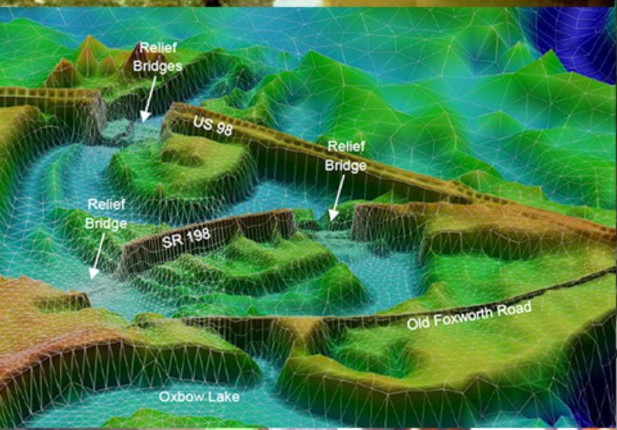


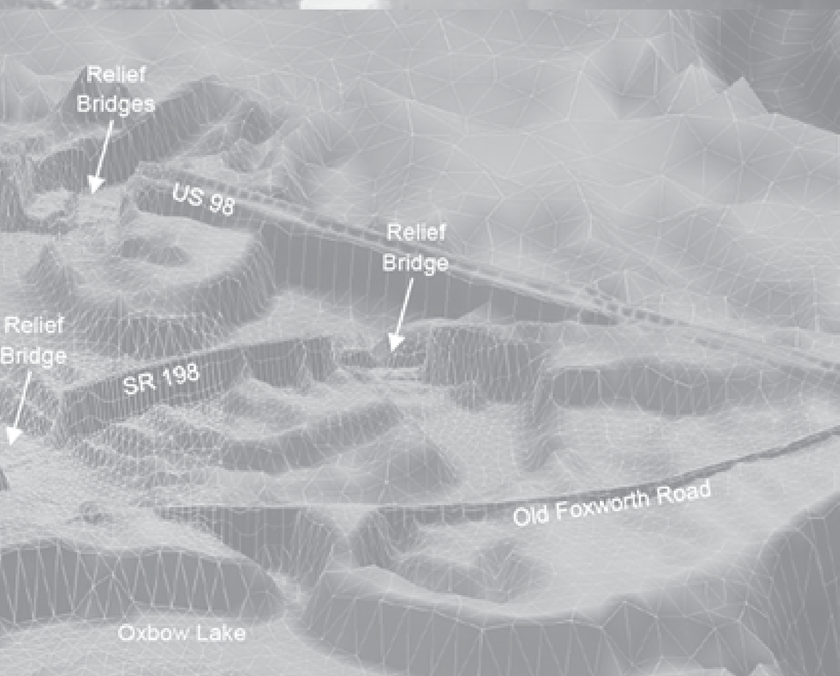
SCAN TEAM REPORT

NCHRP Project 20 68A, Scan 15-02

Bridge Scour Risk Management

Supported by the

National Cooperative Highway Research Program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SR 198
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Oxbow Lake

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The purpose of each scan and of Project 20-68A as a whole is to accelerate beneficial innovation by facilitating information sharing and technology exchange among the states and other transportation agencies, and identifying actionable items of common interest. Experience has shown that personal contact with new ideas and their application is a particularly valuable means for such sharing and exchange. A scan entails peer-to-peer discussions between practitioners who have implemented new practices and others who are able to disseminate knowledge of these new practices and their possible benefits to a broad audience of other users. Each scan addresses a single technical topic selected by AASHTO and the NCHRP 20-68A Project Panel. Further information on the NCHRP 20-68A U.S. Domestic Scan program is available at http://144.171.11.40/cmsfeed/TRBNetProjectDisplay.asp?ProjectID=1570.

This report was prepared by the scan team for Scan 15-02, Bridge Scour Risk Management, whose members are listed below. Scan planning and logistics are managed by Arora and Associates, P.C.; Harry Capers is the Principal Investigator. NCHRP Project 20-68A is guided by a technical project panel and managed by Andrew C. Lemer, PhD, NCHRP Senior Program Officer.

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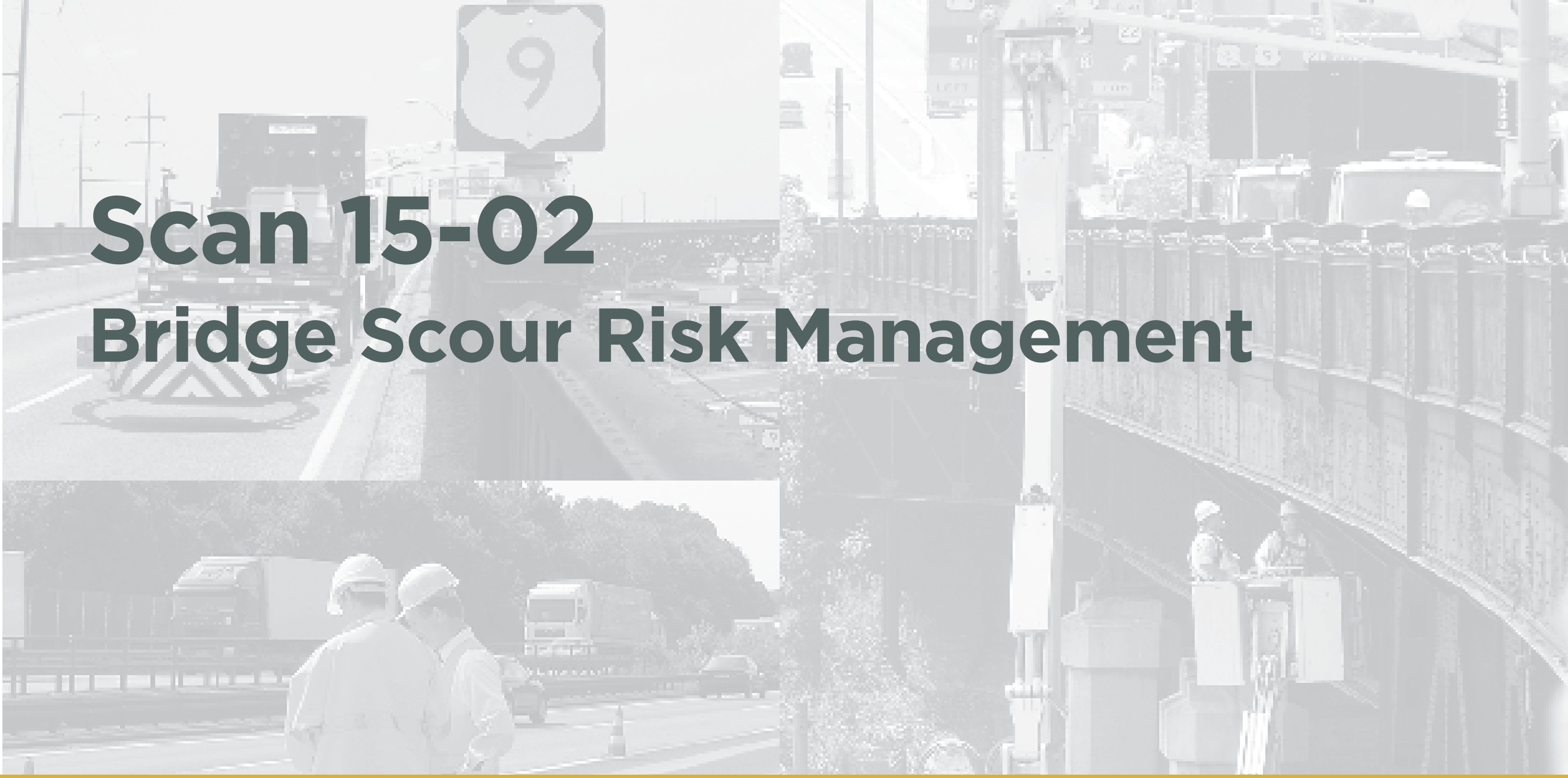
Disclaimer

The information in this document was taken directly from the submission of the authors. The opinions and conclusions expressed or implied are those of the scan team and are not necessarily those of the Transportation Research Board or its sponsoring agencies. This report has not been reviewed by and is not a report of the Transportation Research Board or the National Academies of Sciences, Engineering, and Medicine.

Nothing in this report shall be taken as an endorsement of any company or product. Mention of company and product names is provided for the sole purpose of providing useful information to the reader.



Scan 15-02

Bridge Scour Risk Management

REQUESTED BY THE

American Association of State Highway and Transportation Officials

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The information contained in this report was prepared as part of NCHRP Project 20 68A U.S. Domestic Scan, National Cooperative Highway Research Program.

Table of Contents

List of Appendices

List of Figures

List of Tables

Abbreviations and Acronyms

AASHTO	American Association of State Highway and Transportation Officials
BSA	Bridge Safety Assurance (New York)
Caltrans	California Department of Transportation
CDOT	Colorado Department of Transportation
DOT	Department of Transportation
FDOT	Florida Department of Transportation
FHWA	Federal Highway Administration
HEC 18	Hydraulic Engineering Circular 18, "Evaluating Scour at Bridges"
HEC RAS	Hydrologic Engineering Center's River Analysis System
ITD	Idaho Transportation Department
LaDOTD	Louisiana Department of Transportation and Development
LiDAR	Light Detection and Ranging
MDOT	Michigan Department of Transportation (MiDOT in this report for clarity) Mississippi Department of Transportation (MsDOT in this report for clarity)
MiDOT	Michigan Department of Transportation (MDOT is the correct abbreviation)
MnDOT	Minnesota Department of Transportation
MoDOT	Missouri Department of Transportation
MsDOT	Mississippi Department of Transportation (MDOT is the correct abbreviation)
NBI	National Bridge Inventory
NBIS	National Bridge Inspection Standards
NCHRP	National Cooperative Highway Research Program
NDE	Nondestructive Evaluation
NJDOT	New Jersey Department of Transportation
NYSDOT	New York State Department of Transportation
PennDOT	Pennsylvania Department of Transportation
POA	Plan of Action
RETA	Rotating Erosion Testing Apparatus (a rotating cylinder-style test)
SAR	Scour Assessment Rating
SCBI	Scour Critical Bridge Indicator
SERF	Sediment Erosion Rate Flume (a flume-style test)
SRH-2D	Two-Dimensional Sedimentation and River Hydraulics
TDOT	Tennessee Department of Transportation
TxDOT	Texas Department of Transportation
UDOT	Utah Department of Transportation
USGS	U.S. Geological Survey
WisDOT	Wisconsin Department of Transportation

Executive Summary

Flooding and scour are recognized by the bridge community as the leading cause of bridge failures in the United States. About 83% of the structures listed in the National Bridge Inventory (NBI) cross waterways and are exposed to the threats of flooding and scour. Agencies responsible for bridge safety seek effective threat-mitigation strategies, including installation of scour countermeasures to monitor, control, inhibit, change, delay, or minimize stream instability and bridge-scour susceptibility. Additionally, many states are developing innovative approaches for assessment of structural vulnerability and bridge scour susceptibility; however, the practices differ from state to state. Thus, there is a need to better understand the current state-of-practice in different states and to identify and document successful approaches to reducing bridge-scour risks through the appropriate use of countermeasures.

This scan's goal was to gather current practices from different states, identify best practices, and propose an implementation plan to improve the consistency in applying bridge-scour risk management. This scan's goal was achieved in three stages:

- A desk scan (see Chapter 2)
- A comprehensive questionnaire with amplifying questions for various related topics (See **Appendix A** for the questionnaire and **Appendix B** for a summary of the responses.)
- A workshop with representatives from various states (see **Appendix C**)

In the desk scan, a detailed literature review was conducted regarding scour assessment and countermeasure practices and new developments in these practices. Based on various sources of information, the scan team identified topics that are essential for understanding bridge-scour risk management:

- General Procedures and Risk Analysis
- Scour Modeling and Analysis
- Monitoring and Field Inspection of Scour critical bridges
- Design, Construction, and Sustainability of Countermeasures
- Plan of Action

Various departments of transportation (DOTs) were contacted to collect the information regarding bridge scour assessment and mitigation. The desk scan showed that many DOTs can provide meaningful information on bridge scour assessment and countermeasure processes and practices. However, due to time constraints, a limited number of DOTs were selected for follow-up and further investigation. During the organizational meeting and based on input from the literature review and discussions with the scan team members, the scan team selected 17 states for participation: California, Colorado, Florida, Idaho, Iowa, Louisiana, Michigan, Minnesota, Mississippi, Missouri, New Jersey, New York, Pennsylvania, Tennessee, Texas, Utah, and Wisconsin.

A comprehensive questionnaire of amplifying questions covering various topics was distributed to the selected states (see **Appendix A**); the responses to the questionnaire were compiled and are summarized in Appendix B. Fourteen states made technical presentations during the workshop (see Appendix C), which was held to identify the best practices and propose an implementation plan for the future.

The findings of this scan provided a better understanding of the current state-of-practice for bridge scour risk management and identified best practices. Based on the findings, the scan team made recommendations and proposed an implementation plan to improve scour assessments and countermeasures. These findings, conclusions, and recommendation are summarized in this report.

Introduction

Overview

Bridge structures constitute a major part of the national investment. There are 611,845 bridges in the United States and about 83% of them are over waterways and require scour consideration (National Bridge Inventory [NBI], 2015)[1]. Major decisions must be made to allocate the limited funds available for bridge monitoring, repair, rehabilitation, and/or replacement. The basis for these decisions should be based on risk management, including guidelines for the assessment and evaluation of the bridge foundation's structural integrity due to scour. Because scour is the number one cause of bridge failures, a definite need exists to understand better the current state-of-practice within the contiguous U.S. to help achieve enhanced safety in this area.

This scan was built upon the findings of various National Cooperative Highway Research Program (NCHRP) studies related to the assessment of scour, focusing on how to manage the risk of scour. In addition, the scan compiles further details on the current policies and procedures that govern the scour risk management within the U.S. and which are of particular interest to state departments of transportation (DOTs) and the American Association of State Highway and Transportation Officials (AASHTO) Subcommittee on Bridges and Structures[2].

Invited Agencies

The information regarding scour risk management was collected from the agencies invited to participate in this scan (see **Table 1 1**). The scan team engaged structural engineers (including bridge design, construction, and inspection engineers), hydraulic, and geotechnical engineers within the participating states, as well as others deemed appropriate, to study in detail and document their specific processes and procedures for scour management, mitigation, and countermeasures. The team specifically focused on how these DOTs ensure bridge safety, assess vulnerability, and manage risks due to scour.

The scan's findings provide a better understanding of the current state-of-practice for bridge scour risk management. Additionally, this scan identified the need for further research to enhance bridge scour assessment and to provide improved guidance on the methodology for bridge scour risk assessment and management. The scan findings also provide DOTs with valuable information regarding future trends pertaining to bridge scour risk management. This scan was conducted as a Type 3 Scan – Peer Exchange.

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1 National Bridge Inventory (NBI), Federal Highway Administration (FHWA), https://www.fhwa.dot.gov/bridge/nbi.cfm

2 Committee on Bridges and Structures, American Association of State Highway and Transportation Officials, https://bridges.transportation.org/

State DOT	Office/Branch
California	Caltrans (Hydraulic and Geotechnical)
Colorado	Colorado DOT (CDOT)
Florida	Florida DOT (FDOT)
Idaho	Idaho Transportation Department (ITD)
Iowa	Iowa DOT
Louisiana	Louisiana Department of Transportation and Development (LaDOTD)
Michigan	Michigan DOT (MiDOT)[3]
Minnesota	Minnesota DOT (MnDOT)
Mississippi	Mississippi DOT (MsDOT)[2]
Missouri	Missouri DOT (MoDOT)
New Jersey	New Jersey DOT (NJDOT)
New York	New York State DOT (NYSDOT)
Pennsylvania	Pennsylvania DOT (PennDOT)
Tennessee	Tennessee DOT (TDOT)
Texas	Texas DOT (TxDOT)
Utah	Utah DOT (UDOT)
Wisconsin	Wisconsin DOT (WisDOT)

Table 1.1 Scan participants

Methodology

The team conducted a desk scan to collect information regarding the state-of-the-practice and how various state DOTs manage risks related to bridge scour. The information collected during the desk scan was used to finalize the list of candidate states for further contact and visits. The desk scan included a literature search to identify the best practices and the state-of-art research in scour mitigation. Based on various sources of information, the scan team identified these topics as being essential for understanding scour risk management:

- General Procedures and Risk Analysis
- Scour Modeling and Analysis
- Monitoring and Field Inspection of Scour critical bridges
- Design, Construction, and Sustainability of Countermeasures
- Plan of Action (POA)

Each topic focused on one aspect of the overall framework needed to apply a successful strategy for managing scour risks. In response, and to help get a collective response prior to the workshop, the scan team developed and sent a list of amplifying questions to the invited agencies for their input and suggestions (see **Appendix A**); the questions were designed to also address the five topics listed above. The DOTs' responses to the amplifying questions were comprehensive (see **Appendix B** for a summary).

3 Since Michigan and Mississippi DOTs share the same abbreviation (MDOT), this report uses MiDOT and MsDOT to distinguish between the two agencies.

The scan team members and invited DOT representatives met during a four-day workshop in San Diego, CA, and discussed various aspects of the topics identified during the desk scan. Moreover, other important topics, as deemed appropriate by the team, were addressed during the technical presentations and discussions. The scan team met the day after the workshop for further deliberation and discussion and to finalize the scan's findings, conclusions, and recommendations.

Arora and Associates, P.C.4, developed the workshop program to help facilitate the discussions and technical presentations between the invited speakers and the scan team. At the end of each day of the workshop, the scan team chair provided numerous opportunities for open discussions and for participants to identify the two most-important take-away points from the discussions and presentations. During the fourth day of the workshop, these important take-away points were compiled under the five topics. These points were presented to the workshop participants, who helped provide consensus and prioritization by voting for only the most-relevant and important two items under each topic. Given the interdisciplinary nature of bridge scour, this process included input from structural, hydraulics, and geotechnical engineers who participated in the workshop.

On the last day of the workshop, the scan team reviewed the findings and provided additional input to help finalize the conclusions and recommendations. The following sections provide information from the desk scan and a summary of the findings, conclusions, and recommendations from the workshop based on each of the five previously identified topics.

4 Arora and Associates, P.C., http://www.arorapc.com/

Desk Scan

The desk scan focused on categorizing and focusing on references pertaining to vulnerability assessment, countermeasures, and monitoring systems as they relate to the main topics of the scan. This section of the report provides a review of the literature for each of these topics:

Vulnerability Assessment

Landers (1994)[5] provided one of the earlier studies that developed a bridge scour data management system by the U.S. Geological Survey (USGS) to support preparation, compilation, and analysis of bridge scour measurement data. The data set includes four essential categories of information from a detailed scour measurement: site data, measured scour data, flood event data, and channel geometry data. Various options in the program permit the selection of prediction equations and computation of scour depth estimates for comparison with observed scour depths. The database facilitated developing improved estimators of scour for specific regions or conditions, describing scour processes, and reducing risk from scour at bridges.

Smith (1994)[6] developed a procedure to predict scour depths in bedrock that accounts for both the hydraulic conditions at the bridge site and the bedrock's ability to resist erosion. This report applies its findings to bridge scour analysis and presents an interim procedure for estimating bridge scour depths in bedrock and other materials defined by the erodibility index presented by Annandale (1993, 1995)[7],[8].

The Federal Highway Administration (FHWA) released the first version of Hydraulic Engineering Circular 18 (HEC-18), "Evaluating Scour at Bridges," in 1991[9] to serve as a guidance manual. This manual has been updated several times as new methods and approaches become available. The current version was released in 2012. Stein et al. (1999)[10] developed a method for assessing the risk associated with scour threat to bridge foundations. The risk of scour failure is calculated as the product of the cost associated with failure and the probability of scour failure. The method is based on data included in the NBI. The risk determines the ranking of bridges for gathering foundation data in support of more detailed scour evaluation. The calculated high risks could vanish if substantial foundations are discovered.

5 Landers, M., (1994) "Bridge Scour Data Management", Hydraulic Engineering: Saving a Threatened Resource—In Search of Solutions: Proceedings of the Hydraulic Engineering sessions at Water Forum '92, American Society of Civil Engineers, Baltimore, Maryland, August 2–6, pp. 1094-1099.

6 Smith, S. P. (1994). *Preliminary Procedure to Predict Bridge Scour in Bedrock*. Colorado Department of Transportation.

7 Annandale, G.W., *Analysis of Complex Scour Problems in Rock and Other Earth Materials*, HDR Engineering, 5175 Hillsdale Circle, El Dorado Hills, California, 95762-5700, 1993.

8 Annandale, G. W., *Erodibility*, Journal of Hydraulic Research for publication, 1995.

9 Arneson, L. A., Zevenbergen, L. W., Lagasse, P. F., & Clopper, P. E. (2012). *Evaluating scour at bridges* (No. FHWA-HIF-12-003).

10 Stein, S. M., Young, G. K., Trent, R. E., & Pearson, D. R. (1999). Prioritizing scour vulnerable bridges using risk. J*ournal of Infrastructure Systems*, 5(3), 95-101.

Kattell and Eriksson (1998)[11] conducted their investigation under the Forest Service Scour Evaluation Program by Engineering Technology Development Proposal. This study reviewed the FHWA guidelines and existing public road agency scour programs and developed a scour evaluation program.

Additionally, Briaud et al. (1999)[12] developed a method for determining scour in cohesive soils as a function of time around cylindrical bridge piers. The method utilizes the results of the erosion testing of cohesive soil samples in an erosion function apparatus. This method was then extended in NCHRP Report 516, "Pier and Contraction Scour in Cohesive Soils," (2004)[13] to include contraction scour and complex pier scour. This research was the first to combine actual erosion rates from soil samples to assist in the calculation of scour, which led to the realization that soil type influences scour.

In their detailed report, Annandale and Smith (2001)[14] explained the use of the erodibility index method to calculate bridge pier scour. The method can be used to predict scour in any earth material, including rock and cohesive and noncohesive soils. A relationship between the geomechanical index and the erosive power of water defines the scour threshold that is used in the scour calculations. The report outlined the methods that are used to quantify the geomechanical index and those that are used to estimate the erosive power of water flowing around bridge piers and explained how to calculate scour depth. Application of the method is illustrated with an example.

Additionally, in their report, Henneberg and Strause (2002)[15] presented instructions required to use the Scour critical bridge Indicator (SCBI) Code and Scour Assessment Rating (SAR) calculator developed by PennDOT and the USGS to identify Pennsylvania bridges with excessive scour conditions or a high potential for scour.

Another example of a state-produced manual, the NYSDOT Hydraulic Vulnerability Manual (2003)[16] provided in detail the different facets of a hydraulic vulnerability program.

Federico et al. (2003)[17] proposed a simple procedure to assess the vulnerability of bridge piers in rivers, considering the phenomena governing fluvial dynamics during flood events. The procedure requires an estimation of the maximum scour depth of both the pier and the foundation, as well as an analysis of the bearing capacity of the pier–foundation–soil geotechnical system. Two levels of

11 Kattell, J., & Eriksson, M. (1998). *Bridge scour evaluation: Screening, analysis, & countermeasures* (No. 9877 1207--SDTDC).

12 Briaud, J.-L., Ting, F. C. K., Chen, H. C., Gudavalli, R., Perugu, S., Wei, G., 1999 (a), "SRICOS: Prediction of Scour Rate in Cohesive Soils at Bridge Piers," Journal of Geotechnical Engineering, Vol. 125, No. 4, April 1999, pp. 237-246, American Society of Civil Engineers, Reston, Virginia, USA.

13 Briaud, J.-l., Chen , h.-c., Li y., Nurtjahyo, p., and Wang, j. (2004) "Pier and Contraction Scour in Cohesive Soils," National Cooperative Highway Program (NCHRP) Report 516, pp 136.

14 Annandale, G., & Smith, S. P. (2001). *Calculation of Bridge Pier Scour Using the Erodibility Index Method* (No. CDOT-DTD-R-2000-9,). Colorado Department of Transportation [Division of Transportation Development].

15 Henneberg, M. F., & Strause, J. L. (2002). *Software user's guide for determining the Pennsylvania scour critical indicator code and streambed scour assessment rating for roadway bridges* (No. 2001-446).

16 NYSDOT Structures Design and Construction Division Bridge Safety Assurance Unit. (2003) *Hydraulic Vulnerability Manual.* NYSDOT.

17 Federico, F., Silvagni, G., & Volpi, F. (2003). Scour vulnerability of river bridge piers. *Journal of geotechnical and geoenvironmental engineering, 129*(10), 890-899.

allowable vulnerability (low and medium), bounded by an extreme condition of high vulnerability, are defined and analytically determined as a function of the maximum scour depth and the foundation depth. Specific diagrams corresponding to each category of foreseen actions allow a quick evaluation of the vulnerability of a bridge pier.

In their report, Stein and Sedmera (2006)[18] presented a risk-based approach to manage bridges in the absence of foundation information. Guidelines illustrated how to collect appropriate data, estimate risk of failure from an estimated failure probability and associated economic losses, and use risk in a structured approach to select an appropriate management plan. The risk analysis in this study is specifically used to select appropriate performance standards for various bridge classifications and justify the costs for nondestructive testing of foundations, monitoring activities, and countermeasures. The scour guidelines were then applied to 60 case studies in the U.S. to validate the management plan that it selected for bridges with known foundations and to illustrate its specific application in a variety of settings and conditions.

Briaud et al. (2009)[19] proposed a new method to assess scour in bridges. The method includes three levels of assessments (Bridge Scour Assessment 1, 2 and 3), which are illustrated and applied for the assessment of Texas bridges for scour.

MiDOT (2009)[20] described its policy regarding the evaluation of scour at bridges over water throughout the state.

FDOT (2009)[21] developed a manual describing various aspects of bridge scour in the state, including a summary of scour, detailed treatments of general scour, and calculation of local scour. Additionally, Sheppard (2003)[22] and Sheppard and Glasser (2009)[23] developed equations for pier and complex pier scour, which is currently included in the HEC-18 manual. Also, Bloomquist et al. (2012)[24] developed a means of testing the erosion of soils utilizing a flume-style test (sediment erosion rate flume [SERF]) and a rotating cylinder-style test (rotating erosion testing apparatus [RETA]).

Carpenter and Miller (2011)[25] worked on a study that was intended to improve MiDOT's bridge scour prediction capability. The research team evaluated scour prediction methods utilized by state DOTs, conducted a field-data collection project, and proposed an alternative approach for pier scour prediction. Nine locations and 12 unique spans were selected for monitoring. This investigation

18 Stein, S., & Sedmera, K. (2006). *Risk-based management guidelines for scour at bridges with unknown foundations*. Transportation Research Board of the National Academies.

19 Briaud, J. L., Govindasamy, A. V., Kim, D., Gardoni, P., Olivera, F., Chen, H. C., and Elsbury, K. (2009). *Simplified method for estimating scour at bridges* (No. FHWA/TX-09/0-5505-1).

20 MDOT (2009) *Bridge Scour Evaluation Procedure for Minnesota Bridges*. Minnesota Department of Transportation.

21 FDOT (2005) *Bridge Scour Manual*. Florida Department of Transportation.

22 Sheppard, D.M., (2003) "Scour at Complex Piers," Final Report, Florida Department of Transportation Project Number: BC354 RPWO 35, 48 pp.

23 Sheppard, D.M. and Glasser, T. (2009) "Local Scour at Bridge Piers with Complex Geometries," International Foundation Congress and Equipment Expo 2009, ASCE.

24 Bloomquist, D., Sheppard, D. M., Schofield, S., and Crowley, R. W., (2012) "The Rotating Erosion Testing Apparatus (RETA): A Laboratory Device for Measuring Erosion Rates versus Shear Stresses of Rock and Cohesive Materials," *Geotechnical Testing Journal*, Vol. 35, No. 4, pp. 641-648.

25 Carpenter, D. D., & Miller, C. (2011). *A critical evaluation of bridge scour for Michigan specific conditions* (No. RC-1547).

also included the use of a jet erosion test to experimentally determine if in-situ soil conditions could be correlated with measured bridge scour. In conclusion, a modified HEC-18 pier scour prediction equation was developed for application in Michigan using the National Bridge Scour Database.

Ettema et al. (2011)[26] evaluated the state of knowledge at that time regarding bridge-pier scour, assessed leading methods for reliable design estimates of scour depth, proposed a structured methodology for scour-depth estimation for design purposes, and indicated pier-scour aspects in need of further research. The research information obtained since 1990 compelled the need to change the design method currently recommended by the principal authoritative design guides (notably FHWA's HEC-18[8] and AASHTO[27]) and used widely by bridge-engineering practitioners. Additionally, it indicated that several important aspects of pier scour processes remain inadequately understood and not yet incorporated into design methods.

Heron and Bowe (2012)[28] described the screening and vulnerability rating system that was developed and how it related to the two main industry standard documents on scour inspections (HEC-18[8] and Bridge Advice Note 74/06 (BA 74/06)[29]). It set out the desk study required and the on-site inspections the bridge inspector carries out in combination with an underwater dive team. Each step in the process was set out in a series of logical step diagrams with a detailed explanation of each step.

In response to numerous scour-related bridge failures, FHWA has mandated that states evaluate all bridges over water for scour. In 1991, FHWA released HEC-18, "Evaluating Scour at Bridges," to serve as a guidance manual in evaluating scour. This document has been updated several times; the current edition is the fifth8. It presents the state of knowledge and practice for the design, evaluation, and inspection of bridges for scour and now contains revisions obtained from further scour-related developments and the use of the 2001 edition by the highway community. The major changes in the fifth edition of HEC-18 are expanded discussion on the policy and regulatory basis for the FHWA Scour Program, including risk-based approaches for evaluations, developing plans of action (POAs) for scour critical bridges, and expanded discussion on countermeasure design philosophy (new versus existing bridges). This latest edition includes a new section on contraction scour in cohesive materials, an updated abutment scour section, alternative abutment design approaches, alternative procedures for estimating pier scour, and new guidance on pier scour with debris loading.

Neerukatti et al. (2013)[30] discussed a Gaussian process model, which includes Bayesian uncertainty for prediction of time-dependent scour evolution. The model was validated based on the experimental data conducted in four different flumes in different conditions. The robustness of the algorithm was demonstrated under different scenarios, like lack of training data and equilibrium scour conditions. The results indicated that the algorithm is able to predict the scour evolution with an error of less than 20% for most of the time and 5% or less given enough training data.

26 Ettema, R., Melville, B. W., & Constantinescu, G. (2011). *Evaluation of bridge scour research: Pier scour processes and predictions.* Washington, DC: Transportation Research Board of the National Academies.

27 AASHTO LRFD (2010). Bridge design specifications.

28 Heron, B., & Bowe, C., (2012). Bridge Scour Investigation: *Developing A Screening and Hydraulic Vulnerability Rating System for Bridges.* OCSC.

29 Design Manual for Roads and Bridges BA 74/06, (2006). Assessment of Scour at Highway Bridges. Highways Agency, London.

30 Neerukatti, R. K., Kim, I., Fard, M. Y., & Chattopadhyay, A. (2013, April). Prediction of scour depth around bridge piers using Gaussian process. *In Proc. of SPIE* Vol (Vol. 8692, pp. 86922Z-1).

Lagasse et al. (2013)[31] presented the results of an investigation of risk-based approaches to consider the uncertainties associated with bridge scour prediction. An essential element of this research was the development of software that links the one-dimensional hydraulic model (the Hydrologic Engineering Center's River Analysis System [HEC-RAS]) with Monte Carlo simulation techniques. Tables of probability values (scour factors) that addressed pier scour, contraction scour, abutment scour, and total scour were presented. These tables would allow associating an estimate of scour depth with a conditional (i.e., single event) probability of exceedance when a bridge meets certain criteria for hydrologic uncertainty, bridge size, and pier size. For complex foundation systems and channel conditions, a step-by-step procedure was presented to provide scour factors for site-specific conditions. A set of detailed illustrative examples was included, in addition to a developed software that links a one dimensional hydraulic model (such as HEC-RAS) with Monte Carlo simulation techniques. However, this guide has been published only recently and has not yet been widely used by various DOTs.

Garrow and Sturm (2013)[32] developed a risk assessment framework based on a model developed to assess the probability of a bridge failure due to scour. Risk measures, such as those developed as part of this study, could be included in asset management systems to help state DOTs prioritize maintenance, operation, and replacement schedules.

Zhang et al. (2013)[33] evaluated the applicability of the existing HEC-18 documents method to Louisiana bridges that are mostly situated on cohesive soils and hence develop a more reliable design method for scour depth and scour rate prediction.

