Characterization of Bridge Foundations

Workshop Report

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FOREWORD

Bridge owners face the potential problem of not being able to characterize the foundations of bridges over dry land and waterways (for example, not knowing the integrity and the depth of the piles). This information is critical in their decisionmaking process for determining whether they can rely on the existing foundation to withstand geo/hydraulic hazards for an additional 25, 50, 75, or 100 years of service as they may consider a major bridge rehabilitation, replacement, reuse, or widening of a bridge.

In 2013, the Federal Highway Administration (FHWA) approved a new research program for the characterization of bridge foundations. To narrow the focus of the program and to solicit key stakeholder input, a workshop on "Characterization of Bridge Foundations" was held in Arlington, VA, from April 30 to May 1, 2013. The cross-discipline workshop involved key staff from the FHWA hydraulics, geotechnical and structural disciplines brainstorming with stakeholders in separate breakout sessions. This report presents an overview and documents the results and conclusions of the workshop. The knowledge gained from the workshop will be considered by FHWA as it develops a multi-year Research and Development strategic plan and a roadmap for the new Characterization of Bridge Foundations program.

Jorge E. Pagán-Ortiz
Director, Office of Infrastructure
Research and Development

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16. Abstract

In 2013, the Federal Highway Administration proposed a new research program for the characterization of bridge foundations. To narrow the focus and develop a research roadmap for the program, a workshop on "Characterization of Bridge Foundations" was held in Arlington, VA, from April 30 to May 1, 2013, to solicit key stakeholder input. The workshop opened with plenary sessions to provide the invited participants with a national perspective on the issue; summaries of geotechnical and hydraulic hazards; and, the impact of changes in service loads and foundations reuse. The plenary sessions were followed by breakout sessions. This report presents an overview and documents the results and conclusions of the workshop.

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SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
in	inches	25.4	millimeters	mm
ft	feet	0.305	meters	m
yd	yards	0.914	meters	m
mi	miles	1.61	kilometers	km
		AREA		
in^2	square inches	645.2	square millimeters	mm^2
ft^2	square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2
ac	acres	0.405	hectares	ha
mi^2	square miles	2.59	square kilometers	km^2
		VOLUME		
fl oz	fluid ounces	29.57	milliliters	mL
gal	gallons	3.785	liters	L
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
		NOTE: volumes greater than 1000 L shall be shown in m^3		
		MASS		
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")
		TEMPERATURE (exact degrees)		
°F	Fahrenheit	5 (F-32)/9 or (F-32)/1.8	Celsius	°C
		ILLUMINATION		
fc	foot-candles	10.76	lux	lx
fl	foot-Lamberts	3.426	candela/m^2	cd/m^2
		FORCE and PRESSURE or STRESS		
lbf	poundforce	4.45	newtons	N
lbf/in^2	poundforce per square inch	6.89	kilopascals	kPa

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol
		LENGTH		
mm	millimeters	0.039	inches	in
m	meters	3.28	feet	ft
m	meters	1.09	yards	yd
km	kilometers	0.621	miles	mi
		AREA		
mm^2	square millimeters	0.0016	square inches	in^2
m^2	square meters	10.764	square feet	ft^2
m^2	square meters	1.195	square yards	yd^2
ha	hectares	2.47	acres	ac
km^2	square kilometers	0.386	square miles	mi^2
		VOLUME		
mL	milliliters	0.034	fluid ounces	fl oz
L	liters	0.264	gallons	gal
m^3	cubic meters	35.314	cubic feet	ft^3
m^3	cubic meters	1.307	cubic yards	yd^3
		MASS		
g	grams	0.035	ounces	oz
kg	kilograms	2.202	pounds	lb
Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
		TEMPERATURE (exact degrees)		
°C	Celsius	1.8C+32	Fahrenheit	°F
		ILLUMINATION		
lx	lux	0.0929	foot-candles	fc
cd/m^2	candela/m^2	0.2919	foot-Lamberts	fl
		FORCE and PRESSURE or STRESS		
N	newtons	0.225	poundforce	lbf
kPa	kilopascals	0.145	poundforce per square inch	lbf/in^2

