Jacks/tetrahedron jetty fields	○	○	○	○	●
Vanes	○	◗	○	○	●
Channelization	◗	◗	○	○	●
Flow relief (overflow, relief bridge)	◗	◗	●	○	○
Sediment detention basin	○	○	○	●	○
GROUP 1.B. ARMORING COUNTERMEASURES					
REVETMENTS AND BED ARMOR					
Rigid					
Soil cement	●	◗	◗	◗	●
Concrete pavement	●	◗	●	◗	●
Rigid grout filled mattress/concrete fabric mat	●	◗	◗	◗	●
Grouted riprap	◗	○	○	○	◗
Flexible/articulating					
Riprap	●	◗	◗	◗	●
Self launching riprap (windrow)	○	○	○	○	◗
Riprap fill-trench	◗	○	○	○	●
Gabions/gabion mattress	●	◗	◗	◗	●
Wire enclosed riprap mattress (rail bank/sausage)	●	○	○	○	●
Articulated blocks (interlocking and/or cable tied)	●	◗	◗	◗	●
Articulating concrete/grout mattress (fabric-formed)	●	◗	◗	◗	●
LOCAL SCOUR ARMORING					
Riprap (fill/apron)	●	◗	N/A	N/A	N/A
Grouted riprap	◗	○	N/A	N/A	N/A
Concrete armor units (Toskanes, tetrapods, etc.)	◗	◗	N/A	N/A	N/A
Grout filled bags/sand cement bags	●	◗	N/A	N/A	N/A
Gabions	●	◗	N/A	N/A	N/A
Articulated blocks (interlocking and/or cable tied)	●	◗	N/A	N/A	N/A
Sheet pile/cofferdam	◗	◗	N/A	N/A	N/A

Table 1. (Cont'd) Bridge Scour and Stream Instability Countermeasures Matrix - Functional Applications

Countermeasure Group	FUNCTIONAL APPLICATIONS				
	Local scour		Contraction Scour	Stream Instability	
	Abutments	Piers	Floodplain and Channel	Vertical	Lateral
GROUP 2. STRUCTURAL COUNTERMEASURES					
FOUNDATION STRENGTHENING					
Crutch bents/Underpinning	○	●	●	●	◗
Cross bracing	○	●	●	●	○
Continuous spans	○	●	●	●	○
Pumped concrete/grout under footing	●	●	◗	◗	◗
Lower foundation	●	●	●	●	●
PIER GEOMETRY MODIFICATION					
Extended footings	N/A	●	N/A	N/A	N/A
Pier shape modifications	N/A	●	N/A	N/A	N/A
Debris deflectors	N/A	●	N/A	N/A	N/A
Sacrificial piles/dolphins	N/A	●	N/A	N/A	N/A
GROUP 3. MONITORING					
FIXED INSTRUMENTATION					
Sonar scour monitor	◗	●	●	●	◗
Magnetic sliding collar	●	●	●	●	◗
Sounding rods	◗	●	●	●	◗
PORTABLE INSTRUMENTATION					
Physical probes	●	●	●	●	●
Sonar probes	●	●	●	●	●
VISUAL MONITORING					
Periodic Inspection	●	●	●	●	●
Flood watch	●	●	●	●	●

● **well suited/primary use** - the countermeasure is well suited for the application; the countermeasure has a good record of success for the application; the countermeasure was implemented primarily for this application.

◗ **possible application/secondary use** - the countermeasure can be used for the application; the countermeasure has been used with limited success for the application; the countermeasure was implemented primarily for another application but also can be designed to function for this application.

In addition, this symbol can identify an application for which the countermeasure has performed successfully and was implemented primarily for that application, but there is only a limited amount of data on its performance and therefore the application cannot be rated as well suited.

○ **unsuitable/rarely used** - the countermeasure is not well suited for the application; the countermeasure has a poor record of success for the application; the countermeasure was not intended for this application.

N/A **not applicable** - the countermeasure is not applicable to this functional application.

Hydraulic Countermeasures are those which are primarily designed either to modify the flow (river training) or resist erosive forces caused by the flow (armoring). Structural Countermeasures involve modification of the bridge structure (foundation) to prevent failure from scour. Monitoring describes activities used to facilitate early identification of potential scour problems. Monitoring allows for action to be taken before the safety of the public is threatened by the potential failure of a bridge. Monitoring can be accomplished with fixed or portable instrumentation or visual inspection.

3. COUNTERMEASURE CHARACTERISTICS

The countermeasure matrix was developed to identify distinctive characteristics for each type of countermeasure. Five categories of countermeasure characteristics were defined to aid in the selection and implementation of countermeasures:

- Functional Applications
- Suitable River Environment
- Maintenance
- Installation/Experience by State
- Design Guidelines Reference

These categories were used to answer the following questions: For what type of problem is the countermeasure applicable? For what type of river environment is the countermeasure best suited or, are there river environments where the countermeasure will not perform well? What level of resources will need to be allocated for maintenance of the countermeasure? What states or regions in the United States have experience with this countermeasure? Where do I obtain design guidance reference material? Only one category (Functional Applications) is shown in Table 1 to illustrate the organization of the matrix.

4. DESIGN GUIDELINES

Following the countermeasures matrix, design guidelines are provided for several countermeasures which have been applied successfully on a state or regional basis, but for which only limited design references are available in published handbooks, manuals, or reports. No attempt has been made to include in HEC-23 design guidelines for all the countermeasures listed in the matrix. There are, however, references in the matrix to publications that contain at least a sketch or photograph of a particular countermeasure, and in many cases contain more detailed design guidelines.

FHWA currently has four publications dealing with stream instability and bridge scour countermeasures:

- HEC-18 "Evaluating Scour at Bridges [2]
- HEC-20 "Stream Stability at Highway Structures [3]
- HIRE "Highways in the River Environment" [4]
- HEC-11 "Design of Riprap Revetment [5]

These documents contain detailed design procedures for many standard countermeasures such as impermeable and permeable spurs, guidebanks, and riprap for abutments, piers, and revetment.

A number of highway agencies provided specifications, procedures, or design guidelines for bridge scour and stream instability countermeasures that have been used successfully locally, but for which only limited design guidance is available outside the agency. Several of these are presented in HEC-23 following the matrix for the consideration of and possible adaptation to the needs of other highway agencies. Design guidelines for the following seven countermeasures are provided based on information obtained from State Highway Agencies: bendway weirs/ stream barbs, soil cement, wire enclosed riprap, articulated concrete block systems, articulating grout filled mattresses, Toskanes (artificial riprap), and grout filled bags. Design Guideline 8 presents guidance for pier and abutment riprap protection from HEC-18 [2].

5. CONCLUSIONS

The countermeasures matrix and design guidelines presented in HEC-23 provide a wealth of information on experience, selection, and design for bridge scour and stream instability countermeasures. This information is not readily available in any other single source document, and should prove useful to State Highway Agencies as they prepare and implement Plans of Action for scour critical bridges.

The first edition of HEC-23 represents an initial step toward sharing countermeasure experience, selection, and design guidelines among Federal, State, and local highway agencies. It is expected that revisions and additions to the Circular will be made as additional technology and techniques become available and are tested in the field.

REFERENCES

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3. LAGASSE, P.F., J.D. SCHALL, F. JOHNSON, E.V. RICHARDSON, F. CHANG, 1995. "Stream Stability at Highway Structures," Hydraulic Engineering Circular 20, Second Edition, FHWA HI-96-032, Washington, D.C.

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