Tanasić et al. (2013)[34] discussed the identification of possible modes of bridge failure caused by scouring that depend on soil, structure, and river hydraulic properties. The degradation of soil parameters was assumed to be the main cause of bridge failure. Then a simulation of the redistribution of traffic flows was described for several possible scenarios. These simulations used state-of-the-art software, PTV Visum[35], which was developed for computer-aided transportation planning and analysis. The simulated scenarios include the partial and full closure of road links as a result of bridge failures. The simulations confirmed that the most significant contribution to indirect costs stems from the increase in the total travel time of all network users.

Amini et al. (2014)[36] presented an experimental investigation of clear water scour at complex piers. Five complex piers, comprising different configurations of piles, pile cap, and column, were tested

31 Lagasse, P. F., Ghosn, M., Johnson, P. A., Zevenbergen, L. W., & Clopper, P. E. (2013). Risk-based approach for bridge scour prediction. Final Rep. Prepared for National Cooperative Highway Research Program, Transportation Research Board, National Research Council, Washington, DC.

32 Garrow, L., & Sturm, T., (2013). *Development of a Risk-Based Scorecard to Assess Scour Vulnerability of Georgia's Bridges.* Georgia Institute of Technology Research Report. FHWA-GA-13-1127.

33 Zhang, G., Hsu, S. A., Guo, T., Zhao, X., Augustine, A. D., & Zhang, L. (2013). *Evaluation of Design Methods to Determine Scour Depths for Bridge Structures* (No. FHWA/LA. 11/491).

34 Tanasić, N., Ilić, V., & Hajdin, R. (2013). Vulnerability assessment of bridges exposed to scour. *Transportation Research Record: Journal of the Transportation Research Board*, (2360), 36-44.

35 PTV Visum, PTV Group, http://vision-traffic.ptvgroup.com/en-us/products/ptv-visum/

36 Amini, A., Melville, B. W., & Ali, T. M. (2014). Local scour at piled bridge piers including an examination of the superposition method. *Canadian Journal of Civil Engineering,* 41(5), 461-471.

in a laboratory flume using uniform bed material. The piers were tested for a range of possible elevations relative to the streambed elevation. A comparison of the results for the intact piers and for their components enabled an evaluation of the prediction methods involving superposition of scour depths at piles, pile cap, and pier column. The superposition method was found to give inadequate estimates of total scour depth in many cases.

Benedict et al. (2014)[37] conducted investigations by the USGS and South Carolina DOT that provided bridge-scour envelope curves for assessing scour potential associated with all components of scour at riverine bridges in South Carolina. The application and limitations of these envelope curves were documented and the need to develop an integrated procedure for applying the South Carolina bridge-scour envelope curves was emphasized. To address this need, this study developed an integrated procedure and documented the method in a guidance manual. In addition to developing the integrated procedure, field data from other investigations outside of South Carolina were used to verify the South Carolina bridge-scour envelope curves.

Countermeasures

Agrawal et al. (2007)[38] prepared a handbook to provide unified guidelines for design of scour countermeasures for both new and old bridges in New Jersey to city, county, and state engineers and bridge structural consultants. All important aspects specific to scour conditions in New Jersey have been identified. A detailed review of all available resources on scour countermeasure design, including HEC publications 11[39], 18[8], 20[40] , and 23[41], the CIRIA Manual (2002)[42], the NCHRP 24-07 report[43], scour countermeasure drawings by the Maryland State Highway Administration, and numerous research articles on scour countermeasure design, has been carried out to recommend effective countermeasures suitable to river conditions in New Jersey. Guidelines proposed for selected countermeasures are based on their effectiveness during past applications around the world, physical tests, and the best design practice followed in the subject area. The design guidelines presented in this handbook supplement hydraulic engineering circulars and have been developed with an aim to provide engineers all important aspects of scour countermeasure design for New Jersey conditions in a collective and systematic manner.

37 Benedict, S. T., Caldwell, A. W., & Feaster, T. D. (2014). A Guidance Manual for Assessing Scour Potential Using the South Carolina Bridge-Scour Envelope Curves.

38 Agrawal, A. K., Khan, M. A., Yi, Z., & Aboobaker, N. (2007). *Handbook of scour countermeasures designs.* New Jersey Department of Transportation.

39 Brown, S. A., & Clyde, E. S. (1989). *Design of riprap revetment: Federal Highway Administration Hydraulic Engineering Circular No. 11.* Publication FHWA-IP-89-016.

40 Lagasse, P. F., Zevenbergen, L. W., Spitz, W. J., & Arneson, L. A. (2012). *Stream stability at highway structures* (No. FHWA-HIF-12-004).

41 *Hydraulic Engineering Circular No. 23, Vol. 2.* FHWA NHI-09-112, Federal Highway Administration, Washington, DC.

42 May, R.W.P., J.C. Ackers and A.M. Kirby. *Manual on scour at bridges and other hydraulic structures.* CIRIA 2002, Construction Industry Research and Information Association, London, 2002

43 Lagasse, P. F. (2007). *Countermeasures to protect bridge piers from scour* (Vol. 593). Transportation Research Board.

Abboud and Kaiser (2012)[44] reviewed state-of-the-art scour countermeasure technology and developed methodology and procedures for selecting and designing functional and cost-effective scour countermeasures for Pennsylvania scour critical bridges, with special reference to District 6-0 scour critical bridges. District 6-0 engineers identified five scour critical bridges for this project, which were used to apply the research results. The state-of-the-art in scour countermeasures technologies currently used in the U.S. and around the world were narrowed down to apply specifically to Pennsylvania bridges. Methodologies and procedures were developed and proposed to simplify the process of prioritizing scour critical bridges, select an appropriate scour countermeasure based on both performance and cost, and design the selected countermeasure(s) at the bridge site.

Monitoring Systems

Haas et al. (1999)[45] proposed that an algorithm based on code contained in the Bridge Inventory, Inspection and Appraisal Program (BRINSAP) database can be used effectively to prioritize bridge sites for further consideration of scour countermeasure implementation. Remote mechanical monitoring is an emerging method for detecting and tracking bridge scour. Using mechanical scour monitors equipped with data telemetry equipment was proposed to provide a safe and effective means of tracking scour at bridge piers and abutments.

O'Connor (2000)[46] briefly overviewed the hydraulic vulnerability assessment process, including screening, classifying, rating, and POAs; FHWA Item 113 code in NBI, FloodWatch®[47], a web-based monitoring software program, and critical items during field inspection were also discussed.

Nassif et al. (2002)[48] focused on the implementation and evaluation of the NCHRP Project 21-3, "Instrumentation for Measuring Scour at Bridge Piers and Abutments" designated system(s) for monitoring bridge scour. Two systems were considered to monitor the scour critical bridges in New Jersey, including magnetic sliding collar and sonar systems. It was found that the collar and sonar devices complement each other to provide a clear and accurate picture of the scour activity.

ITD (2004)[49] developed a manual with guidance on the procedures for high-flow monitoring as a field reference for use by monitoring crews. It described basic scour concepts and definitions and the content of POAs for scour-critical bridges. It also explained commonly used scour monitoring equipment, monitoring procedures, and emergency action protocols.

44 Abboud, B., Kaiser, S., (2012). *Selection & Design of Scour Countermeasures for Pennsylvania Bridges,* Pennsylvania Department of Transportation, FHWA-PA-2012-001-TEM 001.

45 Haas, C., Weissmann, J., & Groll, T. (1999). *Remote Bridge Scour Monitoring: A Prioritization and Implementation Guideline* (No. TX-00/0-3970-1,). Center for Transportation Research, The University of Texas at Austin.

46 O'Connor, J. (2000). Bridge safety assurance measures taken in New York State. *Transportation Research Record: Journal of the Transportation Research Board,* (1696), 187-192.

47 http://www.usengineeringsolutions.com/flood-watch/

48 Nassif, H., Ertekin, A. O., & Davis, J. (2002). Evaluation of bridge scour monitoring methods. *United States Department of Transportation, Federal Highway Administration, Trenton.* FHWA-NJ-2002-009, March, 89 p.

49 Idaho Department of Transportation. (2004). Scour critical bridges: *High-Flow Monitoring and Emergency Procedures*. Idaho Transportation Department Report.

Ettema et al. (2006)[50] illustrated a practical guide for monitoring, maintaining, and protecting bridge waterways to mitigate or prevent scour from adversely affecting the structural performance of bridge abutments, piers, and approach road embankments. Methods for monitoring waterways and the various methods for repairing scour damage and protecting bridge waterways against scour were discussed. Additionally, the guide may be implemented as a part of the process to check whether existing bridge-inspection forms or reports adequately encompass bridge-waterway scour.

Vieux, Inc. (2008)[51] focused on the hydrologic application of radar that was developed for the Oklahoma DOT.

Hunt (2009)[52] worked on a synthesis describing the state of knowledge, research, and practice for fixed scour monitoring of scour critical bridges. This project carried out a survey of transportation agencies and other bridge owners, including 37 state DOTs, to obtain their experiences with fixed scour monitoring systems. Information on scour monitoring for nonresponding states was obtained from the literature review. For those agencies that have not employed scour monitoring systems, their opinions were requested regarding problems and suggestions. The problems the states reported were very similar. The difficulties with maintenance and repairs to the scour monitoring systems were the most common theme throughout the survey responses. The advancements that bridge owners would like to see for future fixed scour monitoring technology included the development of durable instrumentation, with increased reliability and longevity, decreased costs, and minimum or no maintenance.

Lueker et al. (2010)[53] collected the expertise of various experts in Minnesota to take the first steps toward developing robust scour monitoring for Minnesota river bridges. This study identified the variables of scour critical bridges that affect the application of scour monitoring technology. This information could be used to develop a scour monitoring decision framework that would help MnDOT select the best technologies for specific sites. The final component of the project involved testing the framework on five bridges in a case-study type demonstration; the work plans for two of the sites were developed for demonstration of deployed instrumentation.

Briaud et al. (2011)[54] focused on the application of instruments, including float-out elements, accelerometers, and tiltmeters, to monitor bridge scour. The study provided guidelines and protocols for scour monitoring based on the US 59 over the Guadalupe River Bridge and the SH 80 over the San Antonio River Bridge.

Swartz and Singh (2013)[55] summarized the response of a 14-question survey distributed to 79 state

50 Ettema, R., Nakato, T., & Muste, M. V. I. (2006). *An illustrated guide for monitoring and protecting bridge waterways against scour* (No. Project TR-515). IIHR-Hydroscience & Engineering, University of Iowa.

51 Vieux, Inc. 2008. *Integrated Radar and Hydrologic Modeling for a Bridge Scour Monitoring System*. The Fifth European Conference on Radar in Meteorology and Hydrology.

52 Hunt, B. E. (2009). *Monitoring scour critical bridges* (Vol. 396). Transportation Research Board.

53 Lueker, M., Marr, J., Ellis, C., Hendrickson, A., & Winsted, V. (2010). Bridge scour monitoring technologies: development of evaluation and selection protocols for application on river bridges in Minnesota. In *Scour and Erosion* (pp. 949-957).

54 Briaud, J. L., Hurlebaus, S., Chang, K. A., Yao, C., Sharma, H., Yu, O. Y., & Price, G. R. (2011). Realtime monitoring of bridge scour using remote monitoring technology. *Texas Transportation Institute, Texas A&M University System*.

55 Swartz, R. A., and Singh, C., (2013). *Automated Scour Detection Arrays using Bio-Inspired Magnetostrictive Flow Sensors,* USDOT

DOT hydraulics and bridge management personnel, soliciting their opinions regarding the aspects of the proposed bioinspired scour monitoring system.

Papanicolaou et al. (2014)[56] proposed a comprehensive field detection method aiming at developing advanced capability for reliable monitoring, inspection, and life estimation of bridge infrastructure. This study utilized motion-sensing radio transponders (e.g, radio-frequency identification devices (RFID)) on fully adaptive bridge monitoring to minimize the problems inherent in human inspections of bridges. In addition, a novel integrated condition-based maintenance framework integrating transformative research in radio-frequency identification sensors and sensing architecture was proposed for in-situ scour monitoring, state-of-the-art computationally efficient multiscale modeling for scour assessment.

> *In addition to the desk scan, the team developed a set of amplifying questions (see* ***Appendix A****), which were sent to all state DOTs participating in the workshop. Responses to the questions are provided in* **Appendix B**.
> *The following section presents a summary of information about various unique practices presented by each state DOT that participated in the workshop. Invited agency contacts and scan team contact information are shown in* **Appendix C** *and* **Appendix D***, respectively. Appendix E provides biographical information for the scan team members.*

Cooperative Agreement No. RITARS-12-H-MTU.

56 Papanicolaou, A. N., Moustakidis, I. V., Tsakiris, A. G., Wilson, C. G., & Abban, B. (2014). *An Adaptive Field Detection Method for Bridge Scour Monitoring Using Motion-Sensing Radio Transponders (RFIDs)* (No. TR-617).

Selected Practices from Invite State DOTs

This section presents a brief description of the work being performed by the invited states in various areas related to scour mitigation, risk management, countermeasures, modeling, analysis, and simulation. This information was taken from the material that was presented during the workshop.

Louisiana

LaDOTD considered four phases of scour for existing bridges (new bridges are designed for scour): screening, hydraulic analysis, stability analysis, and implementation of countermeasures.

Rock does not exist in Louisiana. In southern parts of the state, abutments can be over 100 feet deep but in the north they are typically 20 to 60 feet deep. For the screening of bridges with unknown foundations, dispersive wave propagation was the best method for timber and concrete piles, although it does not work well with steel piles. Parallel seismic testing was used to determine the pile lengths for steel piles. **Figure 3.1** shows the application of both methods. More than 2100 bridges were tested. Occasionally larger-than-expected errors were noted in timber piles caused by overdriving during installation. No testing was performed if the piles had less than 5 feet of exposure. After pile lengths have been determined, screening is based on pile penetration and drainage area.

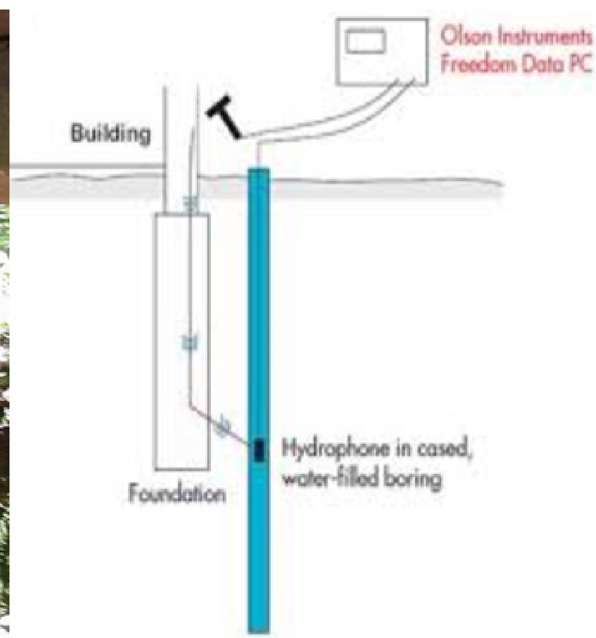


Figure 3.1 *Pile testing: dispersive wave and parallel seismic: field application of dispersive wave (tapping on pile) (left) and a schematic diagram of the parallel seismic method (right)*

Hydraulic analysis is then completed on bridges determined to be scour susceptible. HEC RAS is used to predict scour elevations based on 100- and 500-year flood events. If the predicted scour elevation results in less than 50% pile penetration, the structure may undergo a stability analysis. Structures are selected for the stability analysis after risk-based prioritization based on several factors (e.g., average daily traffic, route importance, and remaining life expectancy) and discussion by a multidisciplinary team that includes structural, hydraulic, and maintenance team members.

The stability analysis uses FB-MultiPier[57] to model the soil-structure interaction and determine the elevation at which the structure would become unstable, known as the critical scour elevation; the POA is then updated to reflect the critical scour elevation. Countermeasures such as helper bents or riprap protection may be implemented if the mud line is near this elevation.

Tennessee

TDOT implemented BridgeWatch web-based monitoring software that helps "bridge owners predict, identify, prepare for, manage, and record potentially destructive environmental events"[58] starting in 2004 (**Figure 3.2**).

- Customizable with TRIMS[59] data
- Continuous monitoring of potentially destructive environmental events
- Default thresholds

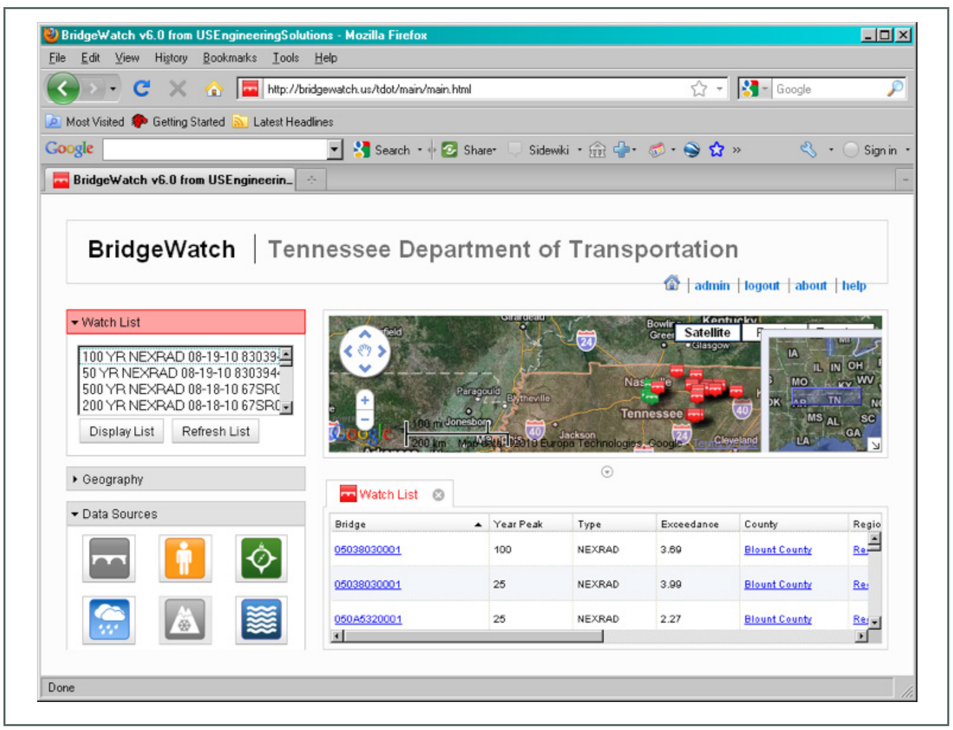


Figure 3.2 Screen shot from BridgeWatch software used by Tennessee DOT (TDOT (2016)

57 FB-MultiPier, Bridge Software Institute, University of Florida, https://bsi.ce.ufl.edu/products/overview.aspx?software=7

58 BridgeWatch®, US Engineering Solutions, http://www.usengineeringsolutions.com/bridge-watch/

59 TRIMS Software LLC, http://www.trims.com/trimscloud.htm

Iowa

ITD uses a remote hydrographic surveying system using an echo sounder, a global positioning system, and radio control to obtain data and provide real-time maps as shown in **Figure 3.3**.

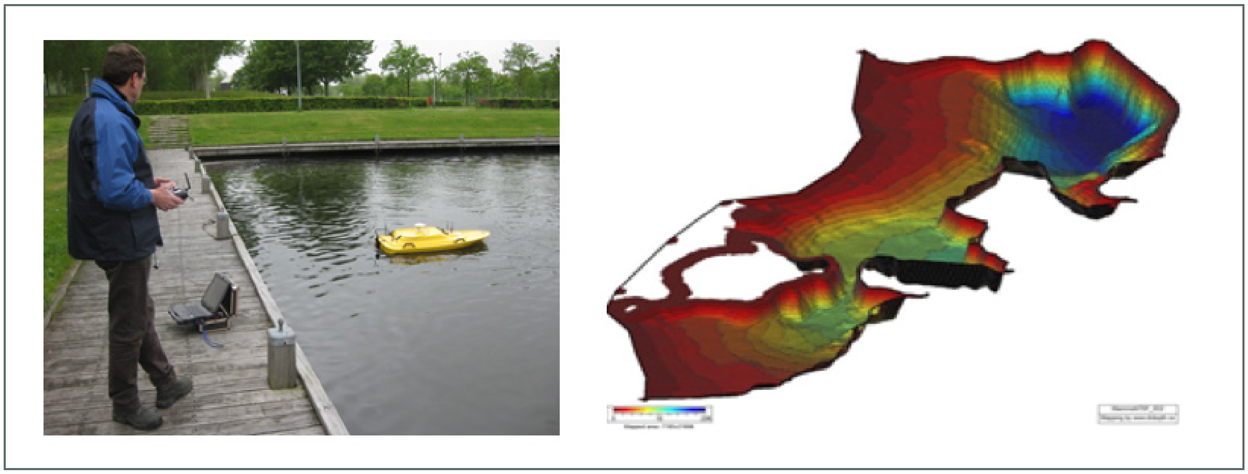


Figure 3.3 Remote hydrographic surveying system: operated using radio control (left) and an example of a real-time map (right)

Texas

TxDOT used two methods for unknown foundation determination for scour: the inference method and the geophysical method. The former worked for bridges with concrete piling and drilled shafts but did not work well for timber piling.

Figure 3.4 shows an example of data correlation between predicted and measured pile depth for concrete piling. **Figure 3.5** shows an example of data correlation between predicted and measured pile depth for concrete piling.

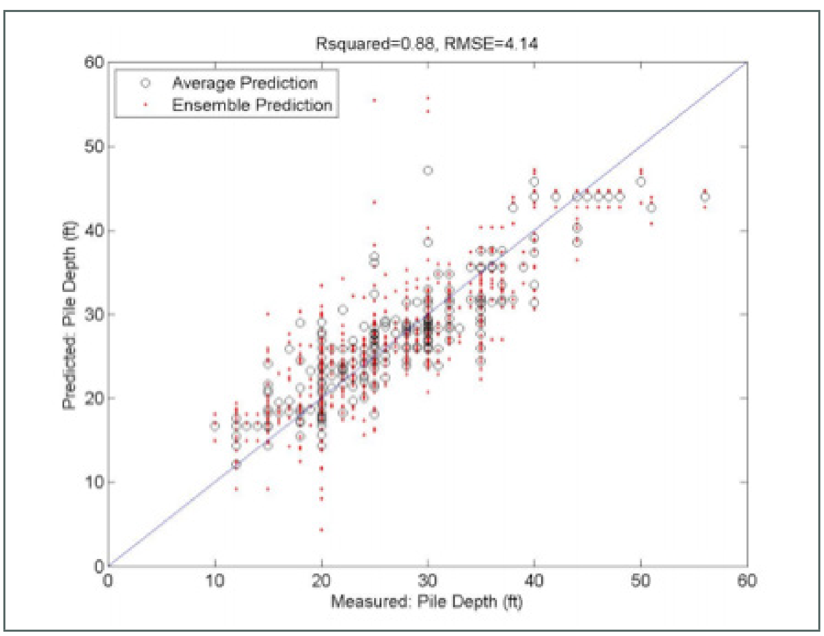


Figure 3.4 Example of ensemble prediction for concrete piles

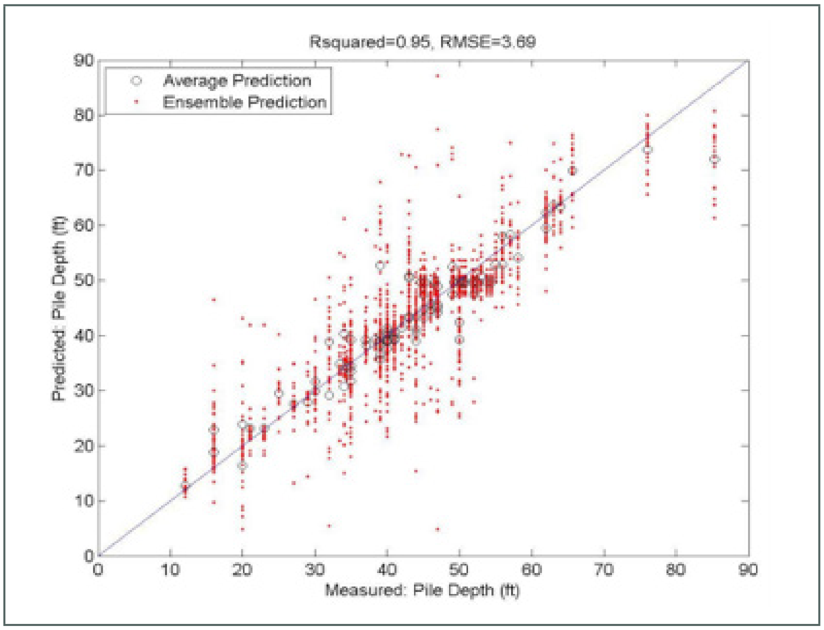


Figure 3.5 Example of ensemble prediction for drilled shafts

Figure 3.6 shows the field instrumentation for Bridge 14 and **Figure 3.7** shows the results from the resistivity data with topography. Similarly, **Figure 3.8** and **Figure 3.9** show the field instrumentation and polarization data, respectively.

Figure 3.6 Bridge 14 profile and field instrumentation for resistivity measurements

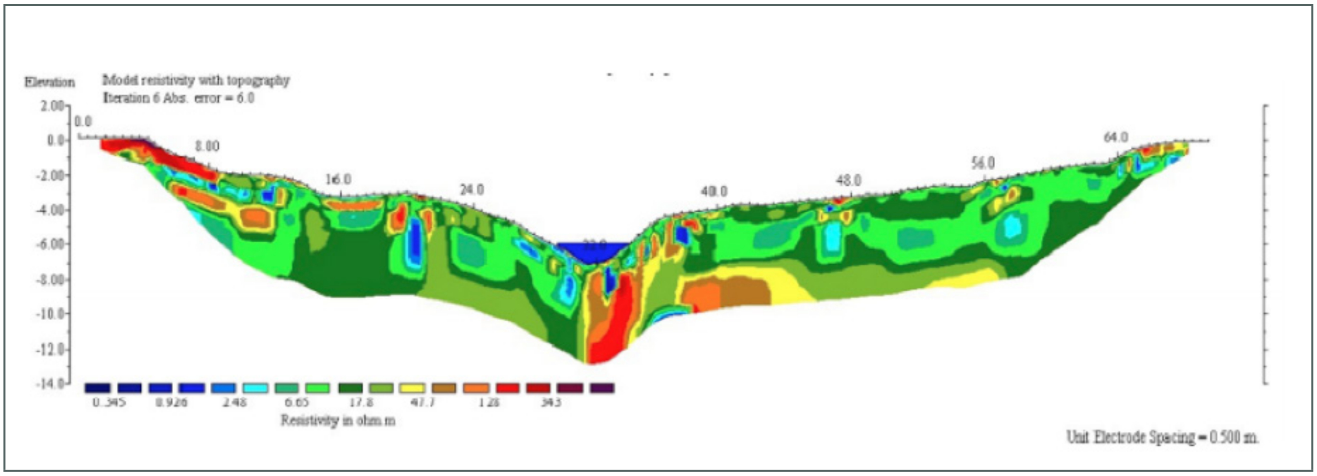


Figure 3.7 Resistivity with topography for Bridge 14

Figure 3.8 Field implementation of polarization instrumentation

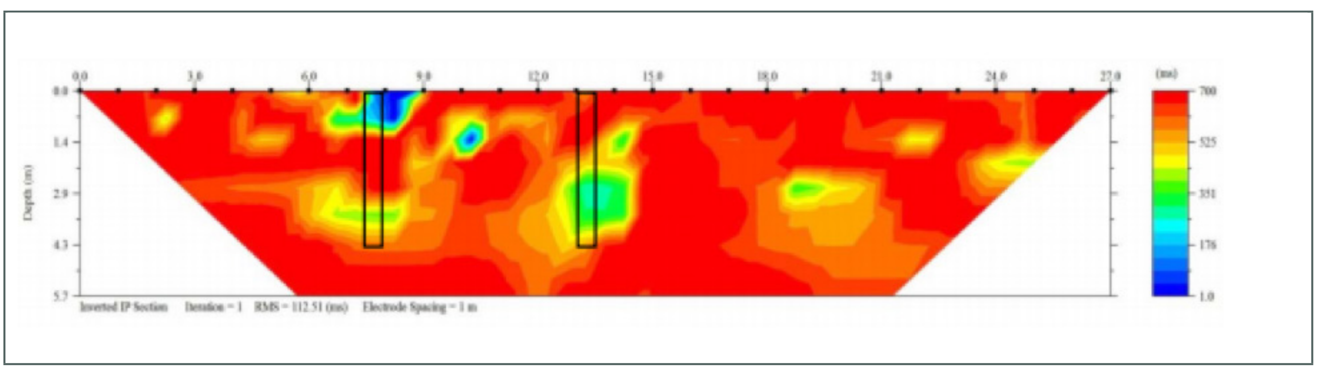


Figure 3.9 Polarization data by Texas DOT

Pennsylvania

Since 1982 PennDOT designs all new bridges to be stable for scour and installs countermeasures (usually riprap) on bridge rehabilitation projects. Additionally, scour vulnerability for other bridges was determined through field evaluations to establish appropriate Structure Inventory and Appraisal (SI&A) item 113 code and PennDOT's observed scour rating. Moreover, PennDOT monitors scour critical bridges during high-water events and performs post-flood damage inspections.

Prior to 113 coding, PennDOT developed its own rating, which is updated during each National Bridge Inspection Standards (NBIS) or biannual inspection. The USGS scour calculator is used to calculate the scour critical bridge indicator (SCBI) code. USGS performed the initial field evaluation, developed two manuals for PennDOT, and performed stream scour assessment rating for roadway bridges.

While FHWA defines an NBI code of 3 or less as scour critical, PennDOT's SCBI are divided into three categories for monitoring of scour critical bridges. The recommended frequencies are 4 hours for Category A, 12 hours for Category B, and 24 hours for Category C. Monitoring means one person checking water levels visually and inspecting for actual movement. Once the water starts to recede, the monitoring stops. A person will be at the bridge for 24 hours if the bridge is located on an evacuation route.

PennDOT's monitoring tools include rainfall forecasting using National Oceanic and Atmospheric Administration and AccuWeather alerts to counties; traffic command centers; bridge lists (**Figuree 3.10**) and bridge maps (**Figure 3.11**), which the central office updates monthly and provides to the districts' bridge units; monitoring logs; contact lists; and a road closure reporting system.