*SI is the symbol for the International System of Units. Appropriate rounding should be made to comply with Section 4 of ASTM E380. (Revised March 2003)

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EXECUTIVE SUMMARY

This report summarizes the findings from the "Characterization of Bridge Foundations" workshop held in Arlington, VA, from April 30 to May 1, 2013. The cross-discipline workshop included key staff members from the Federal Highway Administration (FHWA) hydraulics, geotechnical and structural disciplines brainstorming with stakeholders. The stakeholders included participants from five State transportation departments, academia, and industry.

The workshop initially discussed the issue of unknown foundations as it relates to hydraulic vulnerability for bridge scour. To determine the susceptibility of a bridge to scour, information on the foundation type and depth is needed. FHWA has provided guidance for risk-based analysis and field testing, and many of the States' practices were discussed. The participants discussed the impact of multiple hazards on unknown foundations including other extreme events (seismic, post-event inspection, ship impact, etc.) as well as the issue of load testing of bridges with the unknown foundations.

The workshop led to an expansion of the scope of "unknown foundations" to include "foundation characterization" pertaining to condition evaluation of all bridge foundations whether known or unknown. The engineering problems associated with foundation characterization include assessing foundation type, pile type, embedment depth, geometry and material, foundation integrity, and load carrying capacity.

Discussions during the workshop also focused on the changes in service loads and foundation reuse issues from the perspective of the FHWA and State transportation department personnel. The main concerns with foundation reuse are the ability to assess their condition, their load carrying capacity, the remaining service life, and how the reuse of foundations interacts with new codes and standards. Further expanding the scope of the Research and Development (R&D) program to include foundation reuse was recognized as it also benefited the unknown foundations.

The Workshop provided a platform to discuss pertinent issues as it relates to foundation characterization with key players, both at the State and Federal level. This knowledge shared during the workshop, including existing gaps and recommendations, will be considered by FHWA as it develops its R&D program and a roadmap for the new Characterization of Bridge Foundations (CBF) program.

INTRODUCTION

In 2013, FHWA proposed a new research program for the characterization of bridge foundations. To narrow the focus and develop a research roadmap for the program, a workshop on "Characterization of Bridge Foundations" was held in Arlington, VA, from April 30 to May 1, 2013, to solicit key stakeholder input. This report presents an overview, and documents the results and conclusions of the workshop. The invitation-only workshop consisted of 1.5 days of meetings to solicit key stakeholder input for the development of a research program on the characterization of bridge foundations. This research program will be led by the FHWA Turner-Fairbank Highway Research Center (TFHRC).

The workshop opened with plenary sessions to provide the participants with the national perspective, and summaries of geotechnical and hydraulic hazards and changes in service loads and foundations reuse. The plenary sessions were followed by breakout sessions to discuss these issues. The final session consisted of discussions among the participants to evaluate the results of the workshop and determine what follow-up activities are necessary to capitalize on the workshop results. The workshop agenda is shown in appendix A, and a list of workshop attendees is provided in appendix B. This document is intended to summarize the results of the workshop and frame them in the larger perspective of developing and implementing the CBF program.

BACKGROUND

The transportation system in the United States includes over 600,000 bridges for grade separations, interchange configurations, and stream crossings.(1) The operation and functionality of the highway system depends on the performance of these structures. As of December 2012, the National Bridge Inventory (NBI) included 607,380 structures (bridges and culverts) with a span greater than 20 ft (6 m).(1) Of those structures, 36,076 bridges over waterways (riverine and tidal) are identified as having unknown foundation characteristics. Additionally, there are a number of bridges over land with unknown foundation characteristics, which are not documented in the NBI database.