SCOUR CRITICAL BRIDGE CATEGORY LIST

DIST (5A04)	County (5A05)	SCBI CAT	NBI Str. No. (BRKEY) (5A03)	Structure ID Number (5A01)	Facility Carried (5A08)	Feature Intersected (5A07)	Location (5A09)	Struc Type (6A26-6A29)	SCBI (4A08)	Min Obs Scour (IN03)	Water Adeq (1A06)	Chan (1A05)	Sub (1A02)	LEN (5B18)	BPN (6A19)
06	09 - Bucks	A	7472	09410101000378	OLD BETHLEHEM R	COOKS CREEK	PLEASANT VALLEY 02H1:	69920	3	3	8	4	4	54	4 - Other Non-NHS Route
06	09 - Bucks	A	7434	09405900601248	ROSEDALE ROAD	BRANCH OF UNAMI	STEINSBURG; MILFRD.06J(	86204	3	3	6	4	5	32	4 - Other Non-NHS Route
06	09 - Bucks	A	6772	09001303100000	TRAFFIC ROUTE 13	BRANCH ROCK RUI	.4MI.S.TYBURN RD. 38H10	21103	3	3	6	4	4	40	2 - Other NHS
06	09 - Bucks	A	6794	09003203501847	SOUTH MAIN STRE	AQUETONG CREEK	1.1MI.TO LR 155 25H02	21303	3	3	6	5	5	170	3 - Non-NHS/ADT > 2000
06	09 - Bucks	A	7137	09101400700000	CREAMERY ROAD	TOHICKON CREEK	1MI.W.TR611-OTTSV. 10E1(	86204	4	3	8	4	4	199	4 - Other Non-NHS Route
06	09 - Bucks	A	6997	09031300620111	BROAD STREET	BEAVER RUN	.4MI.SOUTH PA 212 14B01	86204	4	3	6	5	5	40	2 - Other NHS
06	09 - Bucks	A	7328	09207900500445	RUSHLAND ROAD	NESHAMINY CREEI	RUSHLAND,WRIGHTWWN.:	21103	4	3	7	5	5	225	3 - Non-NHS/ADT > 2000
06	09 - Bucks	B	6791	09003203100000	RIVER ROAD	PIDCOCK CREEK	.1MI.LR-326 SPUR 25K08	69920	3	4	8	4	4	156	3 - Non-NHS/ADT > 2000
06	09 - Bucks	B	7396	09402500200000	IRISH MEETINGHOL	BRANCH OF DEEP I	BEDMINSTER TWP. 16A0(	21103	3	4	6	4	5	46	4 - Other Non-NHS Route
06	09 - Bucks	B	6962	09026301700000	OLD YORK ROAD	WATSON CREEK	.5MI.TO LR 656 23J12	21101	3	4	7	5	6	29	3 - Non-NHS/ADT > 2000
06	09 - Bucks	B	7045	09053200700172	BUCK ROAD	MILL CREEK	HOLLAND TWP. 36B11	42206	3	4	8	4	5	114	3 - Non-NHS/ADT > 2000
06	09 - Bucks	B	6984	09031303220446	SWAMP ROAD	PINE RUN	.5MI.N.DOYLESTOWN 22K(	21103	3	4	6	4	5	39	2 - Other NHS
06	09 - B[illegible]	[illegible]	6811	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	3	4	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

Figure 3.10 Monitoring tool—a list of bridges categorized as scour critical

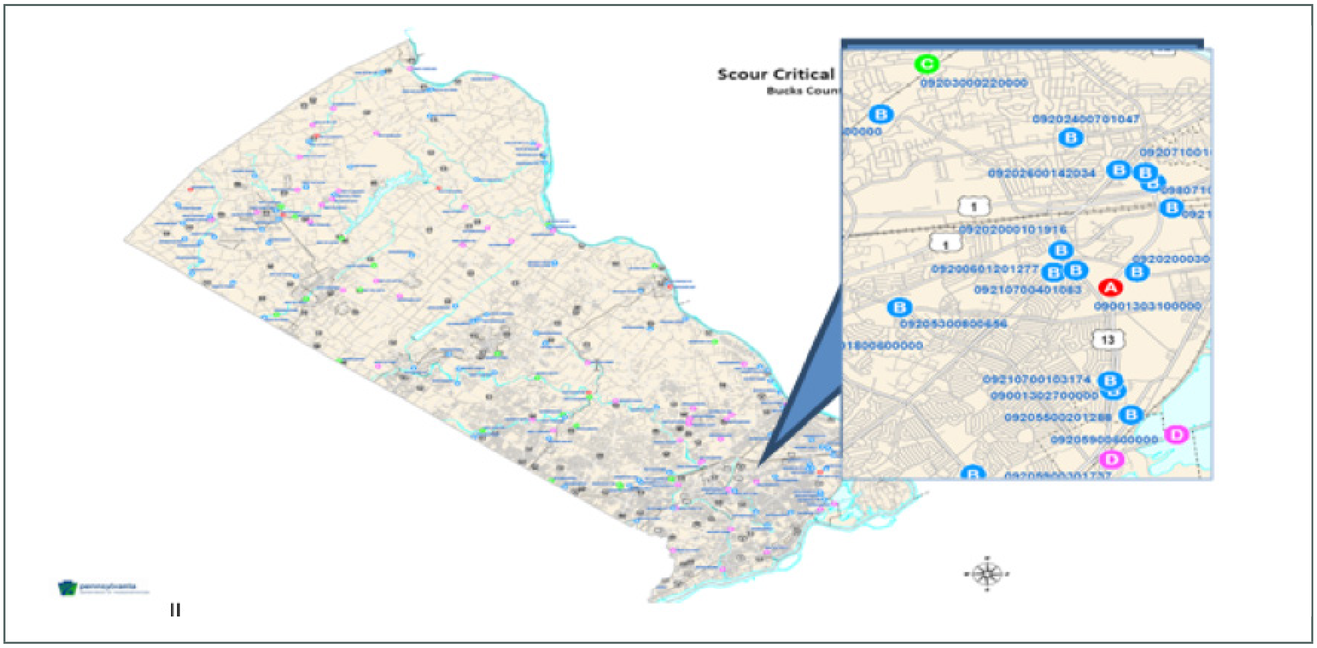


Figure 3.11 Monitoring tool: bridge map

As shown in **Figure 3.11**, each point on the map has a bridge identification that gives its exact location. Category A bridges are inspected first, then Category B and C as time and resources permit. Local bridge owners are kept educated about their responsibilities via a website for local counties that focuses on monitoring and inspection.

For storm frequency analysis and post-flood damage inspection, PennDOT developed and uses the Rainshare geographic information system application, as well as a study by the University of Pittsburgh, which uses more data sources. The National Aeronautics and Space Administration's snow cover data might also be added in addition to runoff, which includes rainfall data. The lack of a good source of real-time data to trigger local scour monitoring inspection propelled PennDOT to plan on using BridgeWatch to trigger small events in local areas.

Florida

FDOT has presented various approaches related to investigating and resolving unknown foundation for 2500 bridges. It was found that using a deterministic approach would be cost-prohibitive. With the help of a consultant, FDOT applied a probabilistic approach as an alternative methodology. It found that more than half of the bridges with unknown foundations are on local roads and only 9% are on principal arterials. Additionally, it found that 605 of the 2500 bridges have a span length less than 100 feet with relatively low average daily traffic(ADT).

FDOT presented a flowchart of its evaluation process of bridges with unknown foundations (see **Figure 3.12)**. The process uses statistical, risk-based approach and is summarized as follows: Phase 1 includes data gathering, risk assessment, and embedment prediction while Phases 2, 3, and 4 include scour evaluations. As shown in **Figure 3.12**, Phase 1 includes steps 1 through 6.2, Phases 2 and 3 include steps 6.3 and 6.4, and Phase 4 includes steps 6.5 through 6.9.

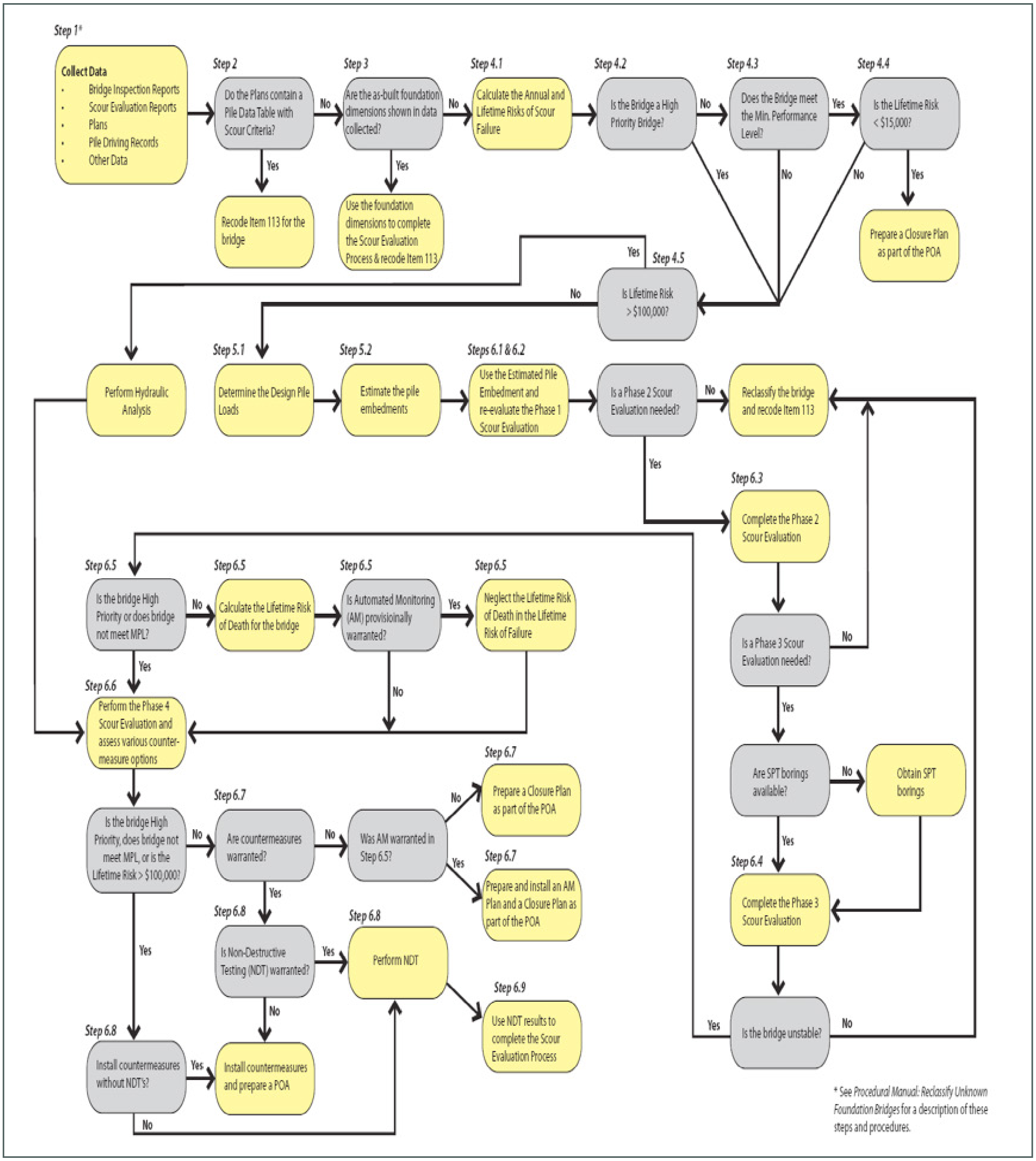


Figure 3.12 Flowchart for scour evaluation

Based on the above phases, risk is calculated using the procedure in NCHRP Document 107[60] as cost of failure, probability of failure, and risk of failure. Using the basic equation Risk = Cost of Failure, Probability of Failure, the risk can be quantified.

60 Risk-Based Management Guidelines for Scour at Bridges with Unknown Foundations, The National Academies of Sciences, Engineering, and Medicine, http://www.trb.org/Publications/Blurbs/157792.aspx. This site includes links to a risk assessment tool and instructions.

When applying the NCHRP process, few modifications were made to include Florida-specific costs, such as duration of detour, rate of failure due to scour, correction for scour vulnerability of 5, and application to tidal bridges. The components of cost included bridge replacement, detour, and loss-of-life costs. The NBI data was used to calculate the length, width, maximum span length, average daily traffic, and average daily truck traffic as a percentage of average daily traffic and detour length.

Two methods were applied for predicting embedment: artificial neural network and geotechnical analysis. The design pile load was taken from the plan value, artificial neural network, or reverse engineering based on design calculations.

Additionally, the main advancement in FDOT's approach has been in the following areas:

- FDOT developed better testing methods of soil and rock. For example, using an erosion test for site-specific type of soils (e.g., rock and clay) would improve scour predictions (rock erosion/Texas cohesive soil methods/predictive models).
- FDOT presented two different laboratory testing methods: SERF and RETA.

Mississippi

Mississippi bridges are prone to scour failure at a rate higher than the national average (70% Mississippi versus 60% U.S.) due to highly erodible soils throughout the state. In Mississippi, 78% of on-system structures are listed in the NBI cross-waterways.

Bridge Scour Risk Management

The bridge scour risk management practices that Mississippi uses comprise these elements, which are discussed in the following sections:

- Collect Data
- Instrumentation
- Inspections
- Scour Assessments and Evaluations
- Plan of Action (POA) for Scour Critical Structures
- Properly Design, Place, and Maintain Bridge Scour Countermeasures

Collect Data

The hydraulics engineer compiles the data for two levels of analysis: quantitative (Phase I) and qualitative (Phase II). The data are existing bridge data, hydrologic data (gauge data), watershed characteristics (drainage area, slope, floodplain skew), stream-reach data (survey), existing and proposed land-use data (aerial photography, topographical maps), floodplain limits (flood maps). **Figure 3.13** shows the monitoring changes on the floodplain and channel of the Tombigbee River.

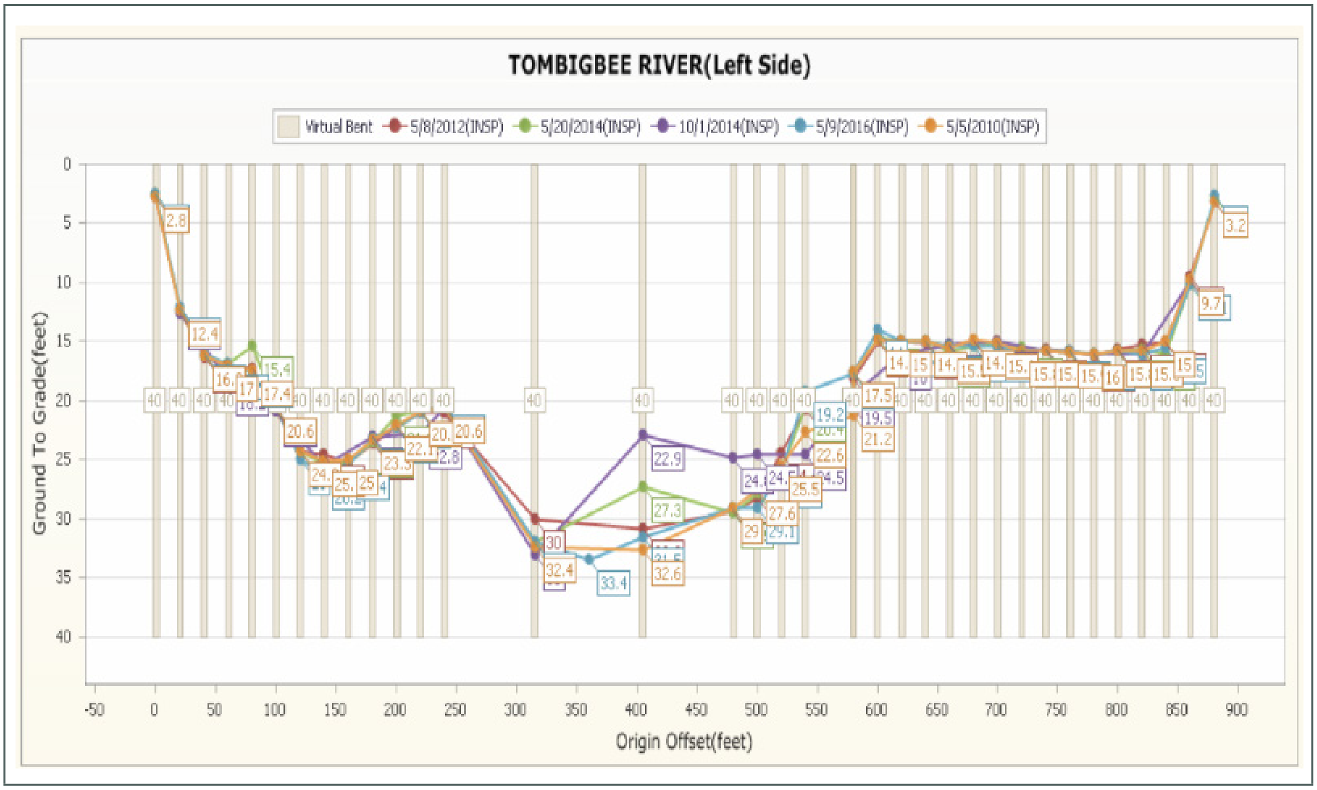


Figure 3.13 Mississippi DOT bent application

Instrumentation

In the past, instrumentation was used to monitor scour effects over time; in the future, it will be used to determine when the stages have reached critical depths and to estimate when the remaining embedment has reached critical depths. **Figure 3.14** shows an example of current bridge scour monitoring.

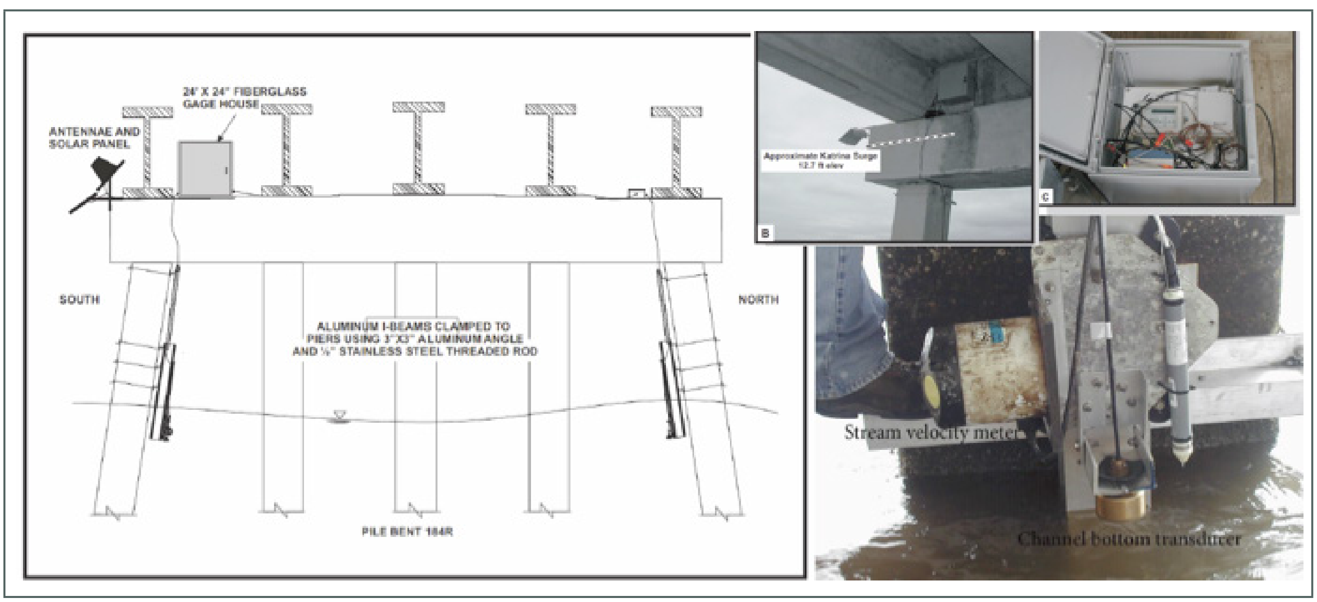


Figure 3.14 Bridge scour monitoring

Inspections

Normal bridge inspections are performed on a 24-month cycle and underwater inspections on a 60-month cycle. MiDOT does not have any alert systems to trigger inspection during flood events.

Scour Assessments and Evaluations

Interdisciplinary (i.e., hydraulic, geotechnical, and structural engineers) team members work together. The MiDOT scour evaluation process consists of four phases (see **Figure 3.15**) as modified from HEC-18. Examples of the analysis done for the Pearl River in Columbia, Mississippi, are shown in **Figure 3.16**.

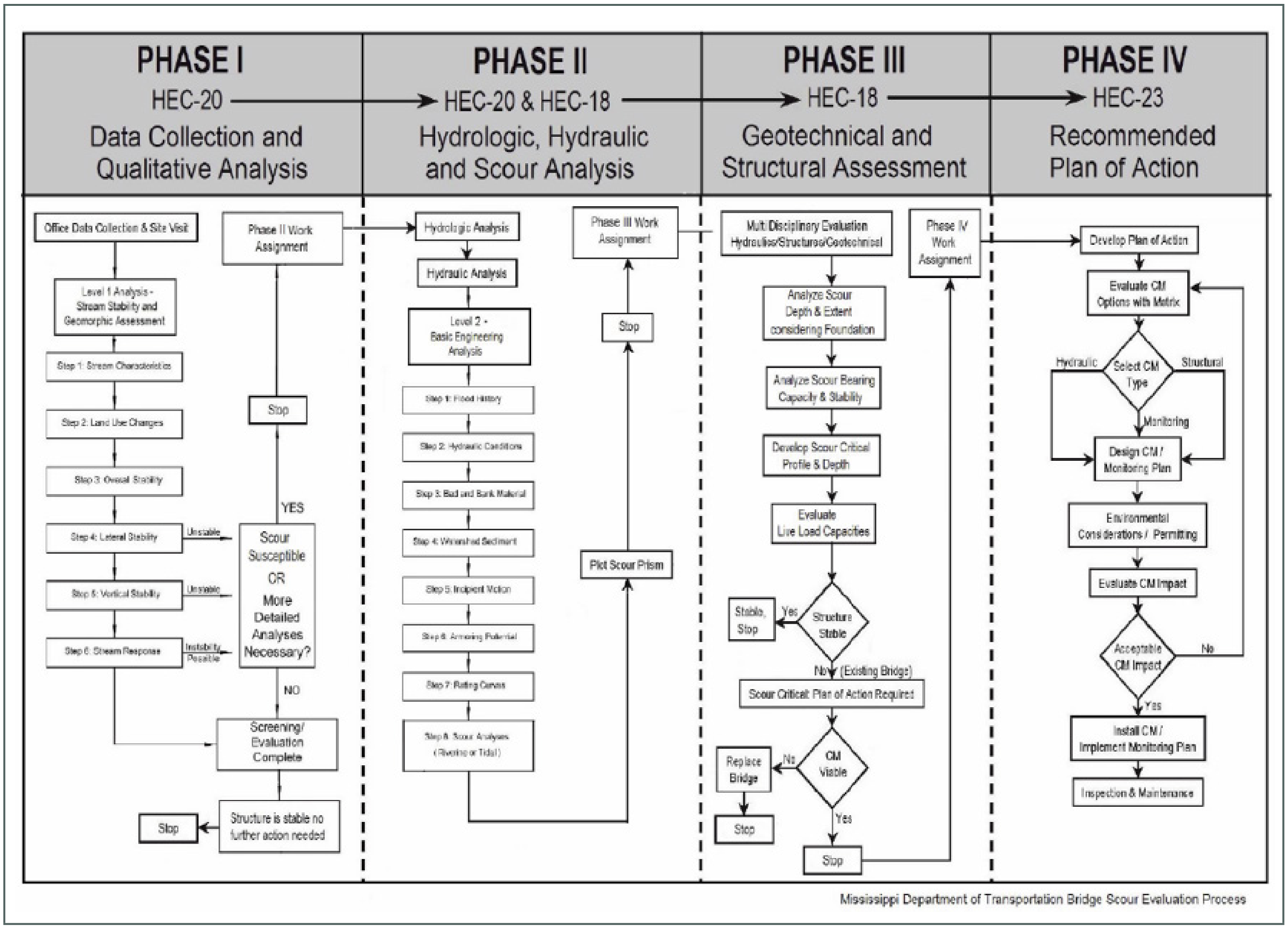
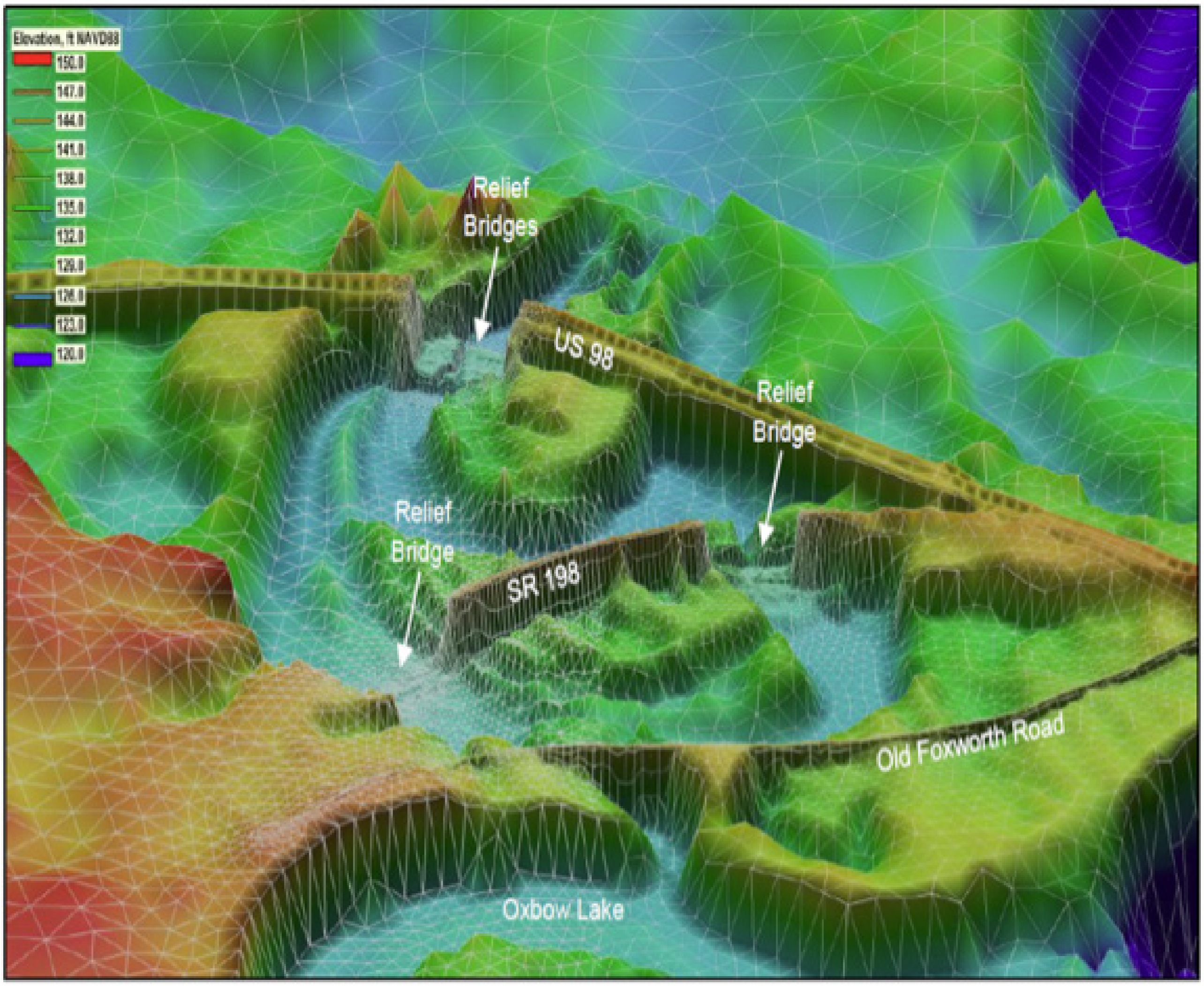
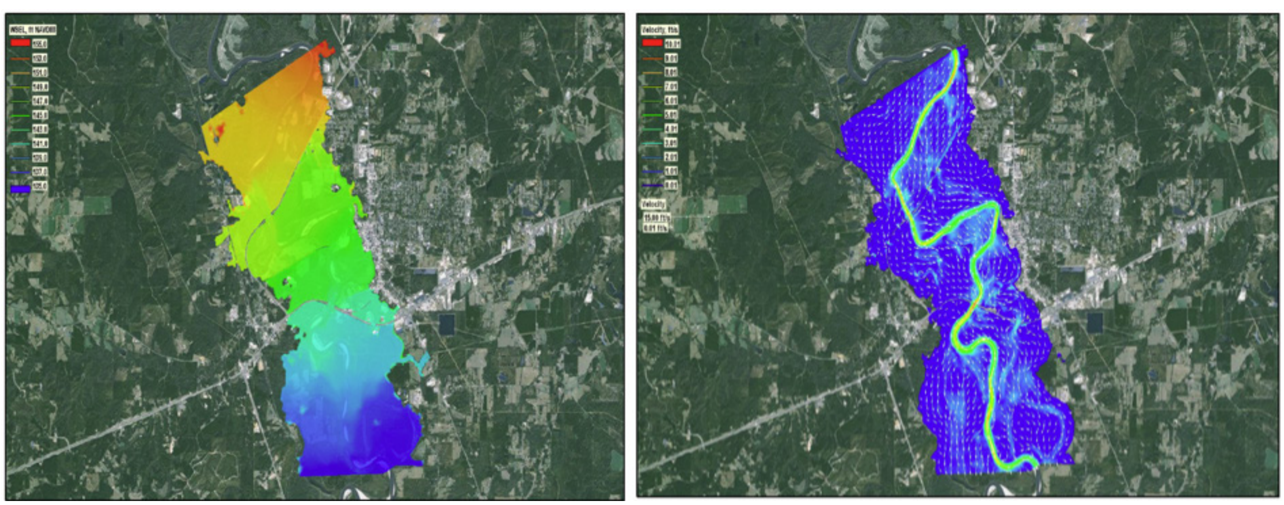


Figure 3.15 Flowchart of scour evaluation process



Isometeric view of Surface-Water Modeling System (SMS) mesh at SR 198 and US 98 relief bridges (looking downstream, 15:1 vertical exaggeration)



The two-dimensional sedimentation and river hydraulics model (SRH-2D) 100-years water-surface elevation contours and with pressure flow (left) and event velocity vectors with pressure flow (right)

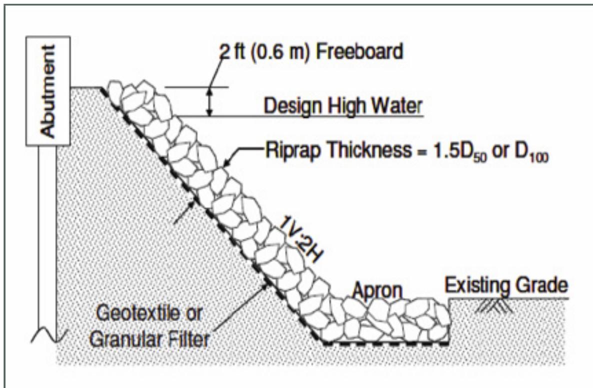
Figure 3.16 Analysis examples for the Pearl River in Columbia, Mississippi

Plan of Action for Scour Critical Structures

Mississippi uses risk-based and data-driven practices to plan the scour evaluation priorities. For data-driven practices, characteristics weighting needs to be determined, as do the priority scores within each characteristic (i.e., functional classification, average daily traffic, commerce routes, hurricane routes, Strategic Highway Network, asset values, replacement date, and detour length). The total score can be determined by multiplying the weight of the data-driven characteristic by its risk-based priority score.

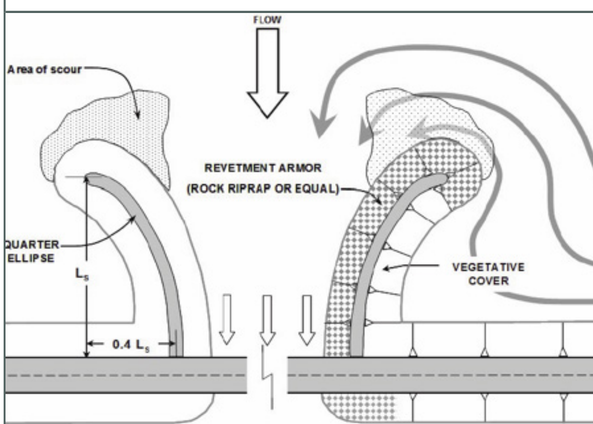
Properly Design, Place, and Maintain Bridge Scour Countermeasures

Different countermeasures were used as summarized in **Figure 3.17**.

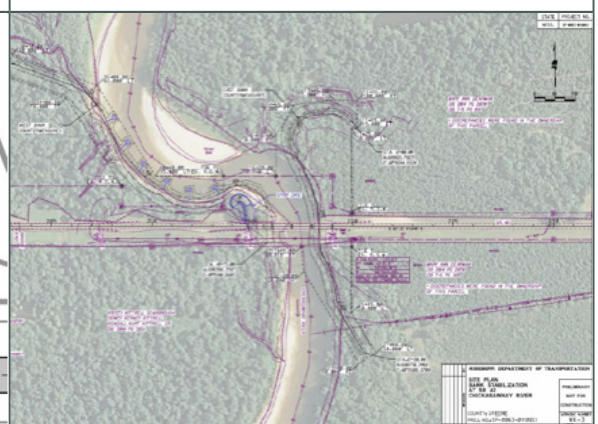


Rock riprap at abutments

Riprap revetment



Guide banks



Bendway weirs

Longitudinal peaked stone toe

Jacks

Figure 3.17 Examples of countermeasures for the Pearl River in Columbia, Mississippi

Bridge Hydraulics Design Process

As depicted in **Figure 3.18**, the design process is initiated by setting up an initial hydraulic model and considering the bridge layout, which would be confirmed by an on-site visit. The model is modified accordingly and scour analysis and countermeasure design would be done as part of the preliminary design. The preliminary design is confirmed by an on-site review of the preliminary bridge layout and the final model is used to finalize the scour analysis and bridge layout.