In 2013, FHWA proposed a renewed effort for the development of a multiyear strategic research plan to address the "unknown foundation" problem. The unknown foundation has been associated with the population of existing bridges over waterways that cannot be evaluated for hydraulic vulnerability related to scour. The primary interest of unknown foundation investigation is determination of the bottom depth of the foundation (pile tip elevation). However, there are other engineering risks besides scour, as described in appendix C.

On January 16, 2013, a multidisciplinary task force met during the Transportation Research Board (TRB) annual meeting. The 14-member task force was comprised of FHWA and State transportation department stakeholders who were selected based on their recognized expertise in the areas of unknown foundation and foundation assessment issues. During the meeting, the task force members brainstormed on steps needed to move forward with a multiyear strategic research plan for unknown foundations. The consensus of the taskforce and FHWA management was to broaden the scope of the research program from "unknown foundation" to "foundation characterization” in order to incorporate multi-hazard issues, including changes in service loads and foundation reuse. Appendix C provides more detail on multi-hazards associated with the unknown foundation problem, including previous FHWA/Department of Transportation initiatives to address this problem.

The objective of the CBF program is to develop and/or evaluate new and existing technologies and methodologies for characterizing existing bridge foundations for the determination of unknown geometry, material properties, integrity, and load carrying capacity. Many foundation characterization/reuse decisions will likely be made in the framework of life-cycle cost and risk management analysis.

SUMMARY OF THE FIRST PLENARY SESSION: FEDERAL RESEARCH PROGRAMS—NATIONAL PERSPECTIVE

INTRODUCTION TO THE PLENARY SESSION

The workshop began with a series of presentations that were designed to focus the participants on key issues relevant to characterization of bridge foundations. Specifically, the participants were tasked to identify and define the key factors and actions related to unknown foundations, foundation characterization, and reuse of bridge foundations. The presentations are available on the TRB Committee on Soil and Rock Properties (AFP30) Web site.(2) It is accessible at https://sites.google.com/site/trbcommitteeafp30/characterization-of-bridge-foundations/may-2013-workshop-fhwa---presentations.[1]

WELCOME, OBJECTIVE OF WORKSHOP, FHWA PERSPECTIVE

Welcoming remarks were provided by Mr. Louis Triandafilou, Acting Assistant Director, on behalf of Mr. Jorge E. Pagán-Ortiz, Director of the FHWA Office of Infrastructure R&D. Mr. Triandafilou highlighted the following:

- The Unknown Foundation Program has been many years in the making, based on a summit held in Lakewood, CO.(3)
- The scour program has high priority within FHWA.
- Bridges flagged with unknown foundations in the NBI should have a risked-based plan of action until a suitable countermeasure is implemented. Countermeasures include structural, hydraulic, and, in some instances, long term monitoring.
- Workshop attendees are challenged to revisit current nondestructive evaluation (NDE) methods and identify what needs to be revisited or updated.

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- FHWA looks forward to the input from the participants in order to develop a roadmap with objectives, strategies, activities, measures, etc.
- The program should include bridges over roadways as well as over waterways.
- The program should develop guidelines for owners to make better data-driven decisions.
- Although the scour program and the unknown foundation issue are vitally important, FHWA have decided to expand the scope of this research to other hazards and concerns. Frank Jalinoos will cover this in his presentation.

OVERVIEW OF FHWA'S CHARACTERIZATION OF BRIDGE FOUNDATION PROGRAM

Frank Jalinoos, Research Engineer at the FHWA Office of Infrastructure R&D, provided a comprehensive overview of the draft CBF program. The Schoharie Creek Bridge failure in April 1987 started the national bridge scour program; the failure also involved an unknown foundation. What was started as a program for pre-event vulnerability assessment for scour has expanded to include other hazards with unknown foundations, changes in service loads and foundation reuse, and available tools and technology for the characterization of bridge foundations.