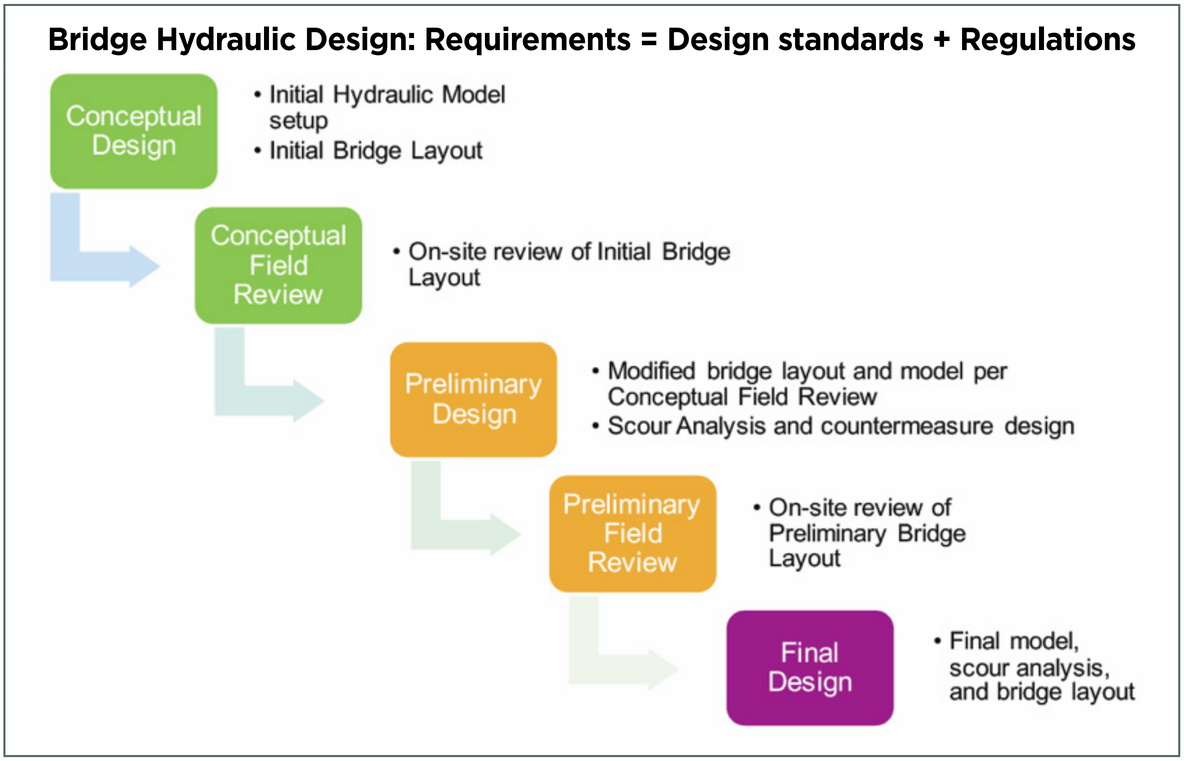


Figure 3.18 Bridge hydraulics design process

Minnesota

Minnesota initiated the scour program by bridges evaluated based on the flowchart for its bridge scour program as shown in **Figure 3.19**. Of the 350 scour critical bridges in Minnesota, MnDOT owns 37; the rest are local agency bridges.

Inspectors take bridge inspection refresher training every two years, which includes training on scour monitoring and inspection. MnDOT uses structure information management to input and track all bridge inspections. All bridges have been evaluated for scour and have an assigned scour code. All bridges rated scour critical, scour stable-protected, and scour stable-further action required have POAs.

MnDOT uses HEC-18 equations for computing contraction and pier scour. Abutment scour is not currently computed. Abutments are protected against scour by designing and installing abutment protection (typically riprap) on all bridge abutments over water.

To complete scour analysis, MnDOT utilizes HEC-RAS and/or the two-dimensional sedimentation and river hydraulics model (SRH-2D) to determine the necessary hydraulic parameters. Use of either software depends on the hydraulic site conditions, as well as foundation and soil information and pile driving reports (for in-place structures).

A typical hydraulic analysis procedure is first to analyze the water surface profile using HEC-RAS, to visually show flooding extents using SRH-2D, to check roadway profile for overtopping, and then to complete the scour analysis. **Figure 3.19** shows an example of SRH-2D output.

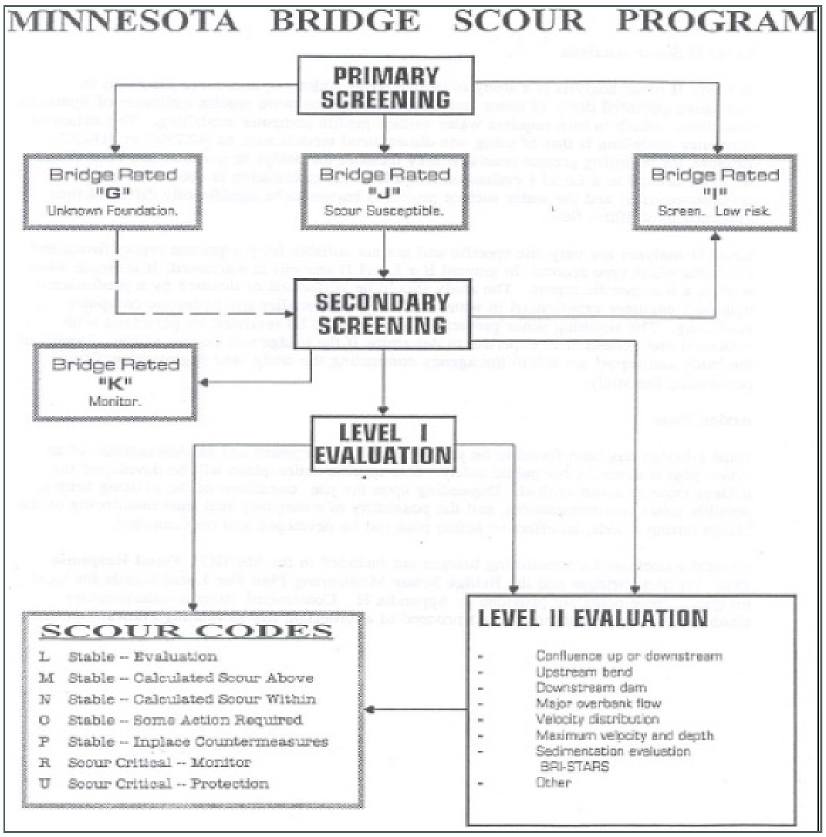


Figure 3.19 ***Flowchart for evaluation of scour critical bridges in Minnesota***

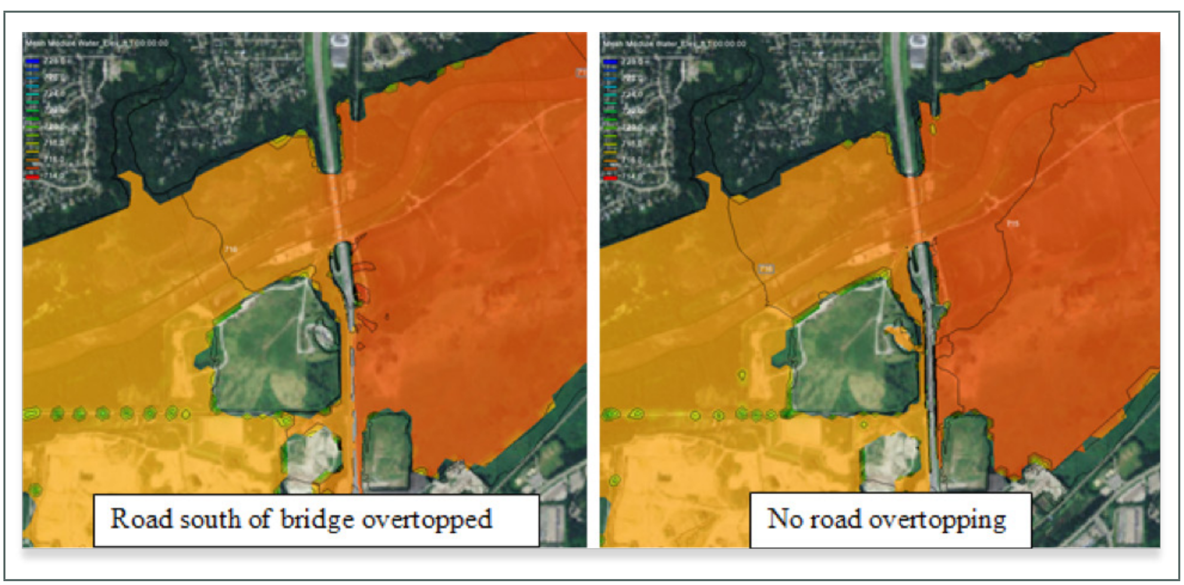


Figure 3.20 ***Comparison of 100-year flood events in-place (left) and proposed (right)***

For existing bridges, if the foundation conditions do not meet the requirement (50% embedded piling for friction pile, 5-foot embedment for end bearing, L/D > 24 for lateral stability check) or if unusual circumstances, such as high ice or debris loading are observed, MnDOT will perform structural analysis for scour concern, typically using LPILE[61]. The most common bridge pier type is a pile bent pier with a concrete pile cap.

MnDOT does not generally complete a cost/benefit analysis; however, the analysis may be performed as a part of scoping, preliminary design, or cost risk assessment and value engineering (CRAVE[62]) study.

New bridges are designed to be scour stable by complying with load and resistance factor design guidance and general structural guidance.

MnDOT has implemented many new scour-monitoring and countermeasure techniques, such as fixed sonar, float-outs, tethered switches, matrix riprap (partially grouted riprap), and geobags (see **Figure 3.21**). MnDOT has had limited success with some of the fixed scour-monitoring techniques, as outlined in the Lueker et al.[49] report. MnDOT has had good success to date with matrix riprap and geobags (see **Figure 3.21**). Many factors are used to select and design countermeasures, including the scour countermeasures matrix in HEC-23. MnDOT has also used advanced computer modeling for scour prediction.

Figure 3.21 Examples of countermeasures for protection: riprap (left) and geobags (right)

Michigan

MiDOT has 4482 state bridges and 6577 local agency bridges; 397 state bridges (8.9%) and 1234 local agency bridges (18.8%) are scour critical. The MDOT has a policy to identify the responsibility for bridge scour and guide the procedure for scouring.

61 LPILE, ENSOFT Inc, https://www.ensoftinc.com/products/lpile/

62 CRAVE™ Study Report: I-35W Transit/Access & Chapter 152 Bridges, Project ID 2782-278, Minnesota Department of Transportation, April 15-19, 2013, https://www.dot.state.mn.us/35w94/pdf/ea/I-35W-ea-Appendix-G/I-35W-ea-Appendix-G-CRAVE-Study-Report.pdf

For scour analysis, two flood levels are considered: 100 years (1% chance/scour design) and 500 years (0.2% chance/scour check flood). Most scour critical bridges were determined from a Level II detailed analysis. Unknown foundations are treated as scour critical bridges. Span length is also considered to reduce scour depths by removing abutments further away from the channel cross-section.

MiDOT targets to reduce the scour critical interstate bridges by 5% per year, from 56% to 14% by 2018-2022 year.

The agency adopted a six-step procedure to perform a vulnerability assessment, as shown in **Figure 3.22**.

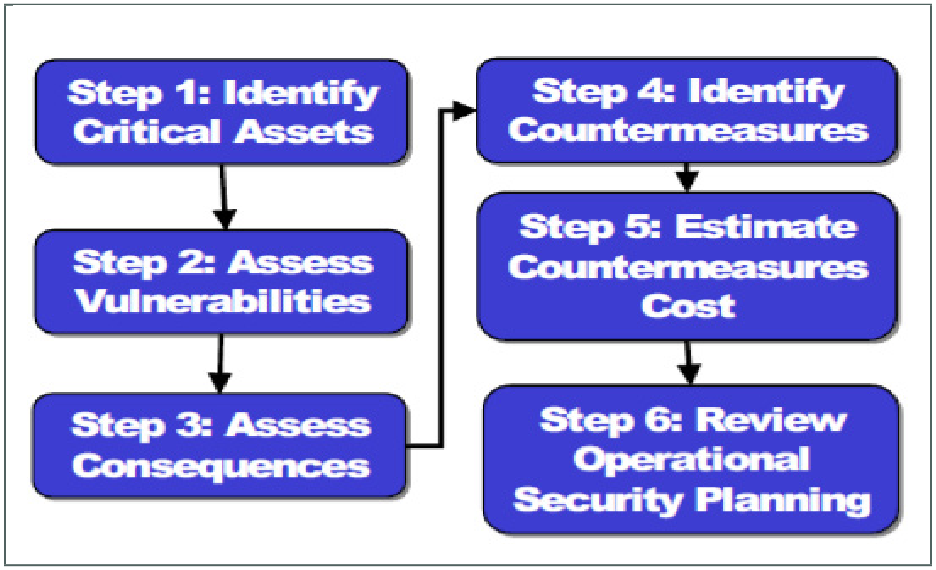


Figure 3.22 **Michigan's six-step procedure for conducting a vulnerability assessment**

MiDOT performs the scour risk assessment with respect to vulnerability and criticality and then categorizes the high-, medium-, and low-priority bridges as shown in **Figure 3-23**.

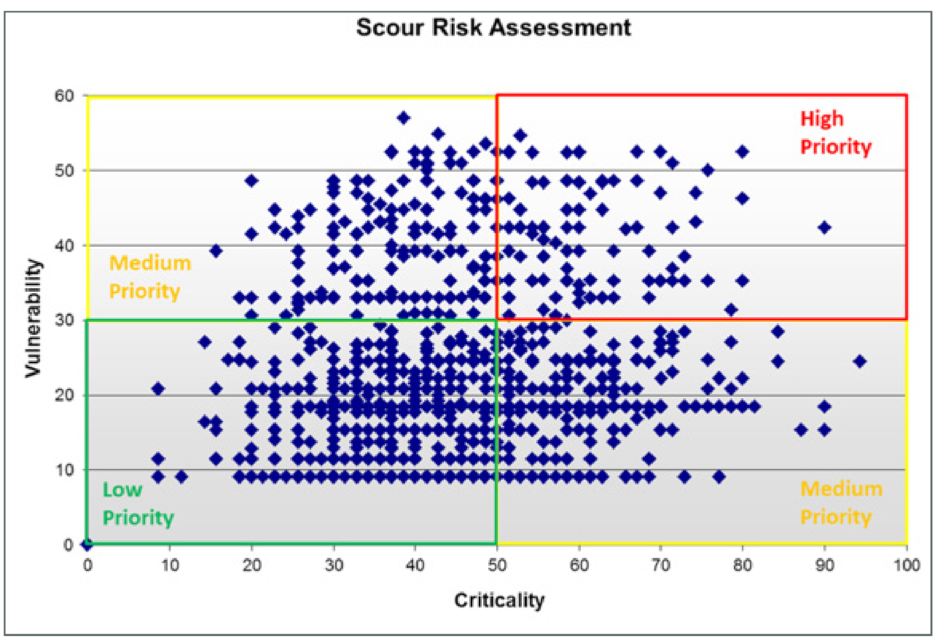


Figure 3.23 **Scour risk management for critical bridges in Michigan**

MiDOT uses one-dimensional HEC-RAS for modeling; calibration is done through field review, historical photos, and known flood elevation. No two-dimensional hydraulic modeling is performed.

MiDOT performs bathymetric survey pickup (via consultants) in larger rivers, with traditional surveying for floodplain data and traditional sections/survey in smaller rivers/streams. Light detection and ranging (LiDAR) data are limited to a few counties in the state.

The HEC-18 equations are used for scour calculation and the analysis form is programmed in Excel and MathCad. Countermeasure design for riprap is sized using HEC-23 equations in Excel.

The Michigan Department of Environmental Quality regulates floodplains in Michigan with Drainage Areas greater than 2 square miles. The Department of Environmental Quality has essentially a zero backwater policy over existing condition, with some exceptions, making countermeasure installation challenging. It also extends this policy to temporary construction conditions, making water diversion a challenge. Floodplain policy came into effect essentially the same time as the scour program.

MiDOT's MiBRIDGE[63] is a web-based bridge-management and field-inspection module **(Figure 3.24)** that:

- Facilitates scour inspection entry for bridges and culverts
- Allows users to record high-flow event history
- Houses scour action POAs

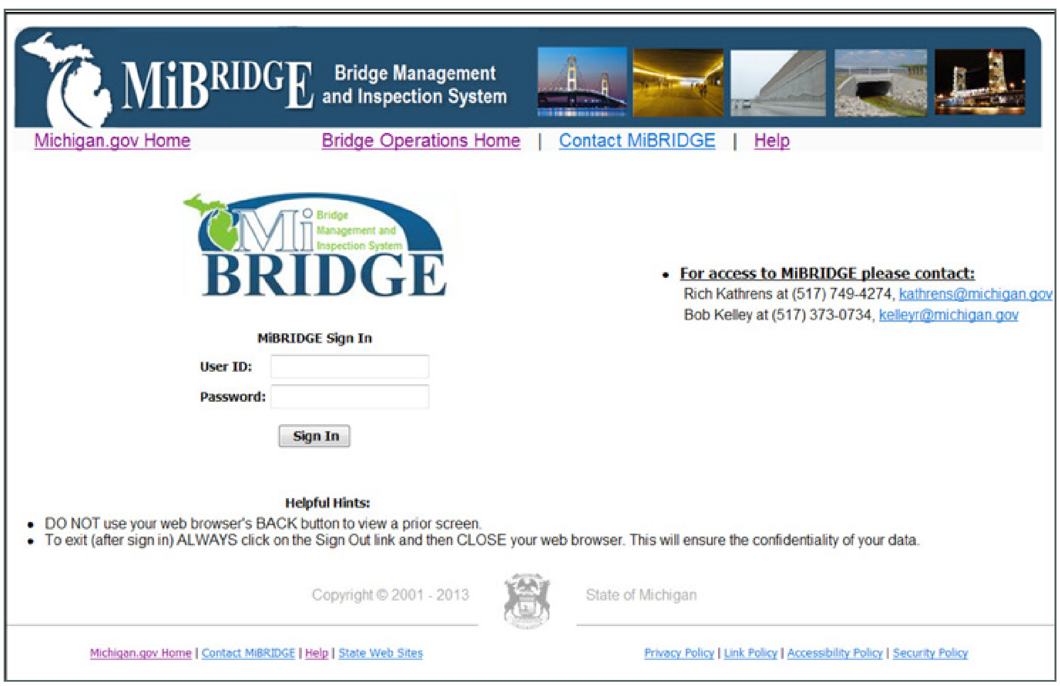


Figure 3.24 MiBRIDGE monitoring and field inspection tool, developed by MiDOT

63 MiBRIDGE, Michigan Department of Transportation, https://www.michigan.gov/mdot/0,4616,7-151-9625_70811_59528---,00.html

The scour countermeasures used by MiDOT are similar to those used by NYSDOT.

MiDOT has developed elements for scour protection and a condition state table to identify scour protection defects. It inputs stream cross-section data into Excel and stores this data in MiBRIDGE.

The agency has installed an in-situ, battery-operated, telemetric stream gauge (with an approximate cost of $3000), however, maintenance of traffic is usually needed whenever gauges would be removed.

Countermeasures have shorter lifespans than the bridge. The different observed failure modes of riprap were shear failure, winnowing failure, edge/transition failure (lateral stream instability, mass sliding), riprap dissolution, and pore water pressure.

Colorado

For the scour critical bridge program, CDOT implemented the POA in 2010 and completed it in 2012; the countermeasure implementation phase began in 2013.

CDOT proposes the following scour critical bridge program for POA phase. First, it is required to collect as-built plans, previous scour assessment information, and Federal Emergency Management Agency (FEMA) data. A multidisciplinary team then conducts a site visit for a hydraulic survey and sediment analysis. CDOT Maintenance and Excavation performs the surface nondestructive evaluation (NDE), such as sonic echo, impulse response, and ultraseismic or spectral analysis of surface waves. Based on the NDE of 19 scour critical bridges, nine were excavated and one was removed from the critical scour bridge list.

Once the data collection is completed, a scour analysis is required. The hydraulic analysis includes hydrologic analysis, hydraulic cross-section survey, and HEC-RAS modeling. Different scour calculation variables, such as pier, contraction, and abutment, are considered. Then the stream stability is calculated to understand the degradation and cannel migration. The scour analysis is performed to evaluate the contraction, pier, and abutment scour, and to produce the scour depth plot and structural stability analysis.

The next step is to make recommendations based on data collection and scour analysis. CDOT provides three recommendations: designing a monitoring plan, detouring the routes, and using scour countermeasures. There are five regional jurisdictions in Colorado (**Figure 3.25**), and each decides its own recommendations.

CDOT performed evaluation of 223 structures using task orders. Among those, 65 bridges were removed, 158 were identified as scour-critical structures, and three are added based on POA studies as shown in **Figure 3.26**. A total of 105 designs are completed, 35 bridges have been constructed, and 70 bridges have been shelved. However, 55 bridges remained to be designed using the countermeasure.

Noncritical bridges are added to the columns for structure asset management.

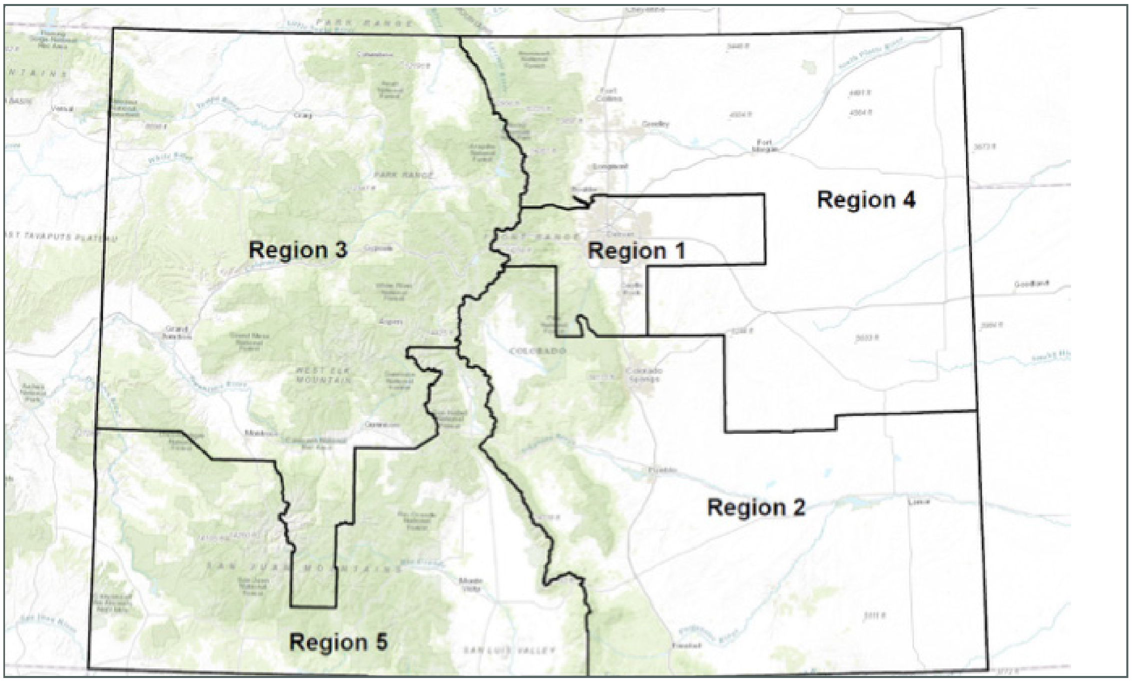


Figure 3.25 Colorado regional jurisdictions

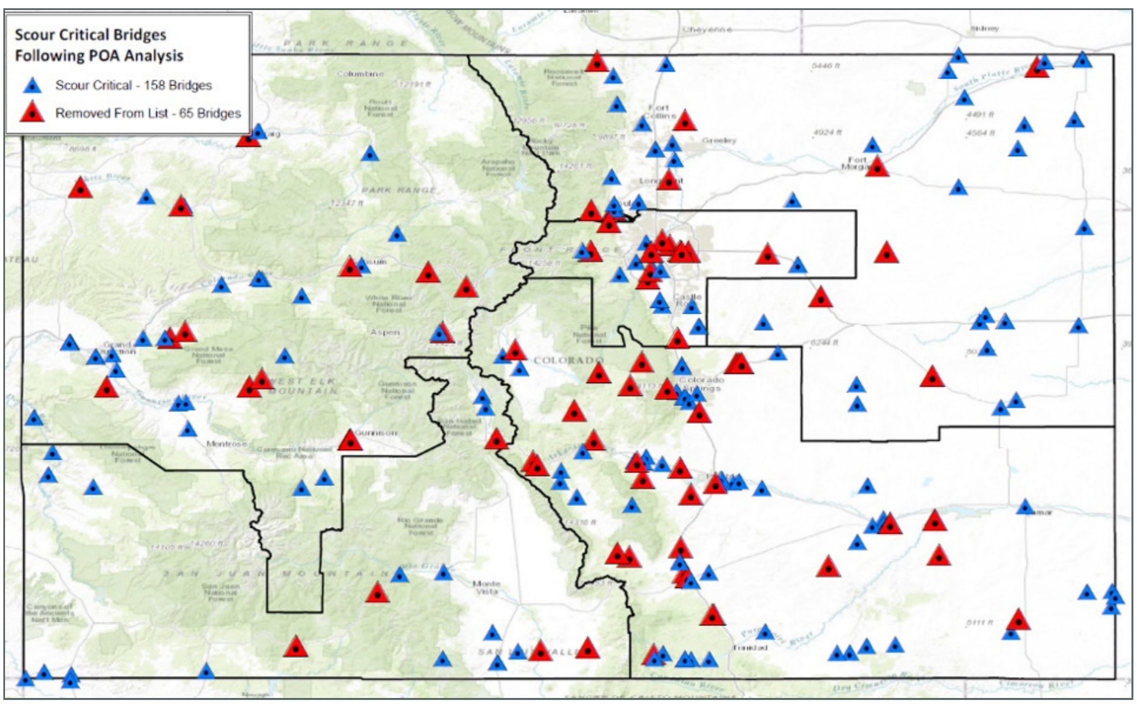


Figure 3.26 Colorado regional jurisdictions with the number of scour critical bridges and bridges removed from the list

New York State

After the 1987 Schoharie bridge failure (see **Figure 3.27**), NYSDOT established Hydraulic and Bridge Safety Assurance (BSA) Units in a response to the FHWA advice T5140.20 (1988), T5140.23 (1991)[64], and 23 CFR 650 Subpart C 313.e.3 (2015)[65].

Figure 3.27 View of the Schoharie Bridge after its April 1987 failure due to scour

NYSDOT also established the hydraulic training programs, which includes HIRE Scour Equation, HEC-RAS (HEC 2), HEC-18, -20, -23 and other hydraulic courses.

The agency developed its Hydraulic Vulnerability Assessment Manual66 under the BSA Unit to evaluate existing bridges for scour. This manual involves interdisciplinary teams comprising hydraulic, geotechnical, and structural engineers. The manual follows this procedure:

- **Screening** – Prioritize the bridge to proceed with the hydraulic vulnerability assessment.
  - This was not done for local bridges.
  - All state bridges were screened; this is no longer required.
  - All new bridges are designed to withstand scour.

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64 Evaluated Scour at Bridges, Federal Highway Administration, October 28, 1991, https://www.fhwa.dot.gov/engineering/hydraulics/policymemo/t514023.cfm

65 "Bridges that are scour critical. Prepare a plan of action to monitor known and potential deficiencies and to address critical findings. Monitor bridges that are scour critical in accordance with the plan." 23 CFR 650.313 - Inspection procedures, https://www.law.cornell.edu/cfr/text/23/650.313

66 Hydraulic Vulnerability Manual, New York State Department of Transportation, February 2003, https://www.dot.ny.gov/divisions/engineering/structures/repository/manuals/bridge_safety/bsa_hyd_vuln_manual.pdf

- **Classifying** – Evaluate the structure's vulnerability to scour failure in terms of many variables, including, for example, general hydraulic assessment, abutment and pier foundation assessment, and bridge size culverts.
    - The primary elements of metal culverts had to be rated.
- **Rating** – Provide a uniform measure of the structure's vulnerability to failure when compared to other structures.
    - NYSDOT uses its own ratings to correlate with FHWA ratings. Inspectors are trained to update the rating of the channel and countermeasures with each inspection. The new rating is used to see if the hydraulic engineer should reevaluate the bridge.
- **Monitoring** – Monitoring includes flood watch, post-flood inspection, and scour monitors.

NYSDOT determines if the source of scouring is instability due to local scour, contraction scour, long-term degradation, or lateral channel shifting.

Missouri

Missouri has 10,394 state bridges and 14,034 local bridges. MoDOT developed and implemented a screening process with the USGS to identify scour-susceptible bridges and to perform a detailed hydraulic evaluation and scour estimate on bridges identified as scour-susceptible; the process was completed in 2007[67].

The Missouri Scour Program has four steps:

- **Screening** – 4700+ span-type bridges were screened; bridges not removed were elevated to Level 1.
- **Level 1 Field Scour Assessment** – 3,082 field scour assessments on span-type bridges over streams were completed; bridges determined to be scour-susceptible were elevated to Level 1+ or Level 2.
- **Level 1+ Rapid Scour Estimate** – 1,396 Level 1+ scour estimates were completed; bridges with scour greater than acceptable were elevated to Level 2.
- **Level 2 Detailed Hydraulic Analysis and Scour Estimate** – 392 Level 2 detailed hydraulic analysis and scour estimates were completed using WSPRO[68].

67 Potential-Scour Assessments and Estimates of Scour Depth Using Different Techniques at Different Bridge Sites in Missouri, Scientific Investigations Report 2004-5213, U.S. Geological Survey, U.S. Department of the Interior, https://pubs.usgs.gov/sir/2004/5213/pdf/complete.pdf

68 WSPRO: A computer model for Water-Surface PROfile computation, United States Geological Survey, https://water.usgs.gov/software/WSPRO/

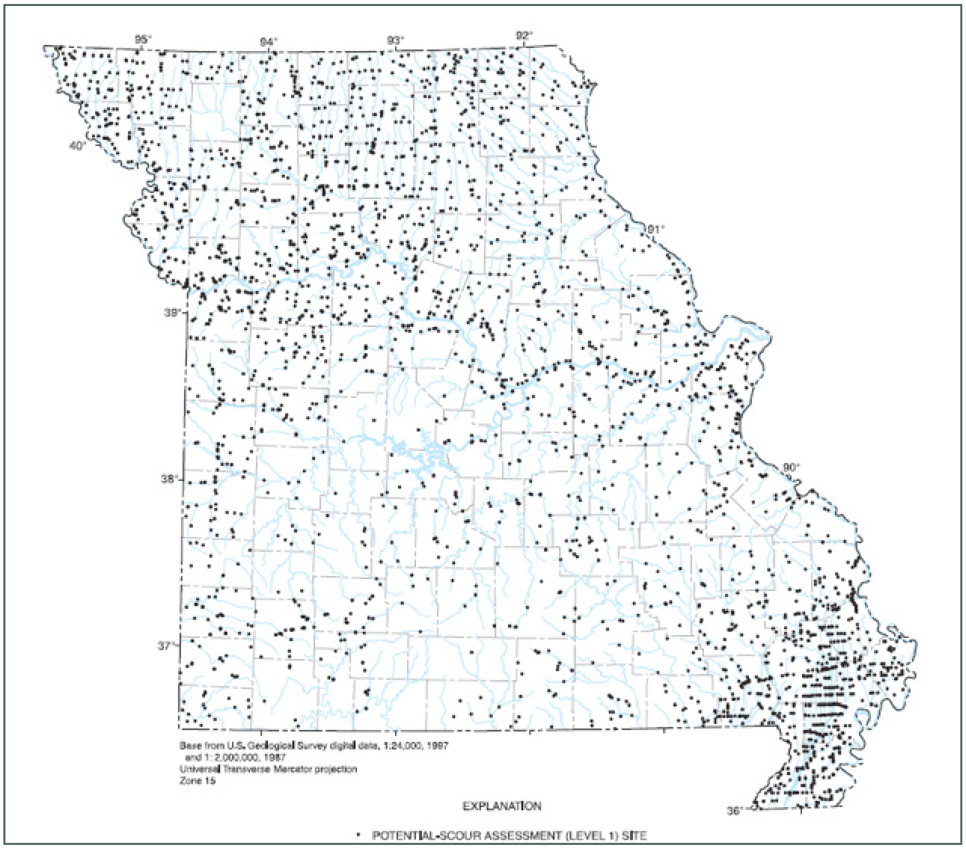

Figure 3.28 Level 1 field scour assessment locations in Missouri

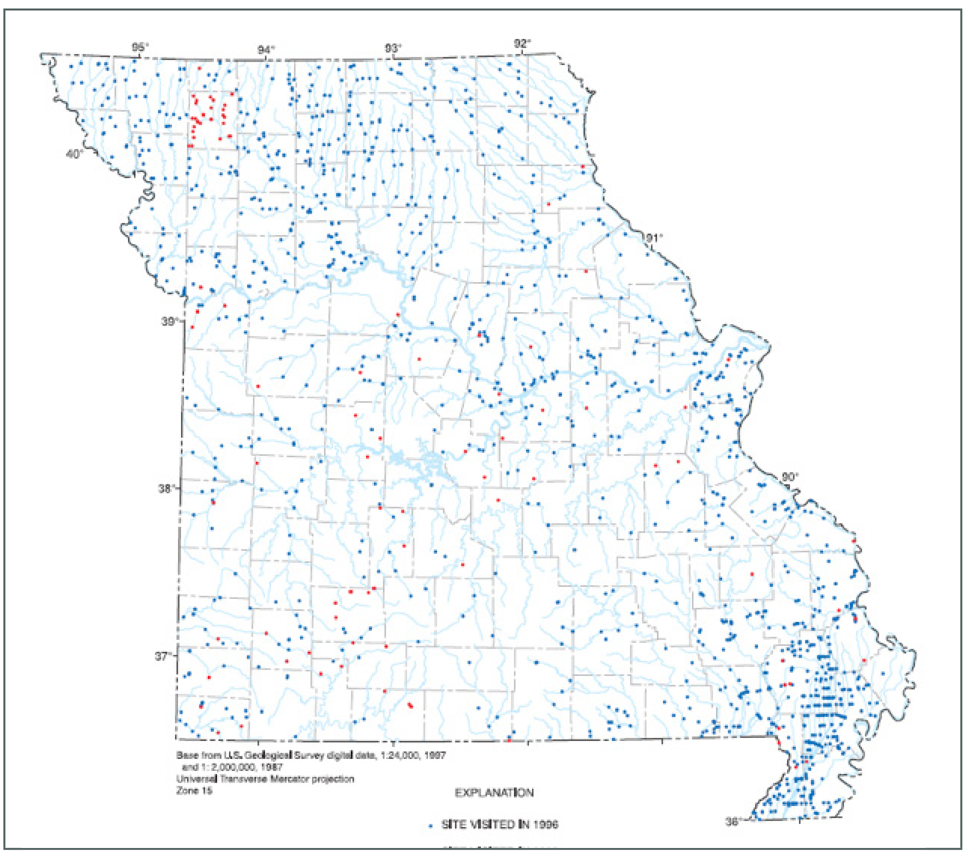

Figure 3.29 Level 1 combined with field scour evaluation locations

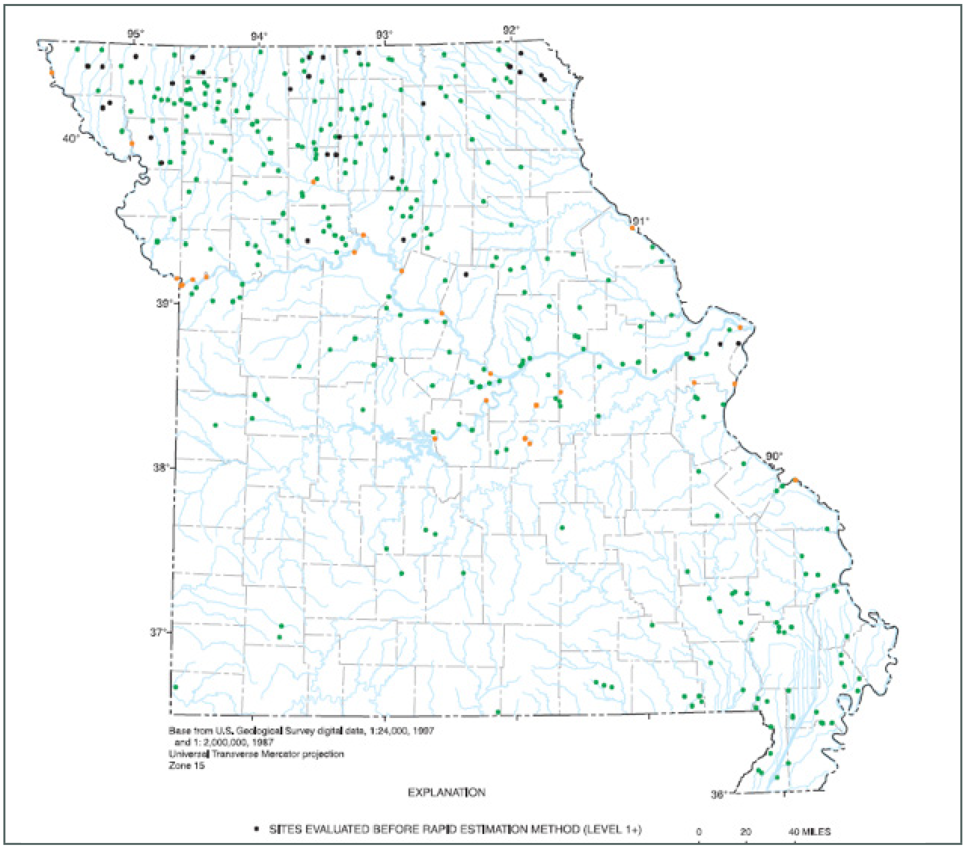

Figure 3.30 *Level 2 scour evaluation locations*

Bridges that received Level 2 Analysis were evaluated and classified by the Bridge Maintenance and Bridge Divisions with consensus from the district bridge engineer. Scour critical bridges were divided into four categories:

- **Category A** – Structure severely at risk during major flood events
- **Category B** – Structure substantially at risk during major flood events
- **Category C** – Structure moderately at risk during major flood events
- **Category D** – Structure minimally at risk during major flood events

MoDOT operates a real-time monitoring and inspection program.

- Real-time river channel-bed monitoring (**Figure 3.31**) on a bridge with USGS (pilot project) result in the publication of USGS Scientific Report 2009-5254[69]; the results are presented below.
- Smart rocks scour monitoring/riprap effectiveness (**Figure 3.32** and **Figure 3.33**) show the smart rock and schematic picture for scour countermeasure monitoring.
- Bathymetric and velocimetric surveys
- Streambank stability/lateral migration using LiDAR scan

69 Real-Time River Channel-Bed Monitoring at the Chariton and Mississippi Rivers in Missouri, 2007-09, Scientific Investigations Report 2009-5254, U.S. Geological Survey, https://pubs.usgs.gov/sir/2009/5254/pdf/SIR2009-5254.pdf

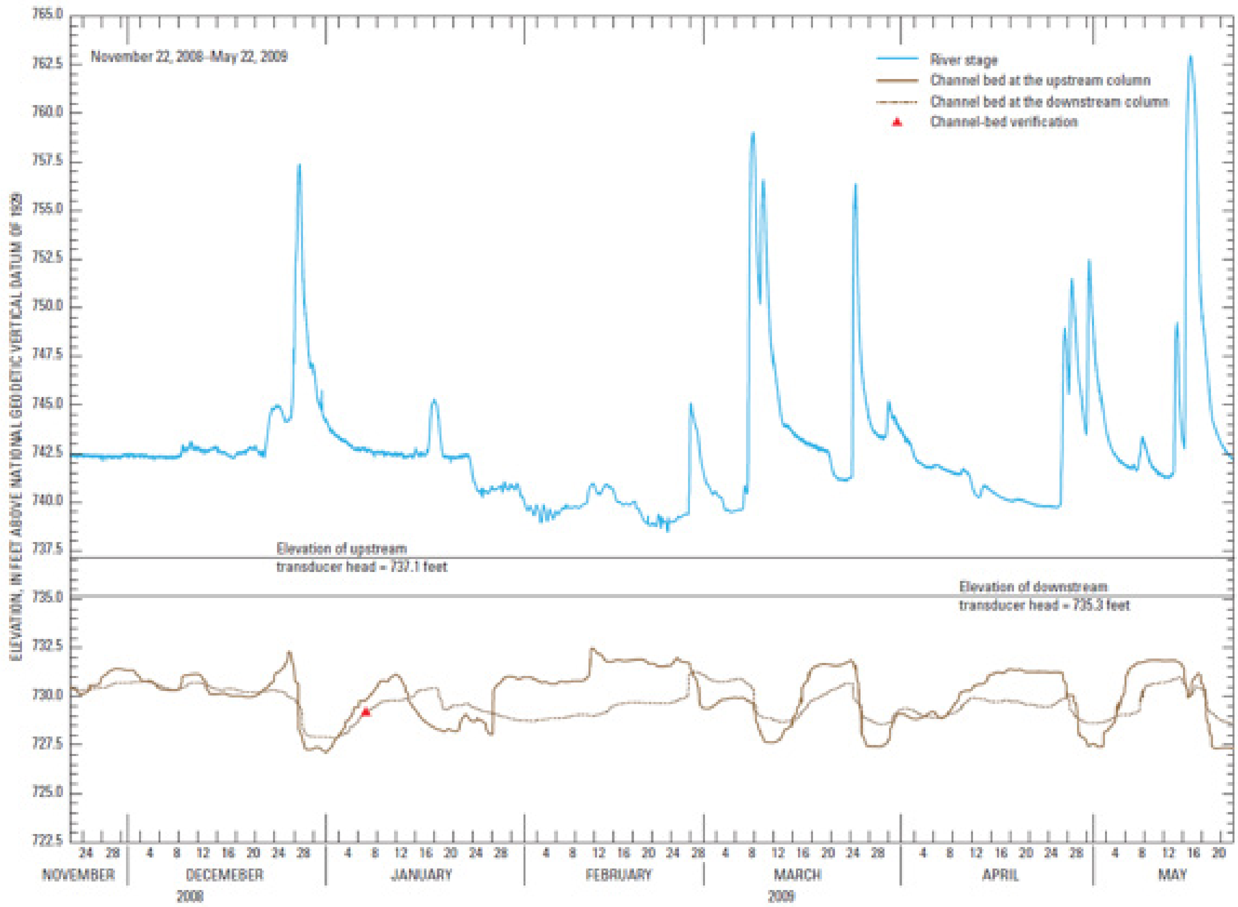

Figure 10. River channel-bed elevation at the downstream side of the upstream and downstream columns of pier 7 and river stage from May 22, 2008, through August 22, 2009, for the Chariton River at Novinger, Missouri (structure L-534).—Continued

Figure 3.31 ***Data from real-time river channel-bed monitoring***

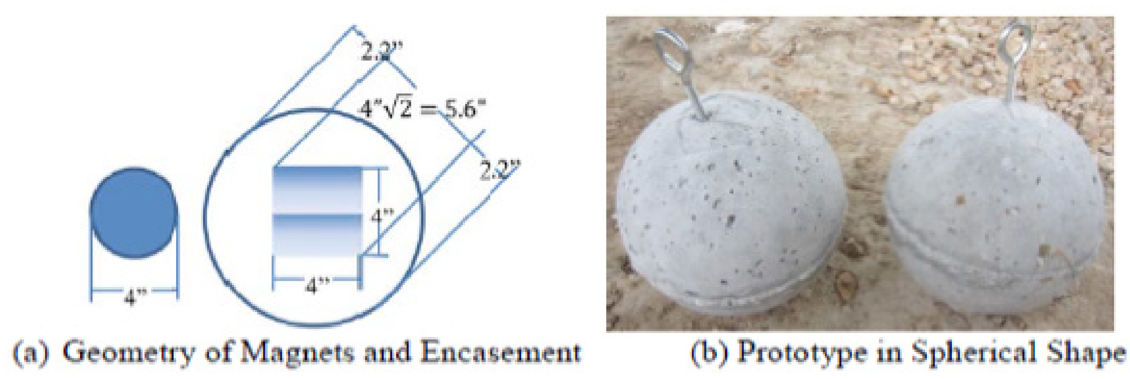

Figure 3.32 ***Design and prototype of magnets (a) and passive smart rocks (b)***

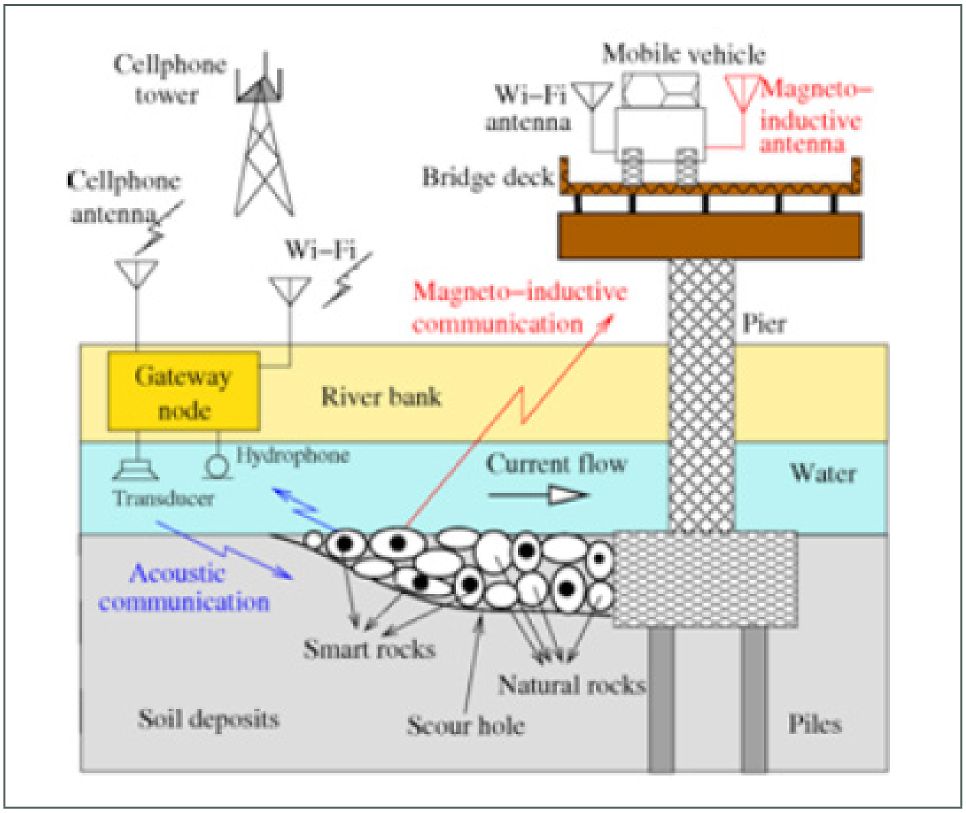

Figure 3.33 Scour countermeasures monitoring

Idaho

Figure 3.34 shows Idaho's flowchart to determine FHWA's NBI Item 113 for new bridges to inventory. New state bridges over waterways are designed with deep foundations (piles or shafts). ITD discourages the use of spread footings or Geosynthetic Reinforced Embankment (GRE) type foundations in areas where there is a potential for scour.

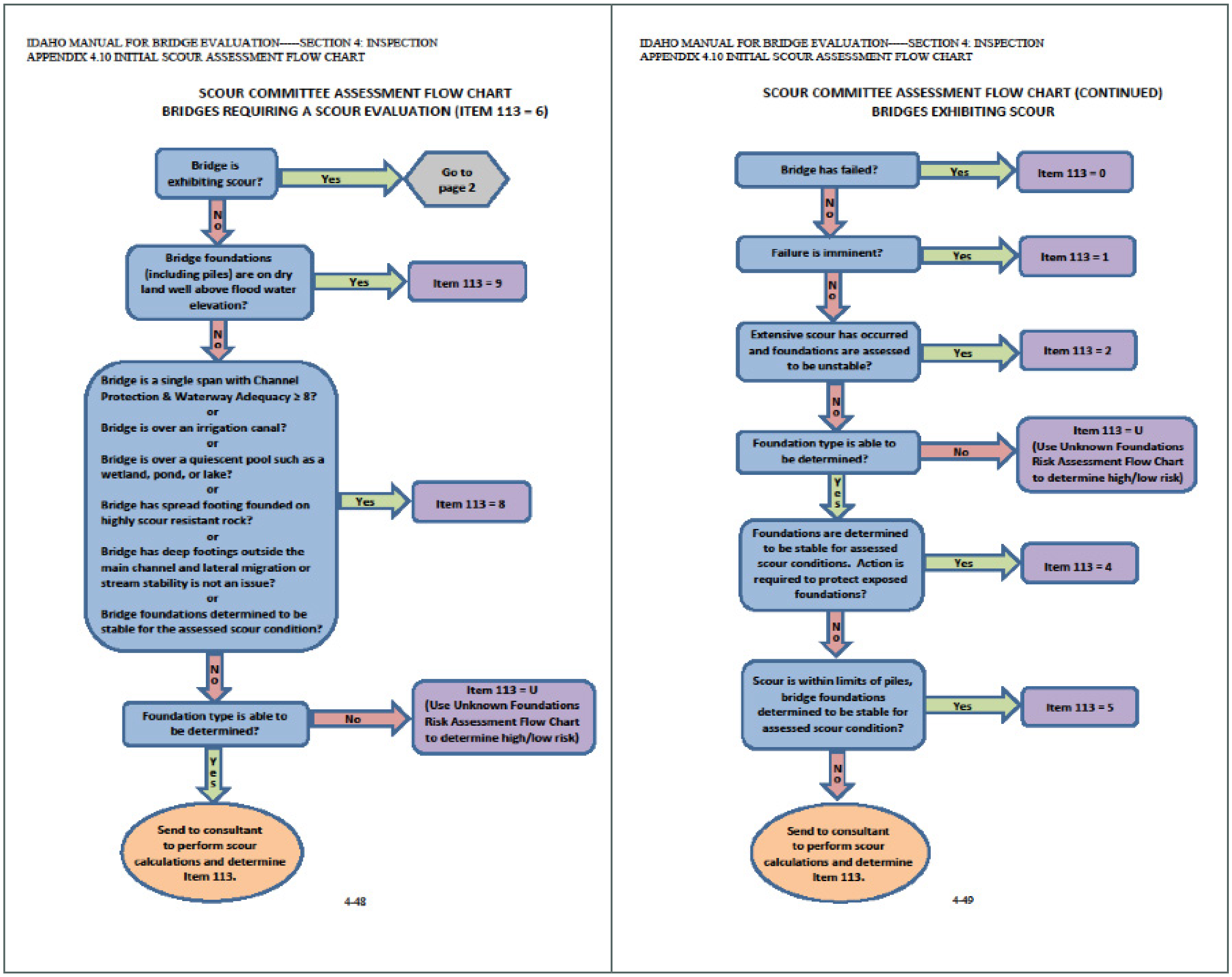

Figure 3.34 Flowchart to determine NBI Item113

For scour modeling and analysis, ITD uses the HEC-18 equations for determining pier scour and contraction scour. The agency typically uses HEC-RAS to model scour with river bathymetry, bed grain size, and hydrology. More-complex models, such as SRH-2D, have been rarely used to better define design or mitigation needs.

For monitoring scour critical bridges, ITD utilizes BridgeWatch, which makes use of information from USGS, next-generation radar (NEXRAD), snow telemetry (SNOTEL), and other data sources (e.g., discharge at dams) to send alerts for over-threshold events. Locations of data sources in Idaho are shown in **Figure 3.35**.

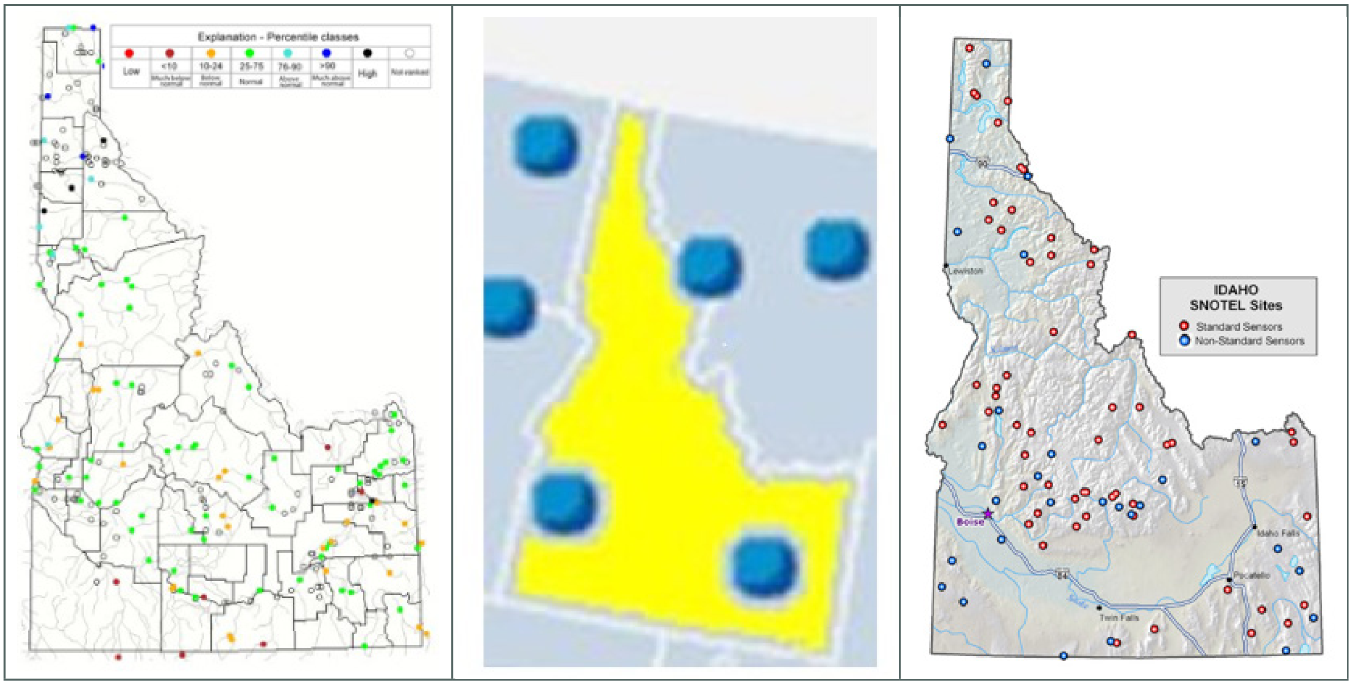

Figure 3.35 Various data sources for use in BridgeWatch (left to right): USGS, NEXRAD, and SNOTEL

The BridgeWatch alert procedure is as follows:

- Evaluate the alert for validity by cross-checking data sources (USGS is most reliable, Doppler radar is acceptable, and SNOTEL is suspect).
- If the alert is valid, send out local maintenance staff to monitor bridge for settlement during high flow.
- Cancel the alert and write a supplemental BridgeWatch report.
- Move up underwater inspection or wait for the next one to determine the high flow's effect on scour.
- Reevaluate recurrence threshold.

ITD uses different countermeasures such as riprap, A-Jacks[70], barbs, micropiles, articulated concrete blocks, and the micropile erosion function apparatus as shown in **Figure 3.36**.

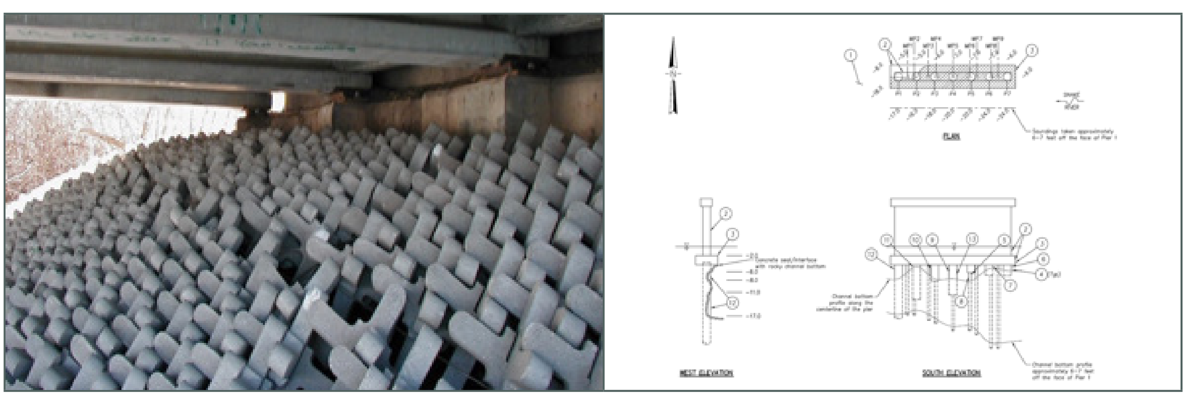

Figure 3.36 A Jacks (left) and micropiles (right) are typical countermeasures used in Idaho

70 A-Jacks®, Contech Engineered Solutions LLC, a QUIKRETE company, http://www.conteches.com/products/erosion-control/hard-armor/a-jacks

A POA was made for all bridges with 113 = 2 or U (high and low risk). The POA was developed in house using data from the AASHTOWare Bridge Management (BrM) software, field inspections, and BridgeWatch. The information is in an Access database that pulls live information from the data sources and can be revised easily.

ITD uses BridgeWatch to monitor its network of bridges during an extreme event; however, a written response protocol for prioritizing inspection of a large number of bridges during an extreme event is in development.

For an unknown foundation, changing the coding to something else typically requires observation of piles or visible confirmation of a spread footing. The high or low risk is determined by the flowchart shown in.

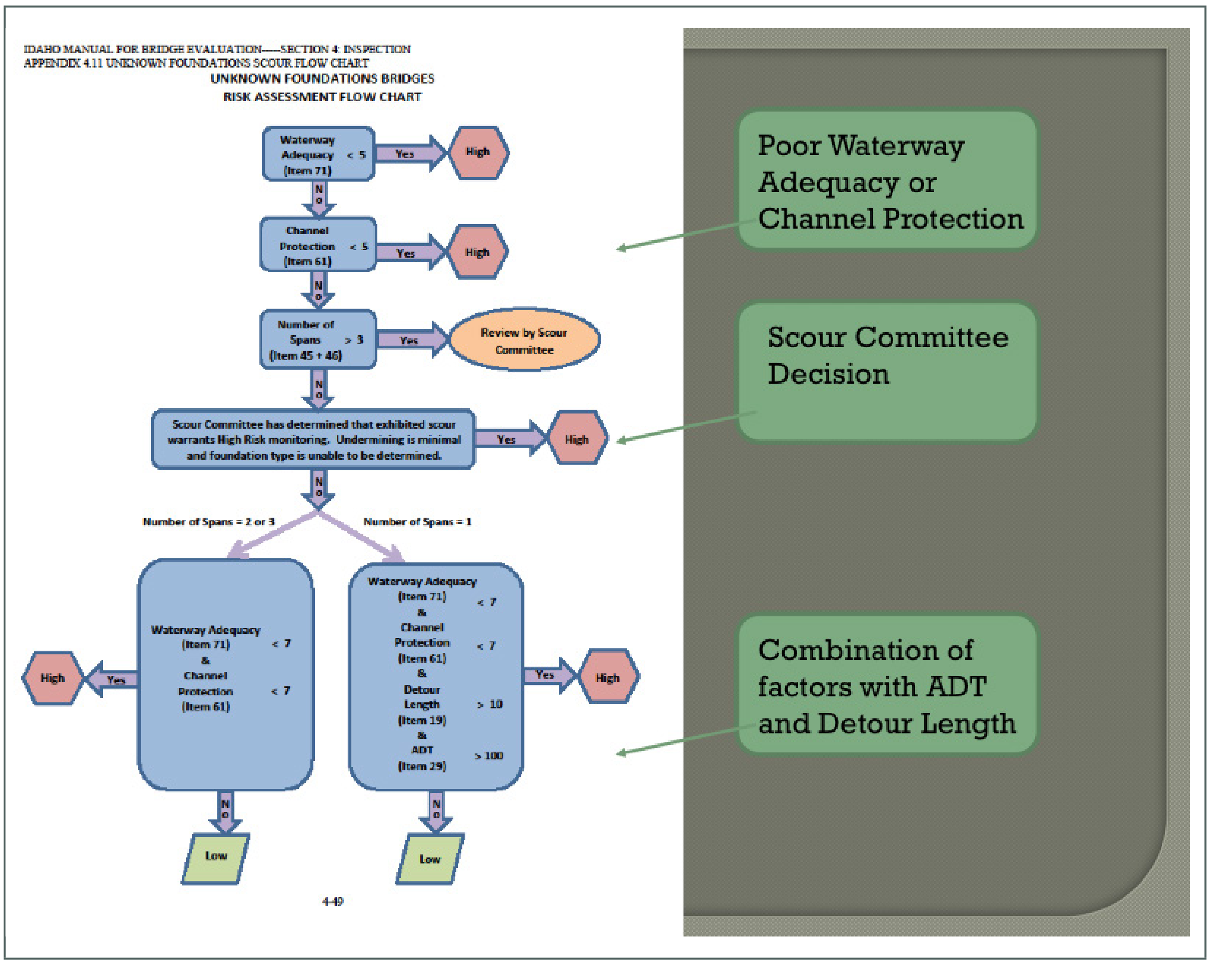

Figure 3.37 Flowchart for risk assessment of bridges with unknown foundations

Critical discharge is initially set to 25 years for all scour critical structures, while the 10 worst structures were set to five years. Then the observations are used to fine-tune the critical discharge following events. If ITD sees scour and no threshold event, it may lower the threshold; if there is a threshold event with no scour, it may raise the threshold.

California

Each district is responsible for roadway drainage and is overseen by HQ Hydraulics and Structures Hydraulics (both in Sacramento) responsible for scour-related issues at bridges.

Before 1995, bridges were screened based on structure type and scour history. Between 1995 and 2002, a rapid scour evaluation of bridges was performed based on cross-section history at bridge face, normal depth hydraulics, and HEC-18, 2nd and 3rd Editions, primarily at piers. Since 2002, unknown foundation and tidal analysis are performed. Recently, various new technologies are being applied:

- **2006** – Inflatable boat, sonar, and total station
- **2008** – Differential global positioning system and two-dimensional modeling
- **2010** – Acoustic Doppler current profiler; begin working with computational fluid dynamics (three-dimensional software)
- **2014** – Acquisition of remote-controlled boat
- **2016** – Inertial navigation system / improved sonar

Caltrans reduces risk by obtaining improved scour measurements (i.e., by "getting wet and living on the edge" and making a concerted effort to collect hydraulic and scour data during high-flow events). The agency also does more detailed hydraulic modeling.

Caltrans adopts an interdisciplinary scour approach, including hydraulics (field assessment, hydrology and hydraulic, and scour based HEC-18) and load rating analysis, as well as geotechnical analysis. Figure 3 38 shows an example of scour analysis. The Load Rating Analysis Branch determines the inventory and operating load rating for the superstructure. The Hydraulics Scour Evaluation Branch performs preliminary foundation stability screening based on criteria provided by Load Rating Analysis Branch. The Geotechnical Branch performs a pile/soil bearing capacity analysis for the estimated scour depths and provides the ultimate load-bearing capacity for the estimated scour depths.

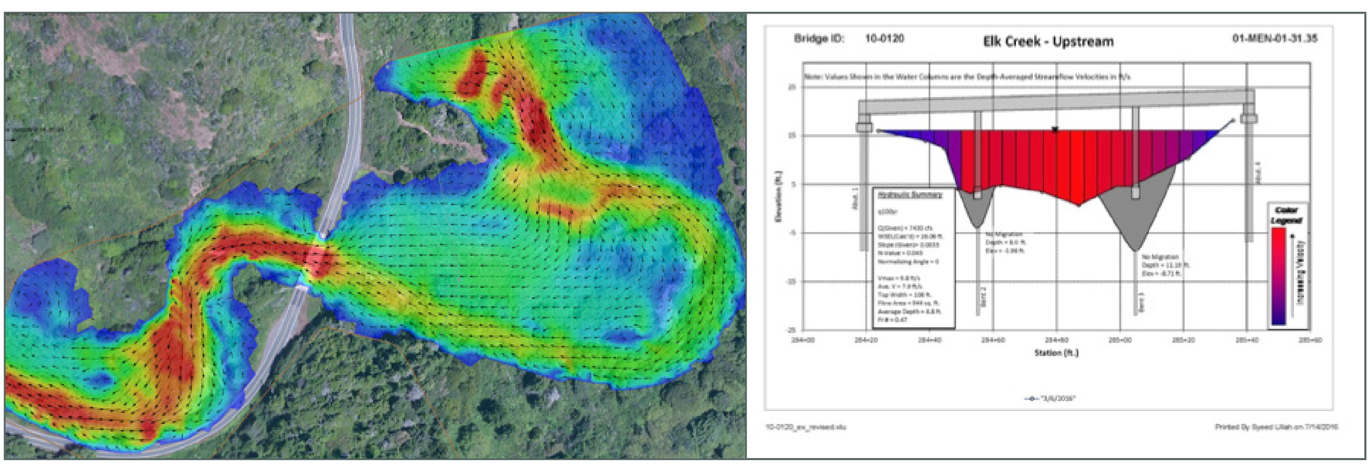

Figure 3.38 Scour analysis of the Elk Creek Bridge (Br. No. 10 0120): hydraulic scour evaluation (left) and foundation stability (right)

Local agencies own 11500 bridges over water in California; 900 bridges have 113 codes of U. All have POAs, which the local agencies developed and sent to Caltrans for archiving. (Ten POAs are missing, mostly for on bridges recently coded U.) Caltrans develops and implements POAs for state bridges and local agencies develop and implement them for local agency bridges.

In California, approximately 11500 local agency bridges are over water and are from 650 different local agencies. Structure Maintenance and Investigations is responsible for the scour assessment. Of these bridges, 383 have 113 codes of 3, 2, 1, or 0; all have POAs on file. Nine hundred bridges have 113 codes of U and all have POAs on file except about 10, which are for bridges that have recently been coded U.