As of December 2011, the NBI includes over 600,000 structures with a span greater than 20 ft (6 m).(1) FHWA provided guidance in January 2008 and June 2009 to eliminate bridges with unknown foundations, with a target date of November 2010.(4) The number of bridges in the NBI database coded as unknown foundation has steadily decreased over the years, from 104,000 in 1996 to approximately 36,000 as of December 2012.(1) FHWA guidance on unknown foundations can be found on the FHWA Web site.(4)

The engineering risk associated with bridge foundations can be summarized as:

- Geo/Hydraulic Hazards.
  - Pre-event vulnerability assessment (scour, seismic, others).
  - Post-event evaluation (flooding, seismic, barge impact, blast, fire, explosion, etc.).
- Changes in Service Loads, Foundation Reuse.
  - Use of heavy loads (military, industrial, mining, truck size and weight (TS&W), including proposed use of higher truck loads by the trucking industries and changes in truck route).
  - Foundation reuse: rehab, widening, and replacement.
- Foundation Inspection (Condition assessment and performance monitoring).

Examples of each risk were shown.

The engineering problems associated with foundation characterization include foundation type, pile type, embedment depth, geometry and material, foundation integrity, and load carrying capacity. Figure 1 illustrates the complexity in evaluating unknown foundation conditions. Available geophysical and NDE techniques are a common means of identifying these characteristics and were briefly reviewed. Although initially the emphasis has been on identifying unknown foundation characteristics for scour issues, recent efforts have also focused on identification for reuse of foundations.

A number of tools and technology exist for identification and characterization of bridge foundations including geophysical tools, NDE, destructive material sampling, load testing, numerical modeling, site investigation, and risk-based analysis. A tentative research plan was proposed that included testing of existing bridges from State agencies and the Long-Term Bridge Performance (LTBP) Program, load testing of decommissioned bridges, and integrity testing of a small testbed constructed with defective foundation types.

Research deliverables will include reports and technical briefs, guidance documents, and tools and technologies.

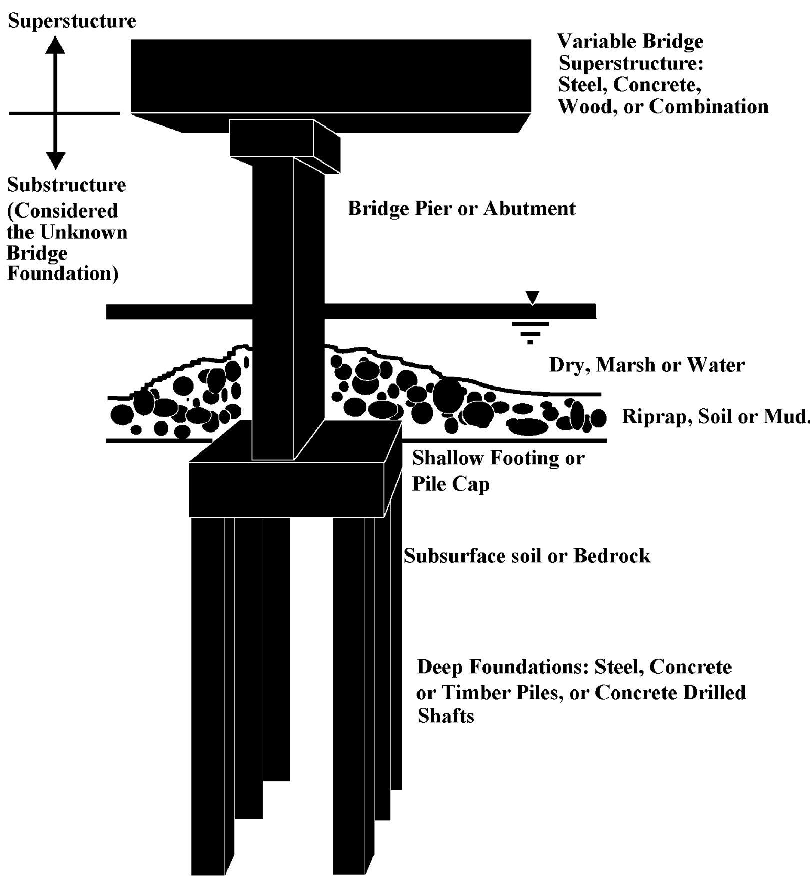


Figure 1. Diagram. Typical foundation conditions.[(5)]

HYDRAULICS RESEARCH

Dr. Kornel Kerenyi, Hydraulics Laboratory Manager at the FHWA Office of Infrastructure Research and Development at Turner Fairbank Highway Research Center (TFHRC), presented an overview of the physical modeling experiments conducted at the TFHRC Hydraulics Laboratory, and the high performance computing simulation conducted at Argonne National Laboratory (ANL). Presently, physical experiments are used to calibrate numerical models, and the vision for the future is to move away from physical modeling towards computational modeling. Dr. Kerenyi showed the current bridge scour research conducted utilizing the hydraulic loading-bridge pier turbulence and soil erosion testing devices.[6] See figure 2 and figure 3. Videos were shown of the Computational Fluid Dynamics model calibration experiments and validation/comparisons, illustrating the importance of matching loading with soil type and the scour associated with fluctuating flow stresses.

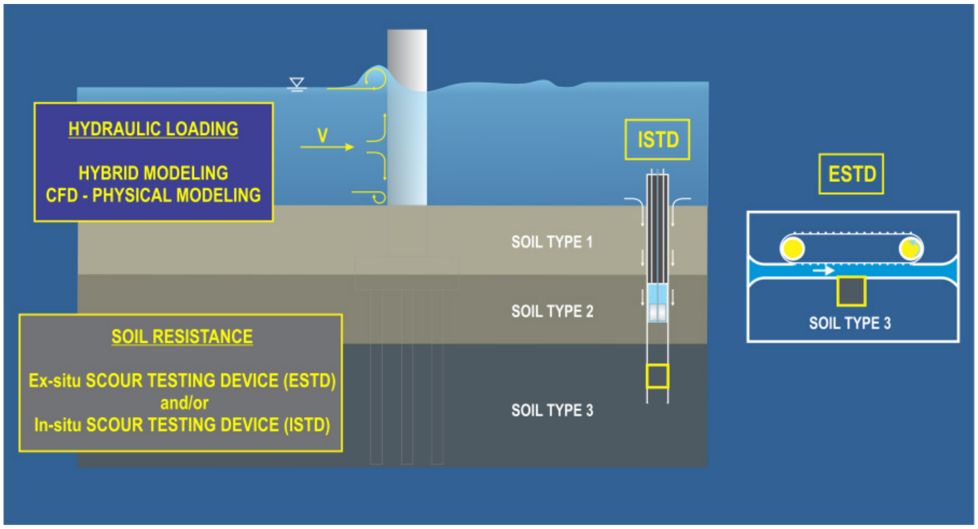
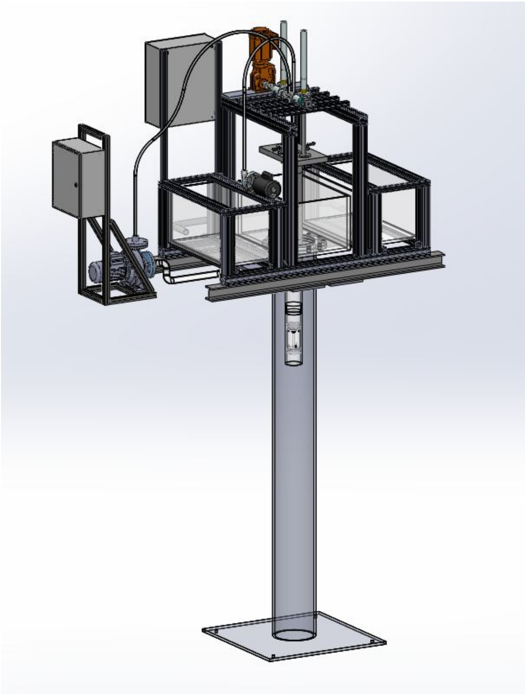


Figure 2. Diagram. Hydraulic Loading—Soil Resistance Approach.[6]



Source: Federal Highway Administration (Patent Pending).