Caltrans adopted several technical approaches to reduce scour risks:

- Emphasis on POAs and properly designed scour mitigation
- Real-time flood monitoring
- Scour instrumentation with tilt sensor, float-out, sliding magnetic collar, smart rock, and acoustic stage gauge (see **Figure 3.9**)
- High-flow data visualization tool (web interface) for field measurements (see **Figure 3.40**)

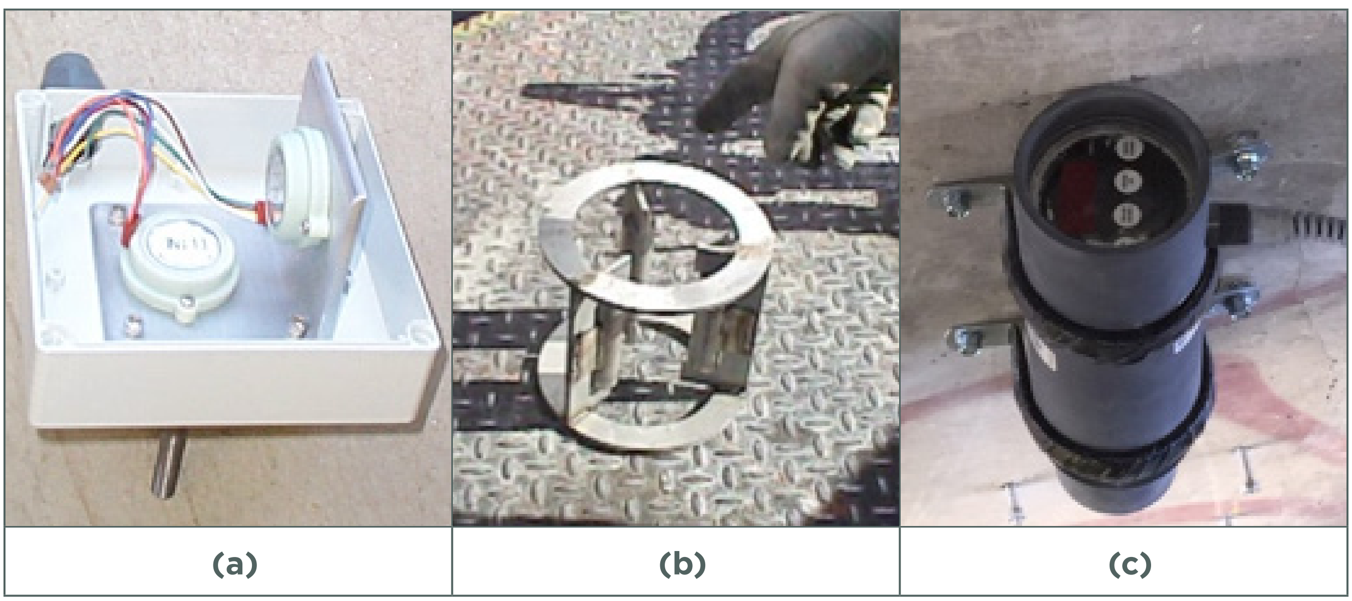

Figure 3.39 Various types of scour instrumentation: (a) Tilt sensors, (b) Magnetic Sliding Collar, and c) Sonar.

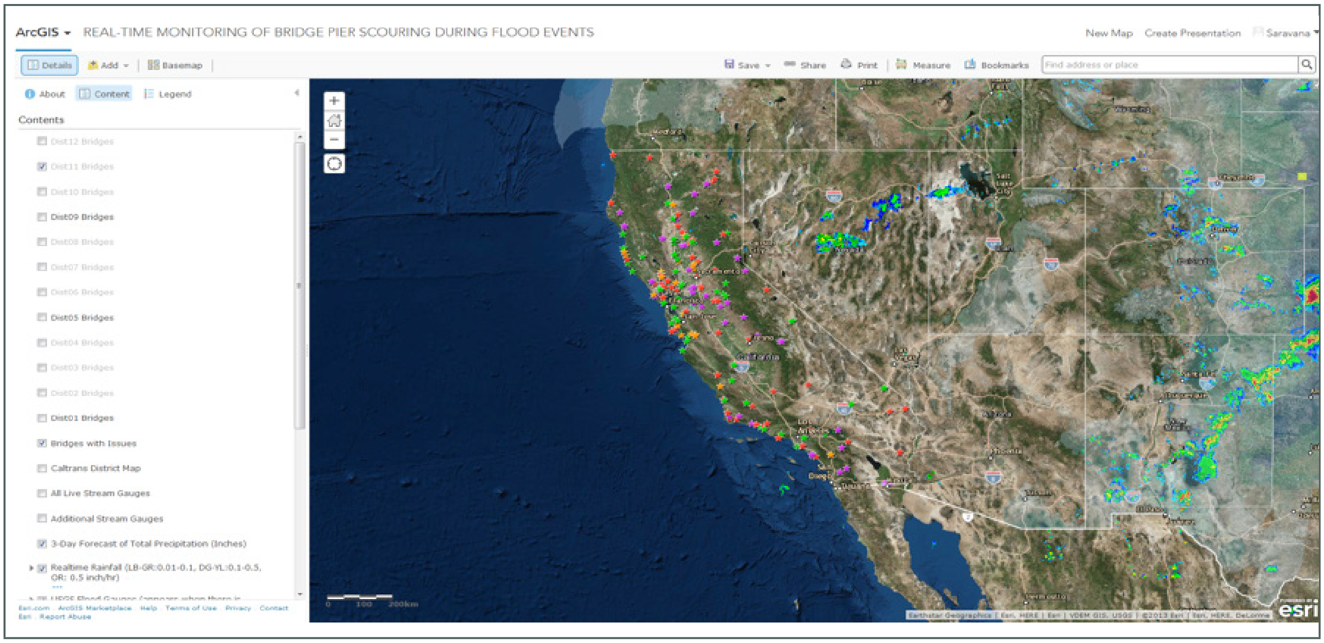

Figure 3.40 Data visualization

Caltrans is performing an FHWA Pooled Fund Program[71] research project TPF-5(211) to study the scour mechanism and time-rate of scour for the Feather River using a physical lab scaled model and a computational fluid dynamics numerical model. The ultimate target is scour prediction as shown in **Figure 3.41**.

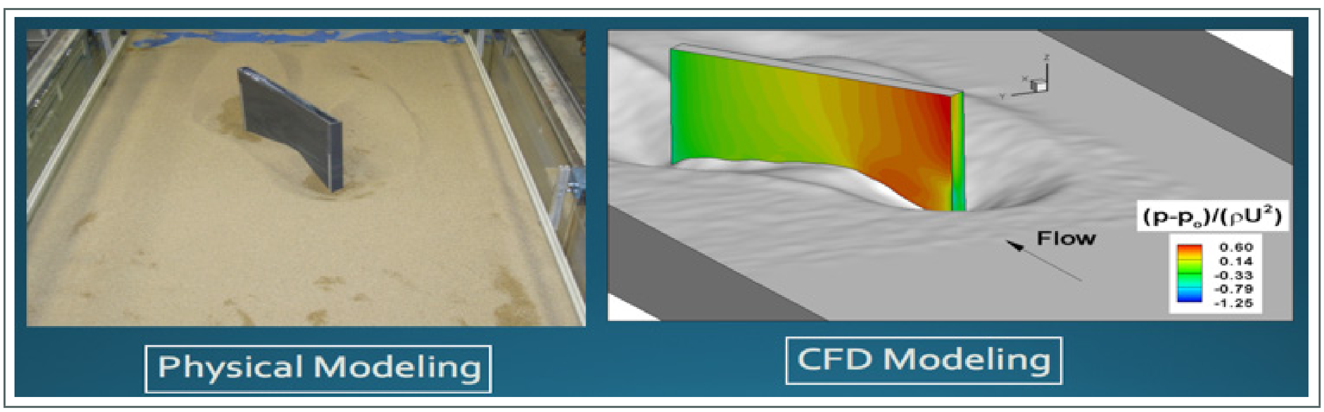

Figure 3.41 Scour prediction

Based on the desk scan (**Chapter 2**) and material presented in **Appendix B**, the scan team deliberated and finalized the findings, conclusions, and recommendations in the next section.

71 Transportation Pooled Fund Program, National Cooperative Highway Research Program, Thttp://www.pooledfund.org/

CHAPTER 4

Findings, Conclusions, and Recommendations

General Procedures and Risk Analysis

Findings

- Most states used criticality while others used probabilistic approaches to help perform risk analysis.
- A number of states perform vulnerability analysis and table scoring to evaluate scour risk and help prioritize projects for scour mitigation.
- Many states have strong teams of structural, hydraulic, and geotechnical engineers.
- Many states have used various methods to help define risk and minimize uncertainty.

Conclusions

- Scour risk management is a complex process and requires input and open communication from multiple disciplines.
- Due to limited resources, states need to prioritize risk assessment, including advanced design, monitoring, and design of countermeasures.
- Prioritization appears to be based on criticality and in some cases on the consequences of failure with limited consideration given to vulnerability.

Recommendations

- States need to form scour committees with interdisciplinary capabilities, including engineers from geotechnical, structural, and hydraulics areas, to help address various issues related to scour mitigation.
- Additionally, since scour is a nationwide threat and the number one cause of bridge failures, a scour committee at the national level is needed. It is recommended that AASHTO create a task force to help form a multidisciplinary body that would develop guidelines and specifications for scour mitigation design and to serve as a clearinghouse for new innovations. (The scan team's proposal to AASHTO is provided in **Appendix F**).
- Due to limited resources, states should consider using risk analysis to prioritize how they can best apply their limited resources.

Scour Modeling and Analysis

Findings

- A number of states are using better testing methods of soil and rock. Using erosion tests for site-specific soil types, such as rock and clay, can improve scour predictions. Idaho, Texas, and Florida DOTS have used this testing procedure.

- A number of states are using two-dimensional/three-dimensional hydraulic modeling to simulate stream flow.
- Texas uses a velocity chart to verify modeling and data management for quality control/assurance. Data checks, such as Texas uses, can help provide quality control for scour predictions.
- Google Earth can be used to study historic stream migration patterns.
- HEC-18 provides a scour methodology for cohesive soils; however, testing needs to be performed and shear stress obtained.
- Improved methods to predict scour depth such as using two-dimensional modeling to include better parameters for the HEC 18 equations. Mississippi presented a case study for comparison only (two-dimension versus HEC RAS [one-dimension or recent two-dimension]). It is also noted that most states are using SRH-2D, a two-dimensional modeling approach.
- Highlight when to use two- or one-dimensional modeling.

Conclusions

- Advanced methods for modeling and material testing can be used to enhance scour predictions.
- Use of external data sources can enhance the quality control of scour predictions.

Recommendations

- Adopt new techniques, such as those developed by Florida or Texas DOTs, for materials testing for cohesive soils or rocks.
- Use two- or three-dimensional models in advanced cases. The conditions or parameters when the two-dimensional models can be applied need to be identified.
- Encourage the states and other agencies that involved in two-dimensional modeling to participate in National Highway Institute courses and other training workshops.

Monitoring and Field Inspection of Scour critical bridges

Findings

- Improved and safer inspection methods such as using sonar in lieu or in support of diving practices. For example, the use of “BlueView” sonar is shown to be effective in visualizing scour conditions.
- Use of three-dimensional sonar in lieu of underwater inspection can improve data and reduce or eliminate the risks associated with diving. Louisiana, Mississippi, and Minnesota DOTs have used this approach effectively.
- A number of states have had successful relationships with USGS through contracts and partnership.

Conclusions

- Advanced technology such as sonar can be applied effectively to enhance data collection efficiency and inspector safety.
- External data sources, such as USGS-generated data, are essential for the successful implementation and management of scour programs in the U.S.

Recommendations

- States should establish collaborative partnerships with USGS and other agencies, which would help facilitate sustainable data collection for scour predictions.
- It is recommended that AASHTO and FHWA establish partnerships with USGS and other agencies for innovative applications that would help advance the state-of-the-art of flooding on highway infrastructure.
- States should work proactively with FHWA for use and acceptance of advanced technologies for underwater inspection, such as sonar, to improve data collection and diver safety.
- Continued and future research are needed to enhance the capabilities of various systems to measure real-time scour; moreover, communication and dissemination of various research projects is needed to raise awareness of accomplishments.
- States are encouraged to share lessons learned based on their specific experience with countermeasure design and application.

Design, Construction, and Sustainability of Countermeasures

Findings

- A number of states have had good experience with various countermeasure designs.

Conclusions

- States had varying levels of success in implementing the same countermeasures.
- The design and installation of countermeasures need to be appropriate given all parameters.
- States had success in innovative techniques for applying countermeasures, such as geobags, caged blocks, A Jacks, and rock riffle.
- Countermeasures have a shorter lifespan compared to the design and service life of the bridge.

Recommendations

- States should pay more attention to inspecting countermeasures during construction and routine inspections.
- A body should be established to help disseminate the information related to the performance of various types of countermeasures.

Plan of Action

Findings

- Implementing inspection during significant flood events can be a strain on departmental resources.
- Reduced work force.

Conclusions

- Few states included some additional information on the POA rather than purely meeting the FHWA mandate.
- A number of states are incorporating innovative methods to implement POAs, such as BridgeWatch and ArcGIS[72] online.
- It has been observed that during extremely large flood events bridges that are not scour critical were also impacted.

Recommendations

- States should consider additional information to enhance their POA, which could be useful to the stakeholders (e.g., include information on bridge cross-section and whether the bridges on the detour route are scour critical).
- It is recommended that states develop emergency protocols for widespread flood events. (POA are bridge-specific.)
- States should create risk-based prioritization for implementing POA during flood events; this could be based on specific triggers for specific bridges.

72 ArcGIS, Esri, https://www.arcgis.com/home/index.html

Appendix A
Amplifying Questions

General Information About the Agency

A. Please specify the following information:

Item	Number	Notes
State bridges		
Local bridges		
Bridges over a waterway		
Scour-critical bridges Please specify type of substructure, etc.		
Bridges with unknown foundations		
Bridges with countermeasures		
Bridges with monitoring devices		
Other, please specify		

Please include other information that might relevant to your bridge inventory.

B. Is there a dedicated scour evaluation team? Centralized or decentralized? What is the procedure for handling scour assessment? Which office handles the assessment and mitigation of scour in bridges; number of staff you have in this office. Do you include engineers from multiple disciplines (e.g., geotechnical, hydraulic, structures, maintenance, environmental, operations, etc.) in your scour assessment teams? Is there a dedicated program with allocated funds to address scour issues such as countermeasures?

C. Current trends or special circumstances such as capital funding levels, maintenance needs, recent legislation, and issues.

D. Who is responsible for developing scour mitigation plans for your state and local bridges?

Topic 1: General Procedures and Risk Analysis

1.1 Please describe your procedure for assessing/evaluating scour based on engineering/hydraulic analysis as well as field inspection.

1.2 Based on your answer to b (in the general section above), please describe how the different disciplines (hydraulics, structural, geotechnical, inspection, etc) are involved in those procedures.

1.3 Does your agency follow FHWA's guidelines for scour design for new bridges and scour countermeasures? If not, do you have your own guidelines? Please specify and provide a copy or a reference. Please describe if/how you apply each flood level: 1) a scour design flood and/or 2) hydraulic design flood, and 3) scour check flood.

1.4 Are you considering or adopting new changes in your scour assessment and mitigation process? If yes, please describe the changes based on your state-specific requirements. (Please provide a copy or a reference of your current process).

1.5 What process tools have been developed to screen bridges and determine scour-critical bridges? Who is responsible to maintain these tools?

1.6 When do you reassess a bridge analysis for scour? After new FHWA guidelines? Regular interval (e.g., every 10 years)? Changes observed during inspection? After a flood event? Or other reasons? Please specify.

1.7 How do you handle the scour analysis for bridges with unknown foundations?

1.8 Are there any state-specific criteria that would prioritize the severity of scour at scour critical bridges (for example, average daily truck traffic, detour length, return period, etc.)? If a return period were used, what would be the value: 25, 50, or 100 years?

1.9 What are your performance measures for addressing scour critical bridges? Who are your audiences for the performance measures?

1.10 Are you considering adding scour as a risk factor in your transportation asset management plan?

1.11 How do you prioritize your scour-critical bridges and calculate risks? What are the criteria for low-risk bridges? How do you define and calculate the risk of bridge scour? Do you have any special requirements or procedures for high-importance bridges?

1.12 How do you define bridge vulnerability to scour? Do you consider using a vulnerability index? If yes, how do you calculate it and what are the factors you consider?

Topic 2: Scour Modeling and Analysis

2.1 Does your agency use HEC-18 equations for determining pier/abutment scour depths equations or have you developed your own equations? Please specify? For example, FDOT developed equations for pier scour.

2.2 What data do you use for the assessment of the bridge scour?

2.3 How do you review and evaluate (i.e., validate) the data that you are using?

2.4 Do you use computer software for scour assessment and/or risk mitigation (e.g., SRH-2D, HEC-RAS, or FB-MultiPier)? For example, do you typically model the hydraulics or the water surface profile with a one-dimensional model (e.g., HEC 2 or HEC RAS) or a two-dimensional model (e.g., SRH-2D or Tuflow[73])? If not, what other software/models do you use for scour assessment and/or risk mitigation?

2.5 Do you perform a detailed/refined hydraulic analysis? If so, what added values do you believe it provides?

2.6 How and when do you decide to perform structural modeling of the bridge to check for stability? (e.g., line analysis or Finite Element (FE) analysis). How detailed of a model is used? Is it cost-effective to perform a detailed structural analysis?

73 TUFLOW, BMT Group Ltd, https://www.tuflow.com/

2.7 Do you perform a cost/benefit analysis prior to performing structural modeling? If so, which types of bridges do you consider for structural modeling?

2.8 What benefits do you get from using the more advanced software programs in comparison with simplified methods? Does it impact the calculated risk?

2.9 Which bridge elements do you consider critical? Do you perform more detailed scour analysis for bridge abutments?

2.10 Do you have a case study that would demonstrate the success of the detailed hydraulic and/or structural modeling and analysis?

Topic 3: Monitoring and Field Inspection of Scour critical bridges

3.1 Do you have a decision-making process for implementing monitoring devices on scour critical bridges? What types of fixed scour monitors have you used and on how many bridges? Please list them in the table below:

Type of Sensors	Yes	No	Number of Bridges with Monitoring Devices	Number of Bridges with Monitors Still in Service
Sonars				
Magnetic sliding collars				
Tilt sensors				
Briscos				
Float-out transmitters				
Vibration sensors				
Sounding rods				
Buried/driven rods				
Piezoelectric polymer film				
Other, please specify				

3.2 If you have used fixed instrumentation, what are the advancements or aspects of this option that were beneficial?

3.3 If you have not used fixed instrumentation for scour monitoring, please provide the particular reasons why you have chosen not to use this option.

3.4 Please provide the reasons that a bridge may have installed scour monitoring devices:

Scour critical rating: Yes ___ or No ___

Bridge to be replaced in about ______ years; Yes ___ or No ___

Research project for ____

Others, please specify____

3.5 Has the monitoring data been useful for the verification of the bridge scour ratings or estimates from equations/models?

3.6 What are the costs of fixed monitoring instrumentation? What are the initial installation and long-term costs? Please provide both the dollar cost and the amount of time someone spent working on it (e.g., % of a position's time).

3.7 What portable scour monitoring devices are being used for field inspection?

3.8 How costly is it to perform inspection using a portable device versus fixed systems?

3.9 Sonar on a line rod has been used to measure scour depths at some bridges on a daily basis. Has your state had success using this type of monitoring during flood events or any other type of monitoring during an event?

3.10 What methods do you use to monitor changes in the channel? How easy is it to find channel cross-sections in inspection reports and are they accessible by bridge inspectors? Are they in a tabular format or plotted graphical?

3.11 Do you have state-specific criteria to reduce the frequency of field inspections for scour critical bridges?

3.12 Are you using a network-wide web-based monitoring system for monitoring rainfall, flooding, etc., and proactive notification of personnel during flood events?

Topic 4: Design, Installation, and Sustainability of Countermeasures

4.1 In addition to FHWA guidelines, what criteria or design standards do you follow to ensure that new bridge designs are not scour critical? Do you have state-specific guidelines for designing and installing countermeasures for scour? Please provide copies or references of your guidelines.

4.2 Do you have guidelines for selecting appropriate countermeasures? Please provide copies or references of your guidelines.

4.3 Does your agency typically upgrade the NBI 113 code after installing scour countermeasures? What information is required to change the 113 code from U? Does a criterion exist that prevents changing the 113 code after countermeasures are added?

4.4 If you have used countermeasures, how do you evaluate their performance? Do you have agency-defined elements for your element-level inspection for scour countermeasures?

4.5 In the effort to reduce structure risk due to scour, are there any countermeasures or foundation types that your department will not use? If so, what are they and why? If there are any particular conditions where a certain foundation or countermeasure would not be used (i.e., steep stream gradient), list those conditions as well.

4.6 How are countermeasures inspected, (e.g., at construction, during an event, and long term stability) to ensure they are providing the necessary protection?

4.7 Are your countermeasures ever recessed below the channel bottom for environmental concerns? If yes, how are they inspected during placement and for long-term stability? What types of countermeasures do you use in underwater installations? Did you encounter any challenges and what were the lessons learned?

Topic 5: Plan of Action (POA)

5.1 Please provide an outline of your POA (bridge scour-specific).

5.2 Do you have a statewide emergency response for inspection and monitoring of a large network of bridges under an extreme event? During an event, what is your protocol for prioritizing which structures are inspected first and which are left until later? How many staff members or engineers do you allocate to monitor these structures?

5.3 What information is required in the scour evaluation section of the POA?

5.4 How do you handle unknown foundations? What information would be adequate to change the 113 code from a U to something else? How do you find this information (testing; if so, which types)?

5.5 If structural or channel improvements or installations of countermeasures have been made, do you request a reevaluation?

5.6 If the bridge is closed to traffic with no prospects of reopening, do you still make a POA?

5.7 Do you typically contract out the POA with qualified engineering firms?

5.8 What if the scour review is very old?

5.9 How do you know what discharge makes the bridge vulnerable to scour? Or what criteria (e.g., discharge, stage, and rain event) are used to implement the bridge monitoring of a POA?

5.10 Do you have emergency action protocols? Please describe or provide typical protocols.

Appendix B

Responses to Amplifying Questions and Survey Results

General Information About the Agency

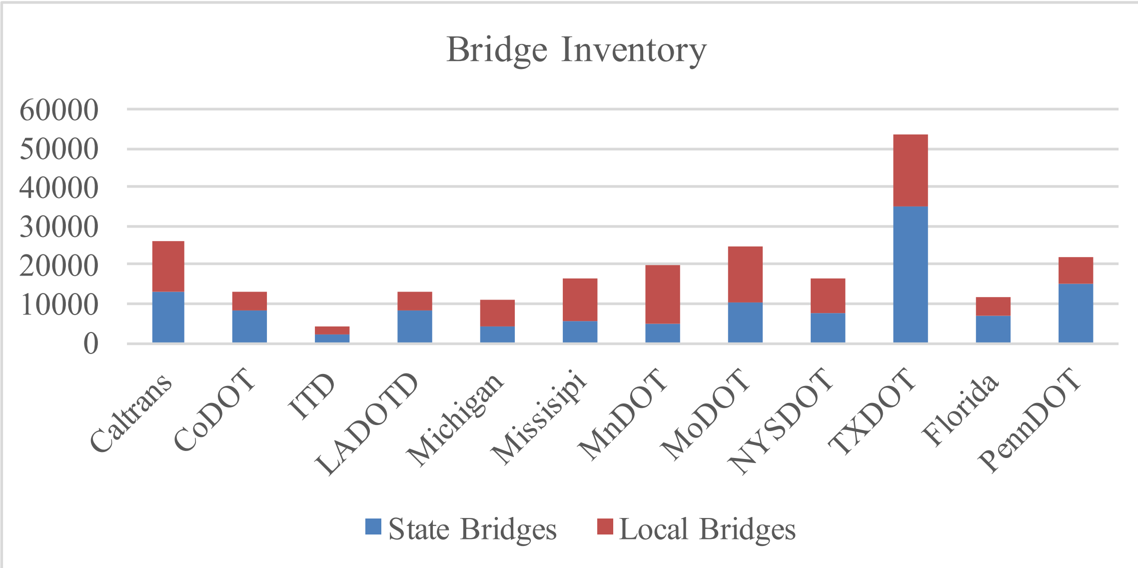

Figure B.1 ***Bridge inventory***

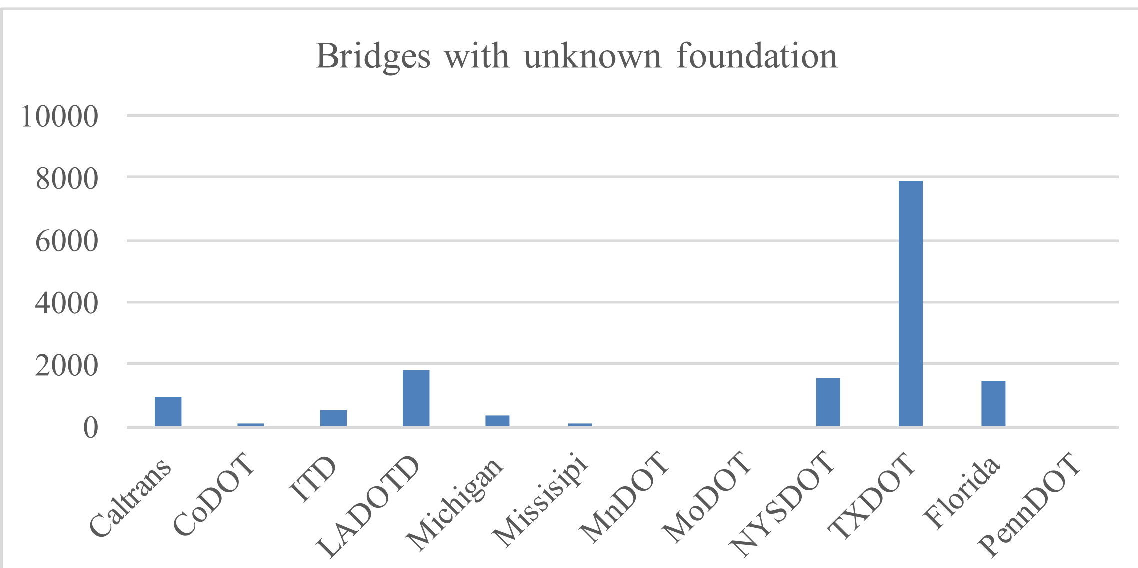

Figure B.2 ***Bridges with unknown foundation***

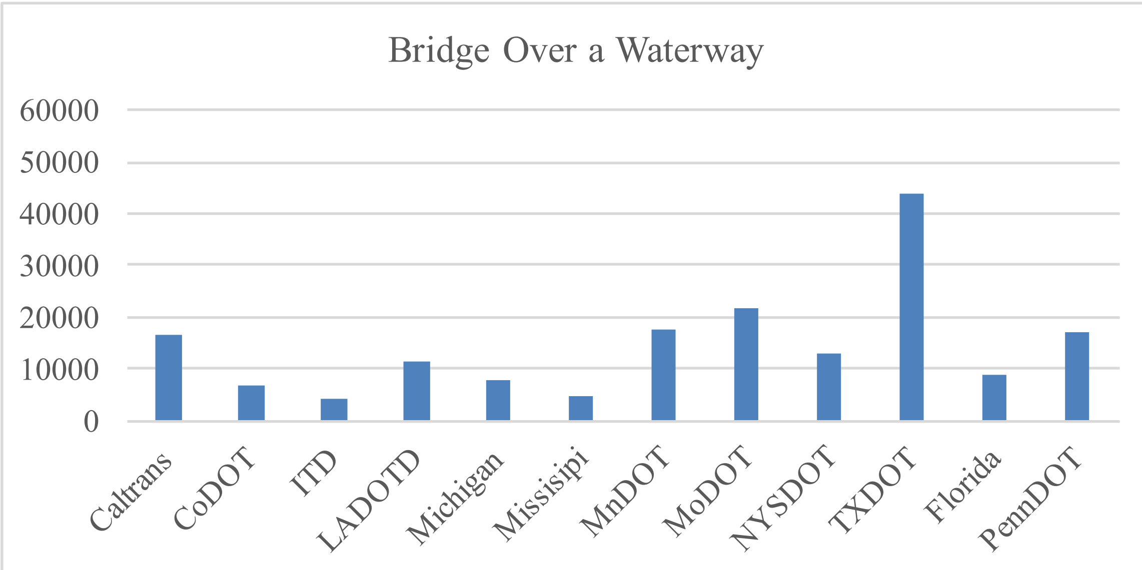

Figure B.3 ***Bridges over a waterway***

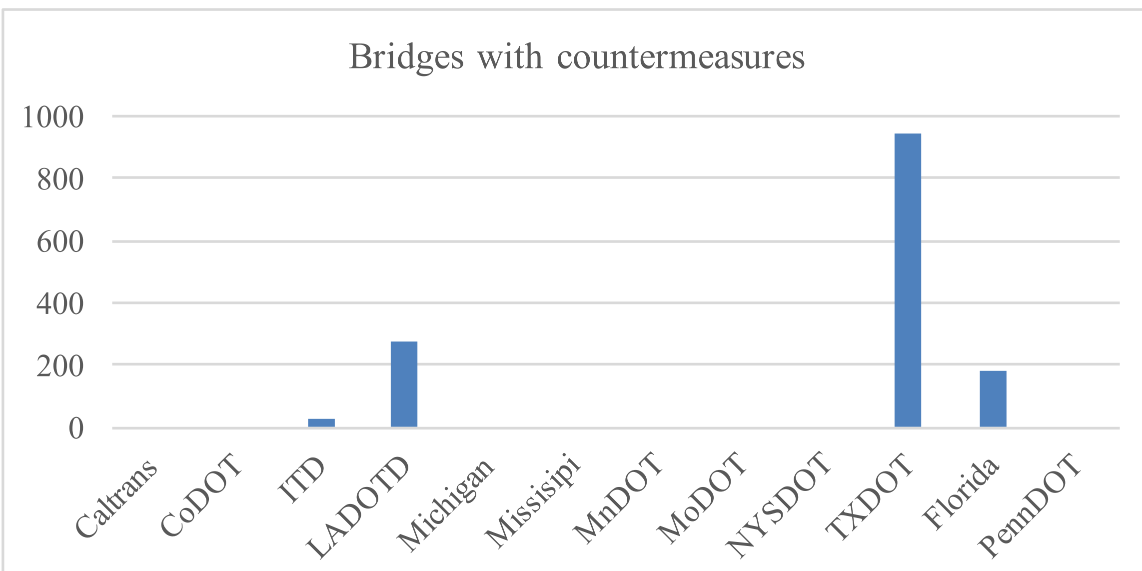

Figure B.4 ***Bridges with countermeasurest***

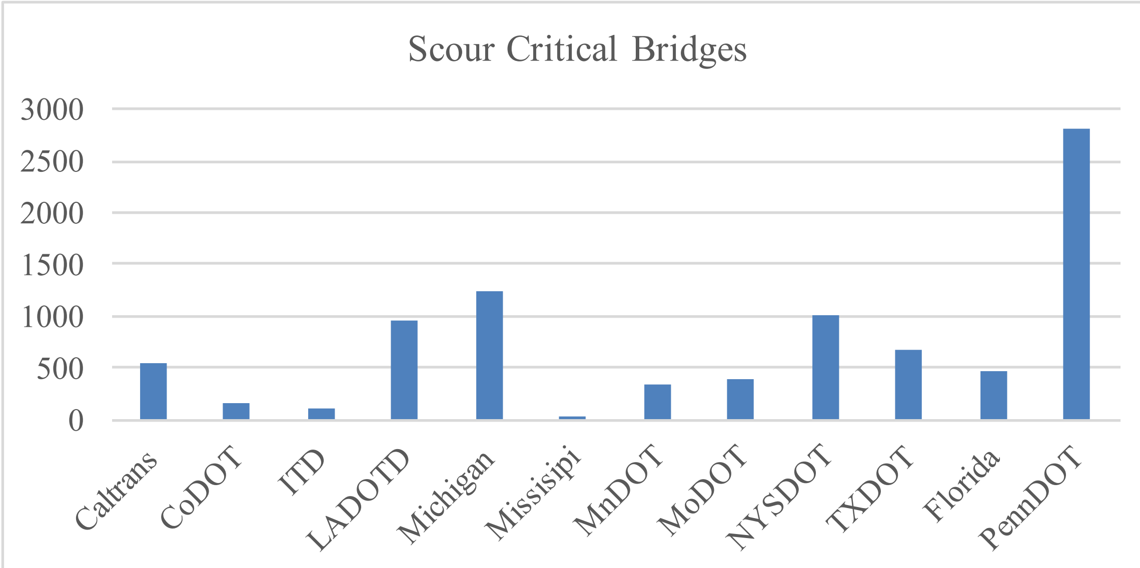

Figure B.5 Scour critical bridges

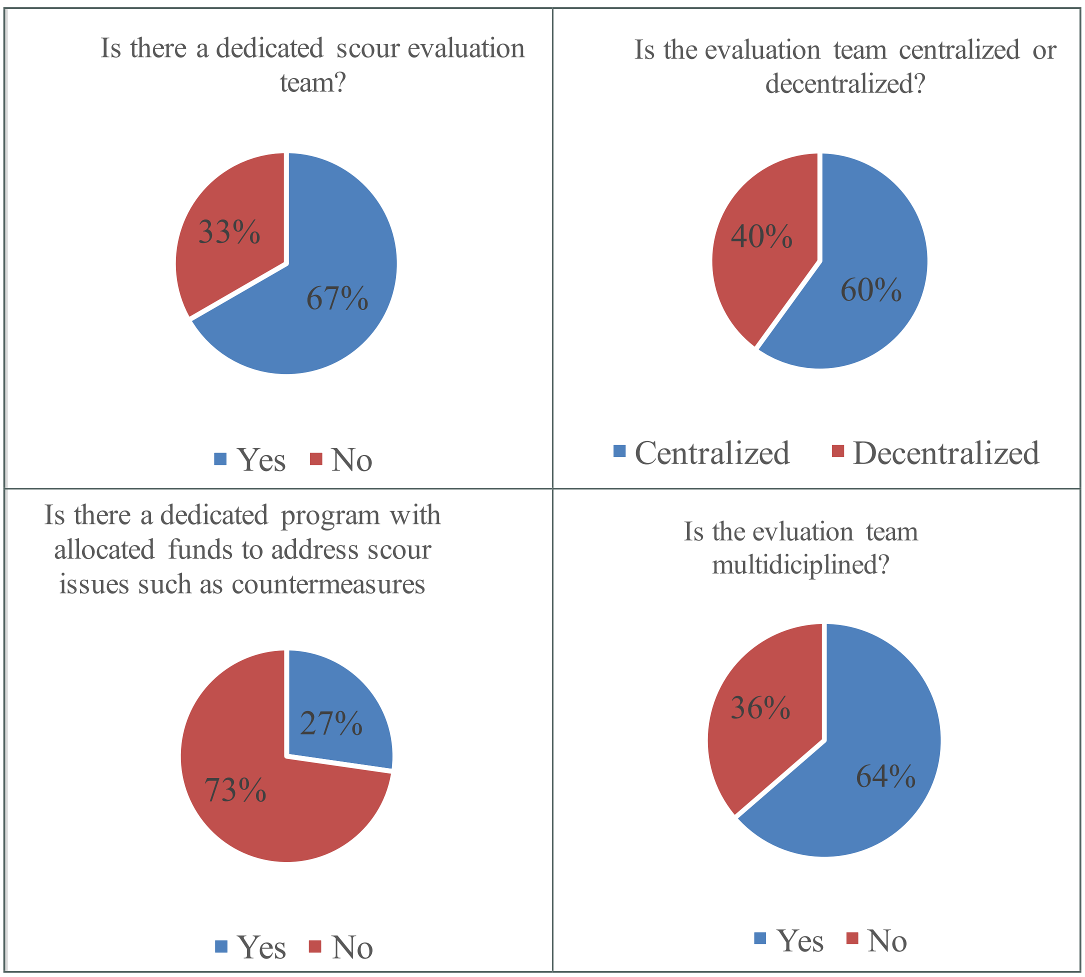

Figure B.6 Dedicated program with funds allocated for scour issues (left) and team composition (right)