Figure 3. Diagram. In-situ scour testing device for a 10-ft-deep erosion test.

Dr. Steven Lottes of ANL provided an overview of their Transportation Research and Analysis Computing Center (TRACC). The TRACC cluster computing capabilities are available to all transportation researchers and analysts, with universities and government making up the bulk of the cluster user groups. Example uses include traffic modeling, bridge hydraulics, bridge structural analysis, and vehicle occupant safety and crashworthiness. Dr. Lottes reported on modeling soil-structure interaction with large deformations using the Oat Ditch bridge failure (figure 4) as well as simulation of soil penetration tests and bridge pier failure. A model of fluid structure interaction for the onset of motion for riprap was presented.

Source: California Department of Transportation

Figure 4. Photo. Failure of Oat Ditch Bridge on I-15 in California.

OVERVIEW OF PAST, CURRENT, AND PLANNED GEOTECHNICAL RESEARCH AT TFHRC

Dr. Jennifer Nicks, Research Geotechnical Engineer at the FHWA Office of Infrastructure R&D, presented an overview of the Geotechnical Research Program at TFHRC, beginning with background information on bridge foundations, including type, cost, and common State concerns. She then described the FHWA Foundation Engineering Research Program (FERP) initiated in the late 1970s. Five FERP projects were detailed: structural consequences of foundation movements, predicting behavior of piles and foundation soils under structural loads (see figure 5 and figure 6), improved design and construction techniques for drilled shafts, innovative load test methods, and improved design for shallow foundations. Past research projects related to bridges were also described. Dr. Nicks indicated that current research efforts are focused on deformation analysis of shallow foundations, performance of Geosynthetic Reinforced Soil (GRS) as a bridge foundation system, steel corrosion in Mechanically Stabilized Earth (MSE) structures, long-term GRS dead load tests, retaining wall asset management, and design and load testing of large diameter driven pipe piles. Important topics for future research include geophysics for reliable determination of soil and rock design parameters, risk analysis for geotechnical structures, and reuse of geotechnical features.

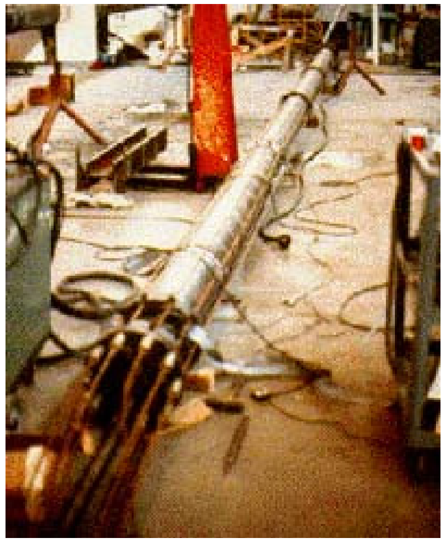


Figure 5. Photo. Laboratory instrumentation of a pipe pile for field load testing.[7]

Figure 6. Photo. Predicting the behavior of micropiles and foundation soils under structural loads.[7]