No.	State	Current trend	Capital funding levels	Recent legislation	Issues
1	California	No			
2	Colorado		Funding levels for bridge scour have decreased		We are seeing more extreme weather and flooding events greater than the 100-year recurrence interval
3	Idaho		No special funds, either through bridge program funding or operational funding	No	
4	Louisiana	No			
5	Michigan	No			
6	Mississippi	N/A			
7	Minnesota		We have a shortfall of $6 billion over the next 10 years		
8	Missouri	Currently replacing a few scourcritical bridges each year	Funding levels are perpetually low compared to needs		
9	New York State	Critical bridges over water and climate change			
10	Texas	No			
11	Florida		Funded through bridge maintenance repair program and uses state funds		
12	Pennsylvania	No	Funded through PennDOT county maintenance funds		

Table B.2 Trends or special circumstances

No.	State	Response
1	California	Caltrans developed POA template. Caltrans develops and maintains its own POAs for scour critical and unknown foundation bridges. Local agencies develop their own POA documents and submit them to Caltrans for review and achieving.
2	Colorado	Staff Hydraulics manages a consultant team that evaluates and ranks potential scour critical structures and develops scour countermeasure designs. The consultant also packages those designs into plans for the region construction projects. Off-system bridges (local) have bridge scour project consultants that evaluate local bridges and develop scour designs.
3	Idaho	Bridge owner. State bridges: District is responsible for the plans with Bridge Design Section.
4	Louisiana	LADOTD prepares the POA for state and local bridges. The local entity is responsible for enacting the POA for local bridges.
5	Michigan	Seven different regions and local agencies are responsible for developing scour mitigation plans for their own structures.
6	Mississippi	State: Bridge Division and Hydraulics Division
7	Minnesota	The bridge owner is responsible for developing plans with guidance from Bridge Hydraulics
8	Missouri	District design divisions
9	New York State	State bridges – regional office; local bridges – local bridge owners
10	Texas	Each district is responsible for its on-system (state) bridge. Counties are responsible for off-system (local) bridges.
11	Florida	Each district maintenance office is responsible for all state and local government-owned bridges.
12	Pennsylvania	Either PennDOT or engineering consultant personnel

Table B.3 Responsibility for developing scour mitigation plans for state and local bridges

Topic 1: General Procedures and Risk Analysis

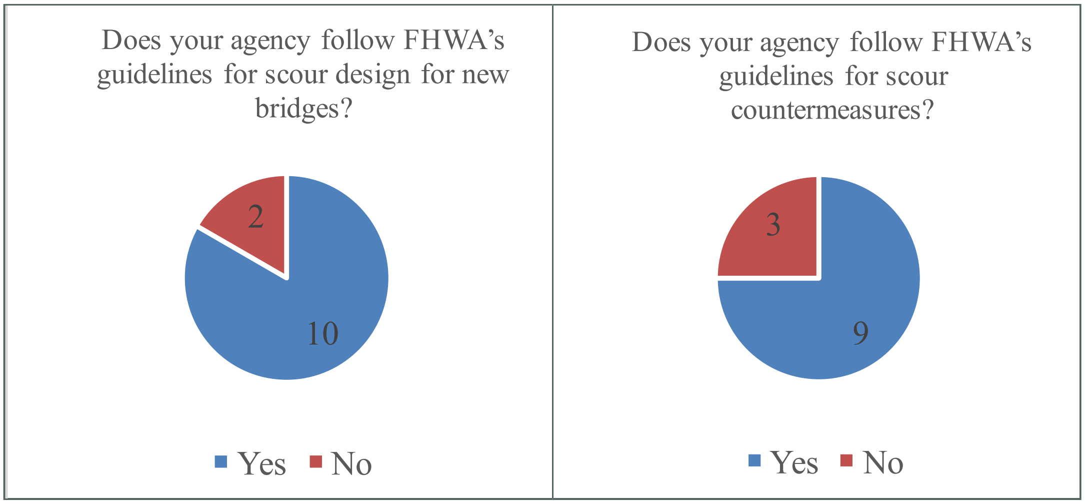

Figure B.7 ***Following FHWA's guidelines for scour design for new bridges (left) and for scour countermeasures (right)***

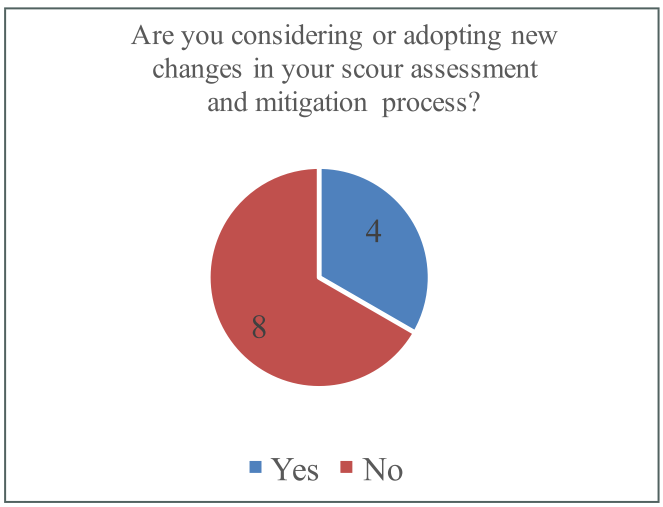

Figure B.8 ***Consideration or adoption of changes to scour assessment and mitigation process***

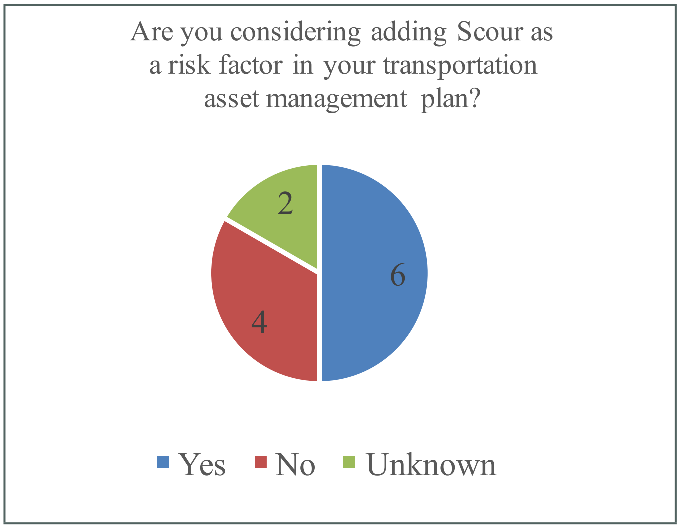

Figure B.9 ***Consideration of adding scour as a risk factor in transportation asset management plan***

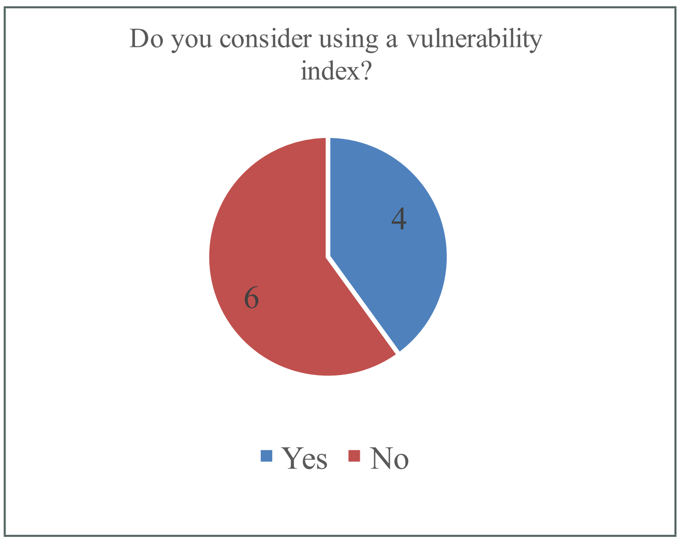

Figure B.10 ***Consideration of using a vulnerability index***

Topic 2: Scour Modeling and Analysis

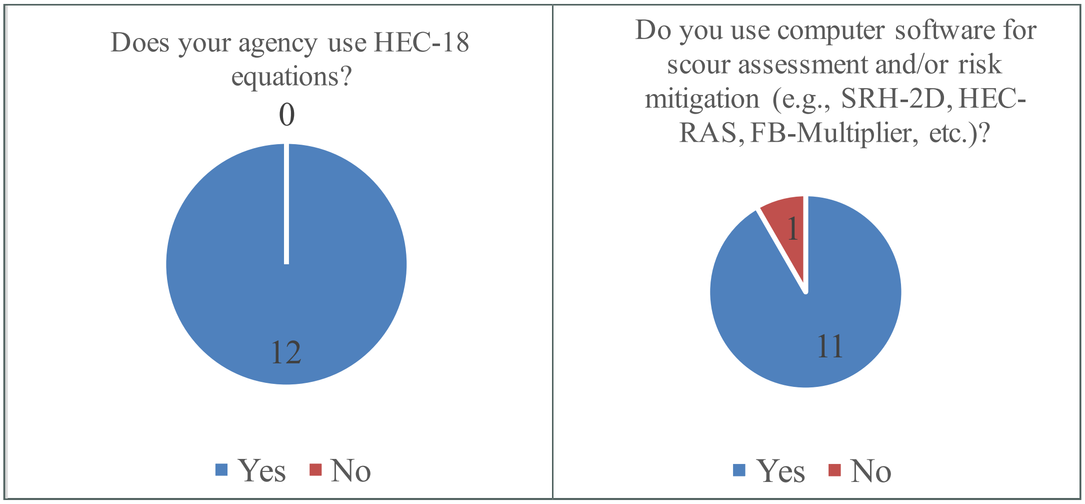

Figure B.11 *Use of HEC 18 equations (left) and use of computer software for scour assessment and/or risk mitigation (right)*

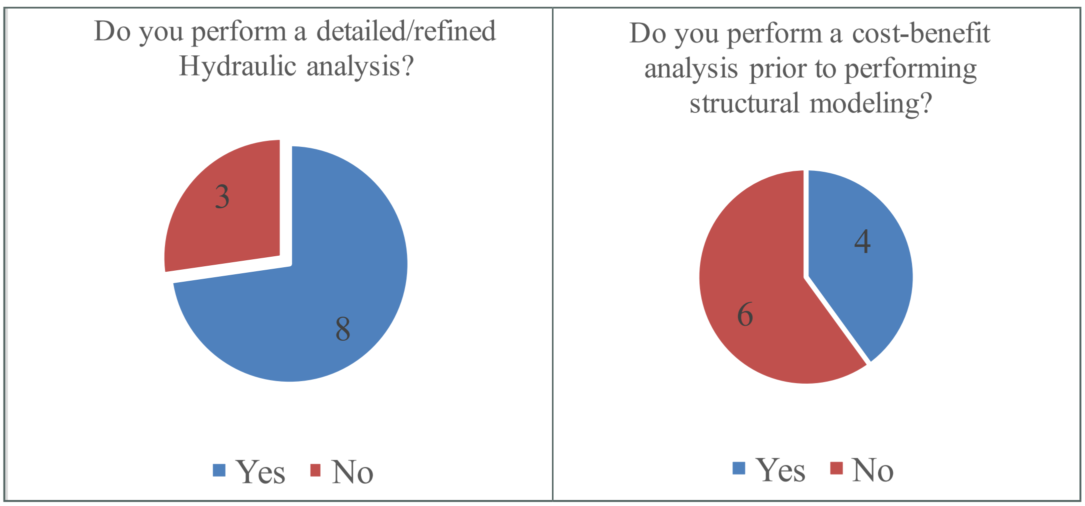

Figure B.12 *Performance of detailed/refined hydraulic analysis (left) and cost/benefit analysis before structural modeling*

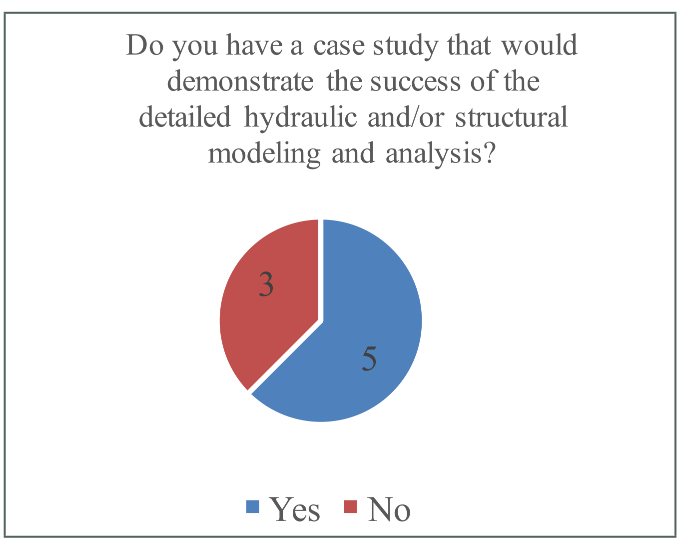

Figure B.13 *Case study that demonstrates the success of the detailed hydraulic and/or structural modeling and analysis*

Topic 3: Monitoring and Field Inspection of Scour critical bridges

No.	1	2	3	4	5	6	7	8	9	10	11	12
Statet	California	Colorado	Idaho	Louisiana	Michigan	Mississippi	Minnesota	Missouri	New York State	Texas	Florida	Pennsylvania
Sonars	1					1	4	2	<10	5		
Magnetic sliding collars	1						1		<10	1		
Tilt sensors	11						3			1		
Briscos	1											
Float-out transmitters	3						2		<3	2		
Vibration sensors							1			2		
Sounding rods							Unk			Unk		
Buried/driven rods			4									
Acoustic Stage gauge	7											
Pressure transducers	8											
Smart rock	1							2				
Sonar on line rod		Yes										
Stream depth gauge					2							
Buried tethered switch							1					

Unk = Unknown

Table B.4 Number of bridges with monitoring devices

No.	1	2	3	4	5	6	7	8	9	10	11	12
State	California	Colorado	Idaho	Louisiana	Michigan	Mississippi	Minnesota	Missouri	New York State	Texas	Florida	Pennsylvania
Sonars	0					0	3	0	<10	0		
Magnetic sliding collars	0						0		<10	0		
Tilt sensors	5						2			0		
Briscos	0											
Float-out transmitters	1						2		<3	0		
Vibration sensors							1			2		
Sounding rods							Unk			Unk		
Buried/driven rods			4									
Acoustic stage gauge												
Pressure transducers	4											
Smart rock	1							2				
Sonar on line rod		Yes										
Stream depth gauge					2							
Buried tethered switch												

Unk = Unknown

Table B.5 Number of bridges with in-service monitoring

1	California	Ability to remotely monitor site conditions uninterrupted has been the primary benefit
2	Colorado	N/A
3	Idaho	Real-time streambed elevation to correlate with flow and properly set thresholds for flow alerts
4	Louisiana	Not very beneficial since it couldn't be monitored remotely
5	Michigan	Stream-depth gauge; text message notifying when flow depth has been exceeded
6	Mississippi	Real-time data
7	Minnesota	Real-time
8	Missouri	Real-time for scour depth
9	New York State	No
10	Texas	Real-time
11	Florida	N/A
12	Pennsylvania	N/A

Table B-6 Beneficial advancements in or aspects of fixed instrumentation

1	California	Cell phone coverage for data transmitting, aesthetics for historical bridges
2	Colorado	Cost
3	Idaho	Cost/benefit
4	Louisiana	Costly and difficult to maintain
5	Michigan	Unfamiliarity with the technology, but interested
6	Mississippi	No response
7	Minnesot	No response
8	Missouri	No response
9	New York State	N/A
10	Texas	Either did not function properly, was damaged due to debris during flood events, or was not maintained by the district(s)
11	Florida	No response
12	Pennsylvania	Durability/reliability issues

Table B.7 Reasons for not using fixed instrumentation

		Scour Critical Rating	Bridge to Be Replaced	(In Years)	Research Project	Others Reasons
1	California	Yes			Yes	
2	Colorado	Yes	No		Yes	
3	Idaho	Yes			Yes	
4	Louisiana	No	No		Yes	
5	Michigan	Yes				
6	Mississippi	No				Loss of embedment creating settlement issues at a bridge pier
7	Minnesota	Yes	Yes	1	Yes	Lack of access
8	Missouri	Yes			Yes	pilot project with USGS
9	New York State	No				Bridges along areas of tidal influence
10	Texas	No			Yes	
11	Florida					
12	Pennsylvania					

Table B.8 Reasons that a bridge may have installed scour monitoring devices

1	California	Yes
2	Colorado	Yes
3	Idaho	Yes
4	Louisiana	No
5	Michigan	Not available
6	Mississippi	No response
7	Minnesota	No
8	Missouri	Unknown
9	New York State	Not enough data to validate
10	Texas	Not enough data to assess the usefulness of them, usually during research project
11	Florida	No response
12	Pennsylvania	N/A

Table B.9 Monitoring data are useful for verifying the bridge scour ratings or estimates from equations/models

1	California	About $15K to $20K for tilt meter installation with stage gauge
2	Colorado	Not available
3	Idaho	$70K for five bridges for buried rods for three years
4	Louisiana	N/A (only research projects)
5	Michigan	Stream gauge $3000
6	Mississippi	Detailed cost in Q&A
7	Minnesota	Not available
8	Missouri	Not available
9	New York State	Unknown
10	Texas	Not available, under research project
11	Florida	No response
12	Pennsylvania	N/A

Table B.10 Costs of fixed monitoring instrumentation

1	California	Sonar head mounted on a pole, also measure flow velocities, discharge and scour from either a manned boat or a remotely controlled boat during flooding
2	Colorado	Sonar on line rod
3	Idaho	Probe
4	Louisiana	Sonar, special cases have used 3D imaging

5	Michigan	Fish finder to identify scour, multi-beam echo sounders
6	Mississippi	Not available
7	Minnesota	Fish finders with fathomers attached to poles
8	Missouri	Depth finder
9	New York State	Sonar equipment
10	Texas	ShiFlow
11	Florida	No response
12	Pennsylvania	Probing rods and weighted tape measure

Table B.11 Portable scour monitoring devices being used for field inspection

1	California	Varies
2	Colorado	Not available, no fixed system
3	Idaho	Using the probe during inspection is cheap but only provides one data point every two years.
4	Louisiana	Minimal costs
5	Michigan	Cheap for fish finder
6	Mississippi	No response
7	Minnesota	Not available
8	Missouri	Unknown – performed as part of monitoring
9	New York State	Less costly and more reliable
10	Texas	Using the Shiflow during events is very inexpensive compared to fixed monitors, which are very expensive.
11	Florida	No response
12	Pennsylvania	N/A

Table B.12 Cost of performing inspections using a portable device versus fixed systems

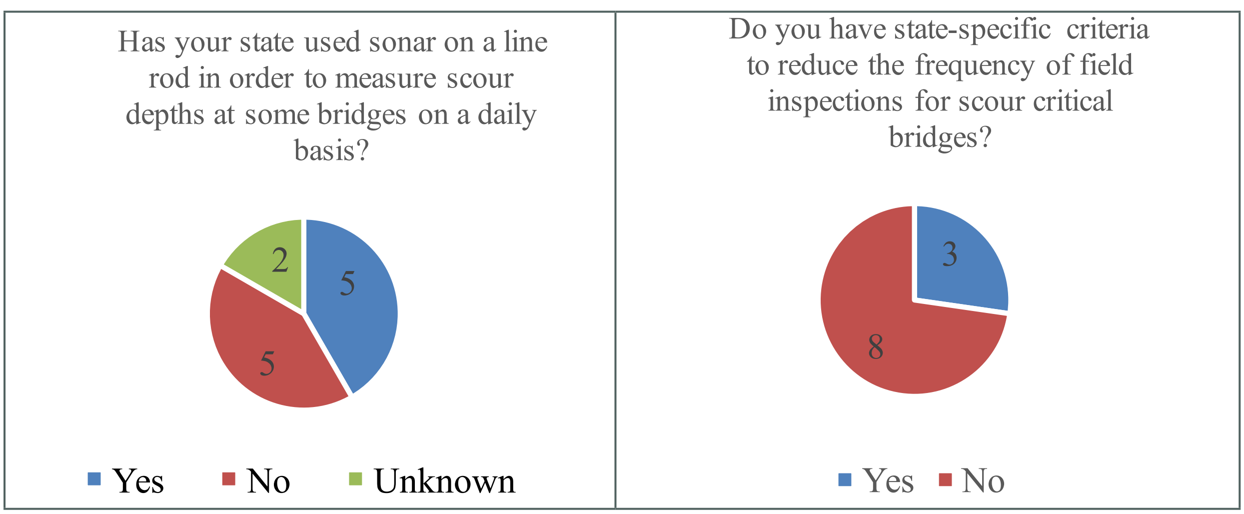

Figure B.14 Use of sonar on a line rod to measure scour depths (left) and criteria to reduce field inspection frequency for scour critical bridges

Note: Details about the methods used to monitor changes in the channel, the ease of finding channel cross-sections in inspection reports, their accessibility by bridge inspectors, and whether they are tabular or plotted graphically are too comprehensive and are not included in this appendix.

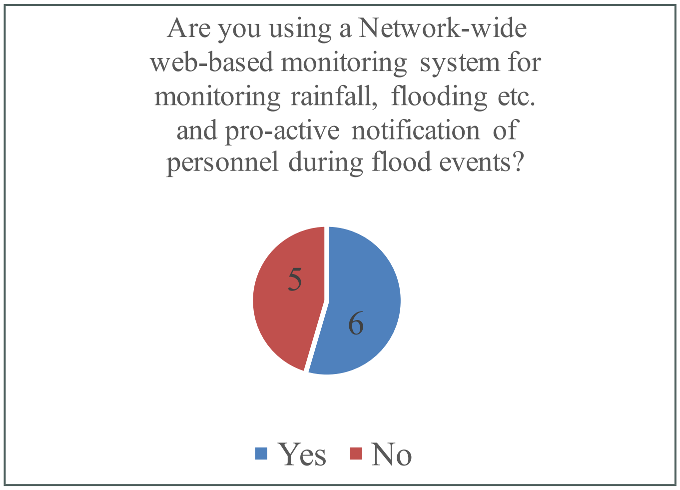

Figure B.15 ***Use of network-wide, web-based monitoring system***

Topic 4: Design, Installation, and Sustainability of Countermeasures

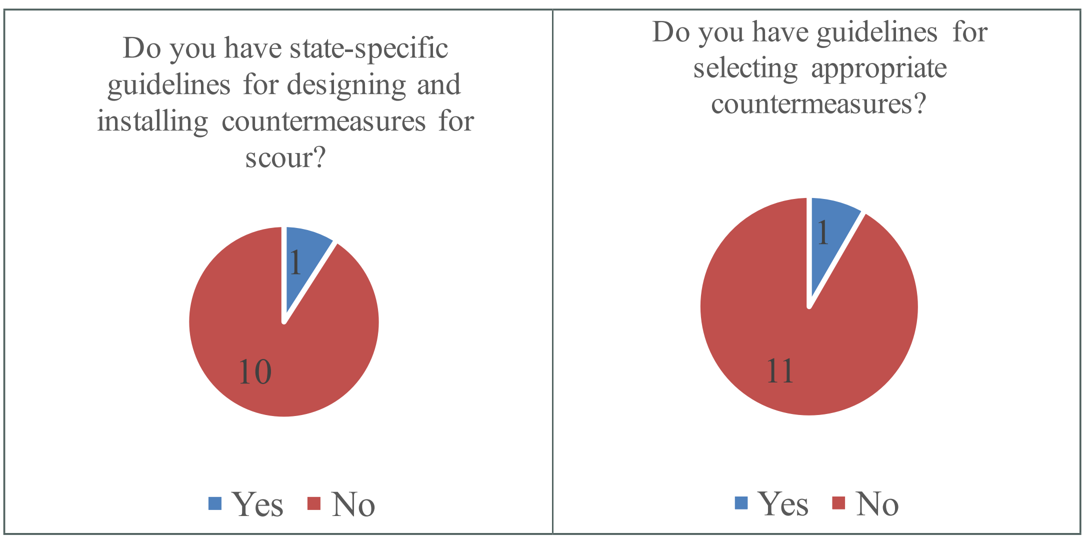

Figure B.16 ***Guidelines for design and installation of scour countermeasures and for appropriate countermeasure selection***

1	California	Yes	If the scour issue is deemed mitigated.
2	Colorado	Yes	
3	Idaho	Yes	If scour countermeasures are installed and functioning properly the code is changed to a 7. If they are stable but need further repairs they will be changed to a 4.
4	Louisiana	Yes	
5	Michigan	Yes	If a properly designed and constructed countermeasure (per HEC23 requirements) is installed with a proper filter, then Item 113 code can be upgraded to an 8 for single-span structures and 7 for multiple-span structures.
6	Mississippi	Yes	
7	Minnesota	Yes	
8	Missouri	Yes	
9	New York State	Yes	
10	Texas	Yes	
11	Florida	No response	
12	Pennsylvania	Yes	

Table B.13 The NBI 113 code is typically upgraded after scour countermeasures are installed

1	California	Both the foundation and the geotechnical property of the soil at the foundation
2	Colorado	Letter from the consultant and region to Staff Bridge that the scour countermeasures have been constructed according to HEC18 and HEC23 requirement
3	Idaho	No response
4	Louisiana	Nondestructive testing; flowchart for bridges with unknown foundations
5	Michigan	No response
6	Mississippi	Definitive substructure depth information, such as pile-driving records
7	Minnesota	Design and construction information
8	Missouri	Currently have no code U scour-critical state bridges
9	NYSDOT	Design scour countermeasure based on HEC23
10	TXDOT	Each district is responsible for installing scour countermeasures and for updating the NBI coding for Item 113.
11	Florida	No response
12	PennDOT	No

Table B.14 Information required to change the 113 code from U

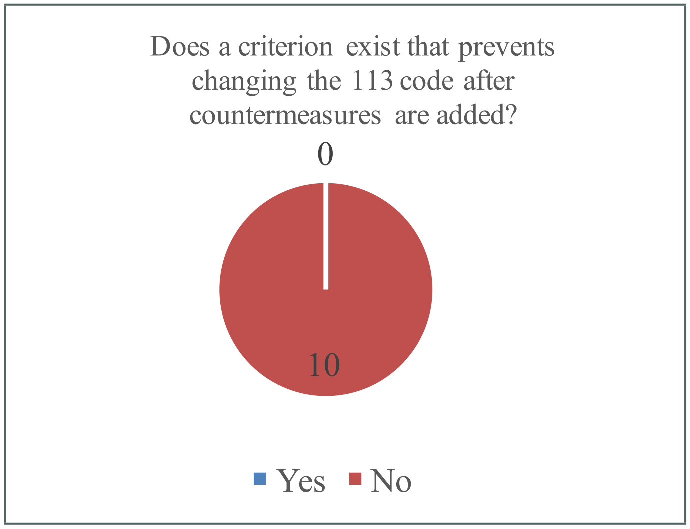

Figure B.17 *Criterion to prevent changing the 113 code after countermeasures are added*

1	California	The frequency and level of evaluation may vary based on the importance of traffic, and the vulnerability and potential damage by the scour.
2	Colorado	Staff Bridge is in process of developing a workflow process for measuring scour countermeasure performance.
3	Idaho	By monitoring them during field inspections
4	Louisiana	Inspect after flood event
5	Michigan	MDOT does have a "scour protection" bridge element, which includes riprap, articulating concrete block, gabion baskets, and other armoring systems. The systems are evaluated during routine inspections, during underwater inspections, and during or following a high-flow event. MDOT has also added an NBI item for "scour inspection," which is collected during routine inspections and is required for all structures coded 3-0, U, and 7 for item 113. This field collects condition data for scour and the countermeasures along the substructure. This information is automatically populated on the scour action plan.
6	Mississippi	Routine inspection
7	Minnesota	We inspect them during and after flooding to ensure they performed as expected.
8	Missouri	Monitor during inspection
9	New York State	By inspection
10	Texas	Scour countermeasures are evaluated for performance by visual inspection during each inspection.
11	Florida	No response
12	Pennsylvania	By field verification after a flood event or during NBIS inspections

Table B.15 *Evaluation of countermeasure performance*

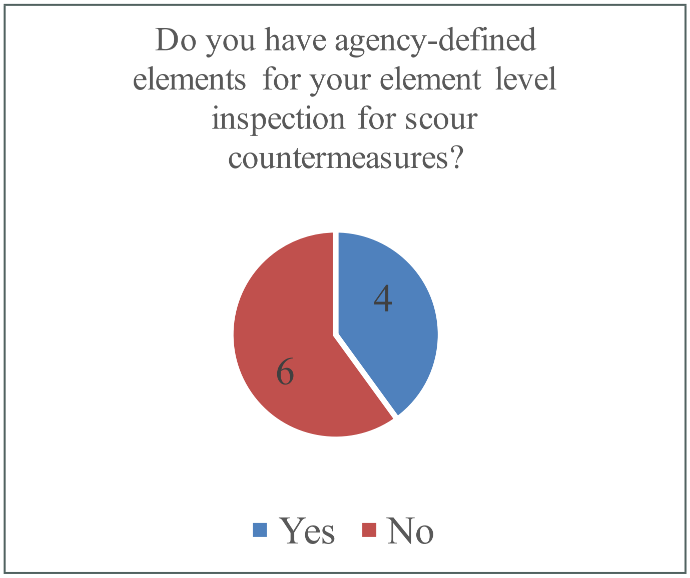

Figure B.18 **Existence of agency-define elements for element-level inspection of scour countermeasures**

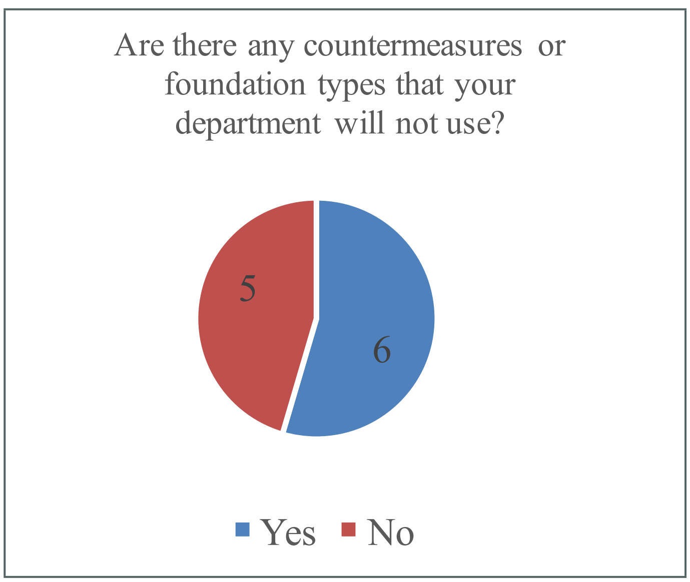

Figure B.19 **Agency-prohibited countermeasures or foundation types**

1	California	Resident engineers (REs) are responsible for ensuring that all countermeasures are installed as per the design and construction guidelines. They communicate with the contractor and discuss the construction plan before every phase. REs also check the size and gradation of the aggregate/rocks, performs a slump test of concrete, and tests the quality of the materials so that they match the Caltrans specification. After each phase, REs measure the dimensions and check quantity of every relevant item.
2	Colorado	Inspected during construction to ensure they are constructed according to plan; the sructure and associated countermeasures are then incorporated into future Staff Bridge inspections.
3	Idaho	Countermeasures are inspected during regular field inspections. Riprap is typically placed with no inspection; A-Jacks would have plans and a construction inspector on site. If they are no longer providing the necessary protection, the inspector makes a note and the Scour Committee reevaluates.
4	Louisiana	At construction as well as during and after a flood event and routine inspections
5	Michigan	MDOT bridge inspectors look at the countermeasures during routine inspections and during or following a high-flow event. The local construction office is responsible for ensuring that they are installed as designed.
6	Mississippi	During construction they are inspected to be sure the countermeasure is installed per the plans. After construction, they are inspected during routine inspections and after major flood events.
7	Missouri	Yes, yes, and yes. During construction, the chief inspector will inspect (mostly visual inspection by our district bridge maintenance folks). Also, during routine inspections and during floods.
8	Missouri	Inspected during construction, post event and during routine inspections
9	New York State	Trained and experienced inspectors.
10	Texas	Scour countermeasures are typically inspected at the end of construction, during routine inspections, and after flooding events.
11	Florida	No response
12	Pennsylvania	Countermeasures are inspected at construction, sometimes during or after an event, and during NBIS inspections

Table B.16 Inspection of countermeasures to ensure they provide the necessary protection

1	California	Yes	Example: Emergency repair of Calada Ditch on I-10 in 2016. In this project, to prevent scour the channel bed was lined with rock mattress, which was then buried with 1-foot-thick native materials. Since the channel bed surface was made as natural as it was before the construction, it will continue to allow the natural migration of desert habitats such as the desert tortoise.
2	Colorado	Yes	
3	Idaho	No	
4	Louisiana	Yes	Weighted tape or level rod for most typical bridges
5	Michigan	Department of Environmental Quality has requested that articulating concrete block be recessed.	
6	Mississippi	Not typically	
7	Minnesota	Yes	They are inspected during placement. We haven't had them in place long enough for long-term stability.
8	Missouri	No	
9	New York State	Yes	During construction
10	Texas	No (as far as is known)	

11	Florida	No response	
12	Pennsylvania	Yes	They are inspected during construction for correct placement; otherwise, the condition is inspected during the NBIS inspection.

Table B-17 Recessing of countermeasures below the channel bottom to address environmental concerns (left) and inspection during countermeasure placement and for long-term stability (right)

1	California	Rock riprap, reinforced concrete structures (e.g., outrigger bends), sheet piles, etc.
2	Colorado	No response
3	Idaho	No response
4	Louisiana	Riprap placement and helper bents with deeper piles
5	Michigan	No response
6	Mississippi	No response
7	Minnesota	We have used geobags covered by riprap. We check the riprap and assume the geobags are still there.
8	Missouri	No response
9	New York State	Stone fill
10	Texas	No response
11	Florida	No response
12	Pennsylvania	N/A

Table B.18 Types of countermeasures used in underwater installations

1	California	Underwater installations are highly challenging from both environmental and feasibility standpoints. Emergency repair work for Elk Creek on Highway 1 in 2016 is an example. As the channel was flowing and rock slope protection was needed to be keyed 5 feet below the channel bed, the site needed to be dewatered and temporary storage of the fish was required. Several things needed to be considered, such as type of countermeasures, type of dewatering system, extent of area, duration of work, possibility of rain and storm, channel flow rate, and types of fish and vegetation.
2	Colorado	Inspection of them has been an issue if they are buried or at high water. Inspectors usually wait until the water subsides to do follow-up inspection. We have a few structures over lakes put that are contracted out for underwater inspection.
3	Idaho	No response
4	Louisiana	No
5	Michigan	No response
6	Mississippi	No
7	Minnesota	It is hard to get contractors to comply with new construction techniques. There have been difficulties in placing geofabric in moving water. Show pictures of installation at Winona.
8	Missouri	No response
9	New York State	Yes, environmental
10	Texas	For underwater installations, stone protection has been used in most cases. This presents challenges as it is difficult to determine if the stone is placed correctly and it is also difficult to inspect.
11	Florida	No response
12	Pennsylvania	N/A

Table B.19 Challenges encountered and lessons learned

Topic 5: Plan of Action (POA)

Note: ***Details of bridge-scour-specific POAs are too comprehensive and were not included in this appendix.***

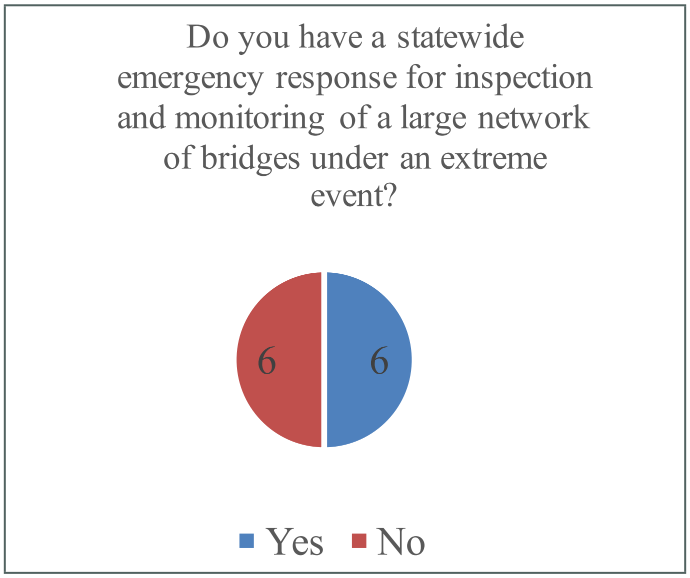

Figure B.20 ***Statewide emergency response for inspection and monitoring of a large network of bridges under extreme events***

1	California	At a smaller scale, however, the protocol for prioritizing inspections of bridges under an extreme event is to look at the scourcritical bridges we have in the affected areas first. After that determination, we then look at other bridges that may be vulnerable to an extreme event.
2	Colorado	We experienced a very large flood with a long duration over a very large area in northern Colorado during fall 2013. In each particular CDOT region there are only a few major rivers or streams. We focus on those river and stream crossings of our interstate and U.S. highways, followed by our state highways. We rely heavily on our Maintenance forces to identify high waters during storm events and resulting flooding of our highways. Interstates and high average annual daily traffic roadways receive priority.
3	Idaho	Each scourcritical bridge has a POA that includes detour maps and ownership information. We continuously monitor all of our bridges utilizing the BridgeWatch system. average daily traffic would probably play a role in prioritizing inspections.
4	Louisiana	Scourcritical bridges or bridges with drift and overtopping problems and known scour issues are inspected first.
5	Michigan	Bridge Management has provided each region a scour risk assessment of each of their scourcritical bridges to help them prioritize their bridges based on vulnerability and criticality. Typically, the highest priority bridges (often those without countermeasures and those carrying interstate traffic) are inspected first and most frequently; history of scour is also taken into consideration. The Southwest Region has four engineers and a maintenance worker as part of the bridge unit that will be deployed during an event. The region also utilizes transportation maintenance coordinators in satellite offices to help with monitoring.
6	Mississippi	Generally, we use functional class for prioritization.

7	Minnesota	It is a district decision as to when to inspect. The owners know which ones are the most critical.
8	Missouri	Handled at the district level
9	New York State	High- and medium-risk bridges
10	Texas	Prior to the extreme event each district is responsible for prioritizing the bridges that need to be investigated first and those that can wait until later. The prioritization begins with the scourcritical bridges and progresses to non-scourcritical bridges.
11	Florida	No response
12	Pennsylvania	Scourcritical bridges are categorized into three levels of vulnerability. The most vulnerable are monitored first. As flooding intensifies, those with medium vulnerability and least vulnerability are included.

Table B.20 Protocol for prioritizing structure inspection during an event

1	California	A summary of historic hydraulic issues and current hydraulic conditions of the channel upstream, within and downstream of the bridge structure
2	Colorado	N/A
3	Idaho	We have a scour vulnerability section that includes the 113 rating and risk if it is an unknown foundation, as well as a history of inspection notes related to scour at the structure.
4	Louisiana	See attached POA, critical bent, mudline elevation history, pile tip elevation, pile length and type, critical scour elevation, and depth and type of soil remaining to the critical elevation
5	Michigan	Please see Chapter 6: Scour of the Michigan Structure Inspection Manual. We list the scour depths relative to foundation depths for the 100-year and 500-year events. If the structure experiences pressure flow in either event, it is noted as well.
6	Mississippi	There are no requirements; it is a short summary of the findings from the scour evaluation study.
7	Minnesota	Critical elevation and detour
8	Missouri	Scour depth of concern at substructure locations; requires bridge closure if depth is exceeded
9	New York State	Classification score, classification assessment, and failure mode
10	Texas	See attached examples of blank POA
11	Florida	See attached
12	Pennsylvania	The evaluation takes into account several factors, such as the foundation type, streambed material type, the presence and amount/depth of scour in relation to the footing, presence or risk of debris blockage, streambed slope, and flooded stream alignment in relation to the substructure units.

Table B.21 Information required in the scour evaluation section of the POA

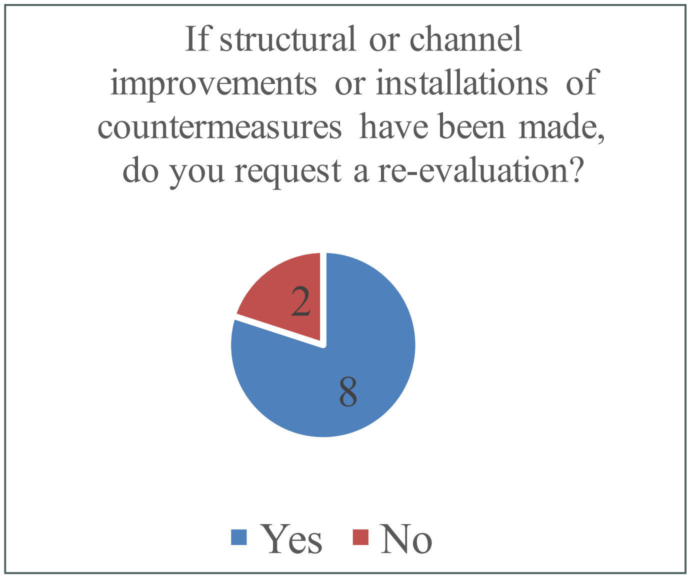

Figure BE.21 ***Reevaluation of countermeasures if structural or channel improvements or installations have been made***

1	California	For state structures, this has not been an issue because they are typically replaced rapidly under an emergency contract. If scour critical or unknown, the local agency is required to have a POA for the bridge. If it is closed to traffic and not scour critical or unknown, no POA is required.
2	Colorado	No but not occurred at CDOT
3	Idaho	We do not typically do a new POA if it didn't previously have one in the case of a closed bridge.
4	Louisiana	No
5	Michigan	The existing POA remains in the file but we do not require them to complete the flood monitoring during extreme events. If the structure is still in the NBI, routine inspections are still performed and scour is evaluated during those inspections.
6	Mississippi	Yes
7	Minnesota	Yes
8	Missouri	No
9	New York State	No
10	Texas	Yes
11	Florida	No
12	Pennsylvania	No

Table B.22 ***POA created for bridges closed to traffic without the prospect of reopening***

1	California	No and Yes	For state structure, all POAs are completed in-house. Local agencies can contract it out or do it themselves. Most have come from the locals themselves.
2	Colorado	Yes	We have contracted out our bridge scour drainage design POA reports along with bridge structure scour evaluations and designs.
3	Idaho	No	We create the POAs in-house using our bridge data, inspection data, and event threshold data from BridgeWatch.
4	Louisiana	No	
5	Michigan	No and Yes	For state-owned structures the POA is developed using in-house hydraulic, geotechnical, and structural engineers and bridge inspectors. Prequalified consultants develop the POA for most structures owned by local agencies.
6	Mississippi	Yes	Consultants complete most scour evaluations and provide a draft POA for review; however, an MDOT staff member finalizes the POA.
7	Minnesota	No	We do all of the POAs for TH side. We have used consultants to do the scour analysis but the POAs are kept in-house. The local units of government use consultants for some of their structures; this is done on a case-by-case basis.
8	Missouri	No	
9	New York State	Sometimes	
10	Texas	No, not that we aware of	Each district is responsible for filling out the POA for bridges in their district.
11	Florida	Yes	
12	Pennsylvania	No	

Table B.23 POAs contracted out with qualified engineering firms

1	California	Reevaluate
2	Colorado	Redo the analysis and prepare a bridge scour drainage design report
3	Idaho	Typically, a scour review will stay in place until an inspector flags that something has changed at the structure.
4	Louisiana	Accepted based on the generally accepted engineering practice at the time. If you did not accept the previous assessment, scour analysis would be needed every time the USGS published a new methodology for estimated peak discharges.
5	Michigan	Reassess, especially if there are site changes or something appears to be in error
6	Mississippi	Unless there have been large changes in the bridge’s or channel’s condition, we still consider it valid.
7	Minnesota	We will look at it if the bridge is being worked on, such as redecking or major rehab, to see if countermeasures can be added to the contract.
8	Missouri	No set procedure
9	New York State	Stay the same until condition changes as documented in the bridge inspection process
10	Texas	If the scour analysis for the bridge is very old (i.e., greater than 10 years), then it should be reevaluated. Bridges should be reassessed for scour under the following conditions: 1) Changes in scour evaluation policy (scour calculations should be updated) 2) After each bridge inspection (scour should be evaluated relative to calculated values and/or POA) 3) After significant flood event (scour should be evaluated relative to calculated values and/or POA) 4) After changes to the watershed that affect the flow at the bridge (scour calculations should be updated)
11	Florida	The need for reassessment is determined through the routine bridge inspection process
12	Pennsylvania	The POA is required to be updated if the scour critical category changes.

Table B.24 Approach when the scour review is old

1	California	Use Q100
2	Colorado	We design our bridges for at least the 50-year and, many times, if in a FEMA-mapped area, the 100-year. So it would be at those return periods (50- and 100-year) that the structure would be vulnerable and need to be monitored. Our monitoring program for scour critical structures with POAs takes into consideration these flows and water surface elevations relative to the low chord.
3	Idaho	Trial and error, most of our scourcritical bridges are set to 25-year event thresholds for flows and rainfall. If scour is observed without a 25-year event, the threshold will be changed to 5-year if no scour is observed.
4	Louisiana	Evaluate Q100 and Q500 or overtopping flood event
5	Michigan	Because of the complexity in comparing calculated values versus field data, we don't really know. We make note if a structure experiences pressure flow in certain flood frequencies.
6	Mississippi	The information is contained in the scour evaluation. We now require the scour evaluation to contain a "critical water elevation" or the stage that may trigger enough scour at the bridge to deem it scour critical.
7	Minnesota	We use a case-by-case assessment on when to start monitoring, gauge nearby, water elevation (show our sign), fixed monitoring, or local precipitation data. Shutting down the bridge is when scour critical elevation is reached or the abutments show signs of undermining.
8	Missouri	Stage
9	New York State	Flood warnings based on the National Weather Service
10	Texas	Districts set the criteria for the conditions required to investigate the bridge. This varies from rainfall events to stage at the bridge.
11	Florida	These should be identified in the POA
12	Pennsylvania	We don't know specifically what discharge makes a given bridge vulnerable to scour. We have set our monitoring criteria based on engineering judgment. For post-flood damage inspections, we initially started with 10-, 25-, and 50-year storm return periods as the triggers for Category A, B, and C scourcritical bridges, respectively. After a few years of experience, we upgraded these to 10-, 50-, and 100-year storm return periods.

Table B.25 ***Determining what discharge makes a bridge vulnerable to scour and the criteria used to implement the bridge monitoring of a POA***

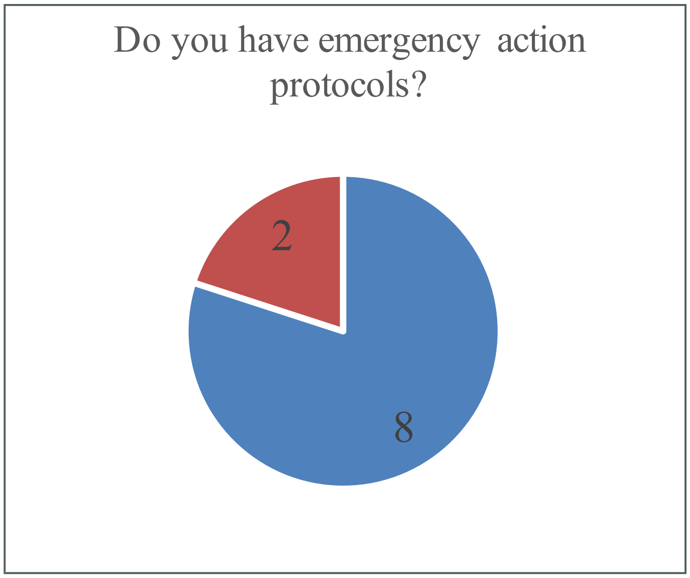

Figure B.22 Emergency action protocols

Appendix C
Invited Agency Contacts

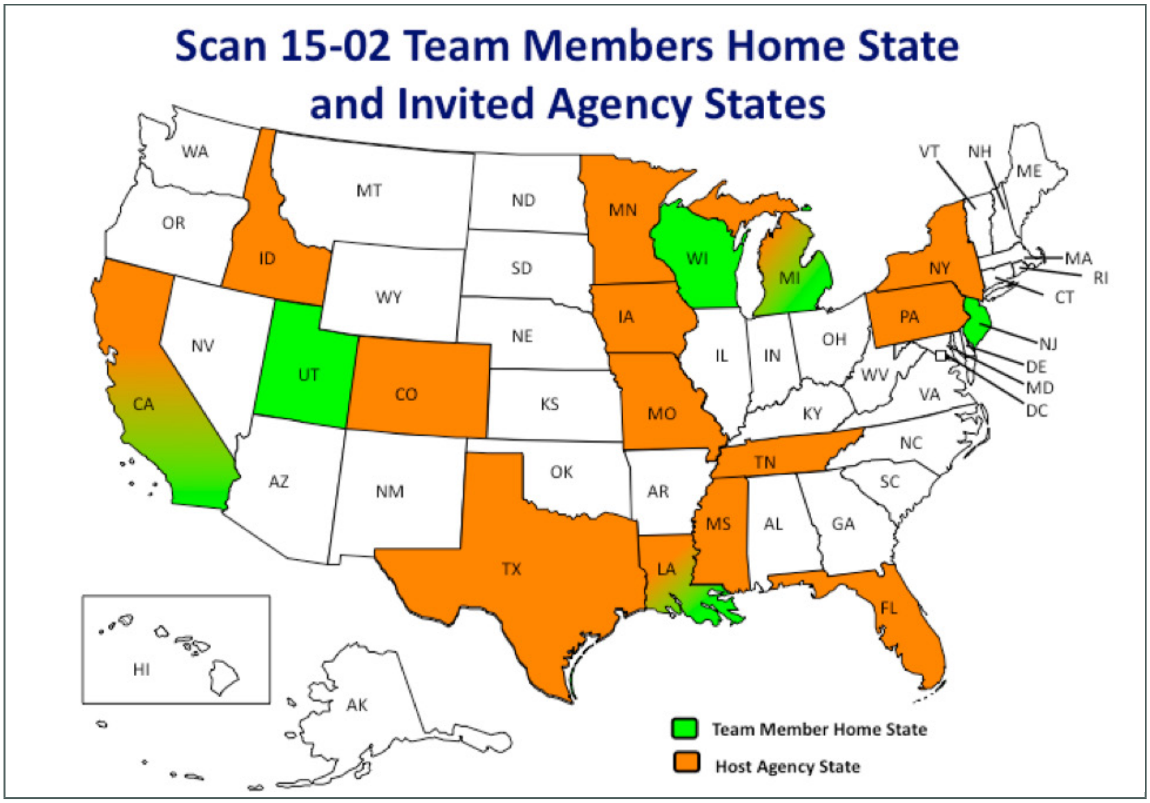

Figure C.1 Scan 15-02 team members' home states and invited agency states

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Appendix E:
Scan Team Biographical Sketches

REBECCA CURTIS (AASHTO Chair) is the Bridge Management Engineer for the Michigan Department of Transportation (MDOT). She provides engineering and administrative oversight to the operational aspects of the department's annual bridge program, development of bridge management systems; improvement, maintenance, and communication of bridge strategy; and performance measures in accordance with MDOT's strategic plan, state goals, and objectives. This includes bridge program management, bridge management systems, bridge load rating, and special structures design. Curtis is a licensed professional engineer in Michigan. She joined MDOT in 2006 and has been in her current position since 2011. She is a member of the AASHTOWare Bridge Management Task Force. She holds bachelor's degree in civil engineering and a master's degree in structural engineering.

JON BISCHOFF is the Geotechnical Engineer Specialist at the Utah Department of Transportation (UDOT). He designs and oversees all geotechnical aspects of UDOT projects, primarily focused on bridge foundations and analyzing and remediating geohazards. Bischoff's participation in the UDOT Scour critical bridge Prioritization program and participation on previous NCHRP panels on the topic of scour at structures (NCHRP 24-18 and 24-36) provides the geotechnical background for the current domestic scan. He is beginning his third term as a member of the TRB Standing Committee for Foundations of Bridges and Other Structures (AFS-30) and has been panel chairman of two other NCHRP projects regarding bridge foundations. He has been a design geotechnical engineer since graduating from Utah State University with bachelor's and master's degrees in 1983 and 1985, respectively. He is a licensed professional engineer in Utah.

STEPHANIE CAVALIER is the Bridge Scour Program Manager for the Louisiana State Department of Transportation and Development (LADOTD). In this role, she manages the Phase III analysis, countermeasure recommendations, and repair projects for scour critical bridges. She has been with LADOTD for 14 years as a structural engineer in bridge design, specializing in bridge design, rating, and scour. She earned bachelor's and master's degrees in civil engineering from Louisiana State University and is a licensed professional engineer in Louisiana. She has served as a Panel member for the Louisiana Transportation Research Center for research pertaining to bridge scour and wave surge design for coastal bridges.

XIAOHUA "HANNAH" CHENG is a bridge and structure engineer for the New Jersey Department of Transportation (NJDOT). Her primary duties with the Bureau of Structural Engineering include development and update of policy, manuals, standards, and guidance for design, construction, and maintenance of state highway bridges and traffic structures. Her duties also include development of special design and construction criteria for major bridge projects, including extreme events criteria. She develops problem statements and oversees state research projects in various topics of bridges and structures, such as on "Design and Evaluation of Bridges for Scour Using HEC 18" (a risk-based study including hydraulic, geotechnical, and structure aspects), "Design and Fabrication of Steel Orthotropic Deck," and "Seismic Design Considerations." Cheng is serving on the American Association of State Highway and Transportation Officials (AASHTO) Subcommittee on Bridges and Structures as a member representing New Jersey. She is a member of committees, task forces, and expert panels of AASHTO, Transportation Research

Board (on general structure, seismic design, and steel fabrication), the National Cooperative Highway Research Program, and American Society of Civil Engineers. Cheng graduated from Tsinghua University (China) with a bachelor's degree in civil/structural engineering. She holds a master's degree from the China Academy of Railway Sciences and a doctoral degree from Nagoya University (Japan), both in civil/structural engineering. She is a registered professional engineer in Pennsylvania.

KEVIN FLORA is a Senior Bridge Engineer with the California Department of Transportation (Caltrans), He has guided the agency's bridge scour program for the past 19 years and has been responsible for overseeing the bridge scour evaluation program for all of California's state-owned bridges. Through software development, improved field data acquisition techniques, and advanced hydraulic modeling, Flora has demonstrated innovative strategies for evaluating structures for scour, helping Caltrans become a strong leader in scour and hydraulic modeling throughout the U.S. As a recognized national leader in the field of bridge scour, he has served on several National Cooperative Highway Research Program panels, including those related to bridge scour: 24-14 on Scour at Contracted Bridge Sites, 24-26 on the Effects of Debris on Bridge Pier Scour and 24-37 on Combining Individual Scour Components to Determine Total Scour. He has also served nationally on the Federal Highway Administration/American Association of State Highway and Transportation Officials Wave Task Force for Bridge Structures. Flora is a registered professional civil engineer in California and earned his bachelor's degree in civil engineering from California Polytechnic State University, San Luis Obispo, and master's degree in civil engineering with an emphasis in water resources from the University of California, Davis.

RICHARD MARZ is the Chief Structure Maintenance Engineer for the Wisconsin Department of Transportation (WisDOT) and is the State Program Manager for Wisconsin's bridge inspection program. Marz oversees the Structure Maintenance Section, which includes policy and procedures for WisDOT's Structure Inspection Manual, bridge inspection, structural fabrication inspection, and bridge repair. Marz has worked for WisDOT since 1988 and has served as a construction project manager, regional roadway maintenance engineer, and design project manager. Marz is a civil engineering graduate of The University of Wisconsin-Milwaukee and is a licensed professional engineer in Wisconsin.

HANI H. NASSIF (Subject Matter Expert) is professor of Civil and Environmental Engineering at Rutgers, The State University of New Jersey, where he has established the Bridge Engineering program. He earned his bachelor's and master's degrees in civil engineering from The University of Detroit. He received his doctoral degree from the Civil and Environmental Engineering Department and a graduate certificate in Intelligent Vehicle-Highway Systems from the Electrical Engineering and Computer Science Department, both at the University of Michigan-Ann Arbor. His expertise includes structural safety, risk assessment, and scour monitoring of bridges. Nassif is a Fellow of the American Concrete Institute (ACI) and past member of its Technical Activity Committee, chair of the newly established ACI Committee 444-Structural Health Monitoring and Instrumentation. He has received various awards, including the American Association of State Highway and Transportation Officials Research Activities Committee "Sweet Sixteen" Project Award (2013), a Project Implementation Award from the New Jersey Department of

Transportation (2013 and 2017), the American Council of Engineering Companies Educator of The Year Award (2006), and the American Society of Civil Engineers Central New Jersey's Educator of the Year Award (2005). He is a member of Sigma Xi, The Scientific Research Honor Society, and the Engineering Honor Societies Tau Beta Pi and Chi Epsilon. Nassif has several years of practical experience in the area of structural design and construction.

Appendix F:
Proposal to AASHTO

Proposal

Formation of a task force to examine the formation of a body within AASHTO to oversee issues pertaining to scour on highway bridges.

The Need

It is commonly recognized that the number one cause of bridge failure is scour. Bridge owners are faced with challenges in dealing with this threat at many levels within their agencies, including asset management and risk assessment; scour modeling and analysis; monitoring and field inspection of affected assets; design, construction, and maintenance of countermeasures; and response during and after an event.

Scour risk management is a complex process and requires input and open communication from multiple disciplines, including hydraulic, structural, and geotechnical. Bridge owners need to engage technical experts from all three areas to help implement an efficient and innovative management of scour risk. Some states have multidisciplinary bodies within their agency to bring these experts together to address scour; however, such a group is not currently available at the national level.

Scour risk management occurs at all levels of the bridge life cycle, including risk management during planning stages; risk determination and hydraulic analysis during design; scour countermeasure installation and construction; and inspection and monitoring. Bridge owners have had varying levels of success in specific applications of managing scour during this life cycle. Bridge owners would benefit from the ability to share experiences in scour management to speed up the implementation of innovations and to learn from the shared experiences of other owners.

Recommendations

1. Scour is a nationwide risk and the number one cause of bridge failures. A scour committee at the national level is needed. This scour committee should include interdisciplinary capabilities (i.e., engineers from geotechnical, structural, and hydraulics areas) to help address various issues related to scour mitigation.
2. This committee should be tasked with establishing collaborative partnerships with USGS and other agencies, which would help facilitate sustainable data collection for scour predictions and maintain awareness of technological advances in data collection.
3. This committee should be charged with investigating and disseminating information on innovative applications that would help advance the state-of-the-art in risk management of flooding on highway bridges.
4. This committee should work proactively with FHWA for use and acceptance of advanced technologies, such as using under water inspection (e.g., sonar) to improve data collection and diver safety.
5. This committee should be responsible for continued and future research needed to enhance the capabilities of various systems to measure real-time scour and minimize uncertainties related to scour risk. Moreover, it should be the focal point for communication and dissemination of various research projects to raise awareness of accomplishments being made by FHWA, NCHRP, and state agencies.

6. This committee would provide a forum to share lessons learned based on specific experience with countermeasure design, installation, and monitoring. The committee would disseminate information related to the performance of various types of countermeasures.

7. This committee could provide guidance on how owners can enhance their scour plans of action (POA), on development of emergency protocols for intensive widespread flood events, and creating risk-based prioritization for implementing POA during flood events.

The Proposal

It is recommended that AASHTO create a task force to help form a multidisciplinary committee that would develop guidelines and specifications for scour mitigation assessment, design, construction, and maintenance and to serve as a clearinghouse for new innovations. This task force should consider representation from SCOBS, SCOM, TCHH, and possibly SOC, SOM, and SCOTSEM.

Potential Benefits

1. Provide for national leadership in dealing with issues involving scour to minimize risk and failures.

2. Provide a forum to act on scour issues across all regions, with FHWA helping ensure uniformity in addressing the issue.

3. Facilitate the application of a higher quality approach and faster implementation of innovations to scour issues based on the collective experience of all states and FHWA.

4. Allow for a forum for sharing of new approaches and technologies. Many states have strong teams of structural, hydraulic, and geotechnical engineers whose experience would be of tremendous benefit in advancing the state of practice.

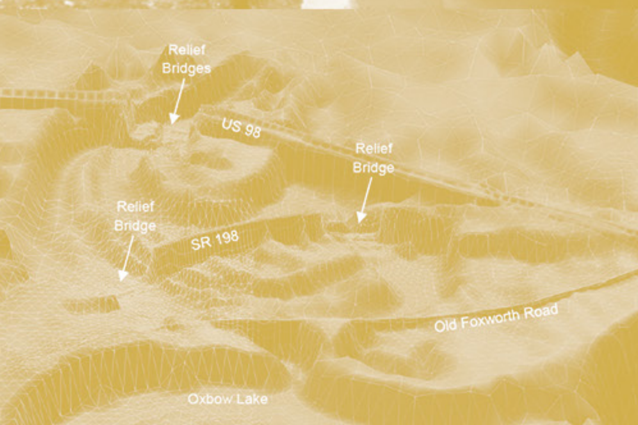
    i. Many states have been using various methods to help define risk and minimize uncertainty to help prioritize how best to apply their limited resources.

    ii. Materials testing for cohesive soils or rocks using new techniques such as those developed by Florida DOT or FHWA can be of tremendous benefit if introduced to all states.

    iii. States experiences in the use of two-dimensional/three-dimensional hydraulic models have shown to be very useful in advanced cases.

    iv. Several states have had good experience with various countermeasure designs.

5. Engaging external data sources, such as USGS-generated data, is essential for the successful implementation and management of scour programs.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