FHWA LTBP PROGRAM – REPORT ON THE WORKSHOP ON BRIDGE SUBSTRUCTURE ISSUES AND OVERVIEW OF THE GEOTECH TOOLS

Professor Vern Schaefer of Iowa State University provided an overview of the LTBP Workshop and the GeoTechTools system. In March 2010, approximately 60 participants from State transportation departments, FHWA, domestic universities, and industry, met in Orlando, FL, to identify bridge substructure performance issues.[8] The bridge performance issues were grouped into three areas: geotechnical bridge performance issues, data needs and gaps, and tools, technology development and monitoring. The participants were divided into three groups to discuss each of these areas and then reconvened to further discuss them. The geotechnical bridge performance issues included abutment/approach settlement; foundations in terms of measuring loads, unknown foundations, and tolerable movements; hydraulic issues of scour and drainage; materials, in particular corrosion/deterioration; and construction quality control, see table 1. The key data needs and gaps identified included existing capacity and integrity of foundation elements; and design scour and measured scour, see table 2. Less emphasis was placed on the tools, technology development, and monitoring, with a simple delineation of what is currently available, what will be available in the near future and what is needed in the long term, see table 3.

Dr. Schaefer also provided a brief overview of the GeoTechTools system, which is a comprehensive web-based information and guidance system for embankment, ground improvement and pavement applications that was developed through the Strategic Highway Research Program (SHRP 2). The system provides guidance on the use of 46 technologies for ground improvement and geoconstruction in transportation infrastructure. For each technology, there are eight products available including technology fact sheets, photographs, case histories, design procedures, quality control/quality assurance procedures, cost estimating, specifications, and a bibliography. A live demonstration of the system was made.

Table 1. FHWA LTBP Workshop Breakout Session 1: Summary of priority geotechnical performance issues identified by each group.[8]

Group 1	Group 2	Group 3
• Abutments: Bump at end of bridge, integral abutments, piles • Foundations: Measured loads, widening, unknown foundations, tolerable movements • Hydraulics: Scour, drainage • Materials: Corrosion • Construction: Quality control	• Approaches: Settlement, global stability • Piers: Scour, total-differential settlement, horizontal movement • Abutments: Vertical and horizontal movement, differential settlement, scour, pile performance • Abutment walls: Corrosion, drainage failure, scour, soil restraint	• Corrosion/deterioration (MSE walls, steel in piles, embankment material) • Bump at end of bridge (significant) • Fatigue/integral abutment/lateral stress • Drainage, runoff, erosion • Remaining service life—long-term performance

Table 2. FHWA LTBP Workshop Breakout Session 2: Data needs and gaps related to performance issues for bridges.[(8)]

Performance Issue	Data Needs: Construction Records	Data Needs: Inspection and Maintenance History	Data Needs: Characterization of Service Environment	Data Needs: Post-Construction Monitoring
Approach-bridge interface	• As-built plans • Foundation report	• Inspection reports • Photos • Voids under slabs • Winter maintenance practices	• Climate data • Traffic • Loads	• Settlement • Rideability • Deformations • Vibrations
Material degradation	• As-built plans	• Inspection reports • Winter maintenance practices	• Climate data • Groundwater info • Soil characteristics	• Corrosion detection • Condition of foundation elements
MSE Walls	• As-built plans	• Visual identification of corrosion	• Climate data • Indications of salt intrusion from poor surface drainage	• Soil pH • Water pH
Hydraulics	• As-built plans • Abutment/pier type • Channel capacity • Type of scour countermeasures • Predicted scour	• Inspection reports	• Flood data/records • Climate data • Ice data • Stream velocity	• Scour depth • Actual scour versus predicted scour

Table 3. FHWA LTBP Workshop Breakout Session 3: Needed tools, technology development, and monitoring.[(8)]

Geotechnical Performance Issue	Tools Currently Available	Short-Term Technology Development	Long-Term Technology Development
Bump at the end of the bridge	• Ground-penetrating radar • Survey • Inclinometer • TDR moisture sensors • Settlement points at depth • Road profiler • Airborne LIDAR • User feedback (phone calls) • Accident data • Maintenance records • Peak particle velocity for vibration monitoring • Quality geotechnical data • In situ geotechnical testing • Tiltmeters	• High-speed pavement profilers • Smart pavement to capture loading	• Earth pressure cells • Smart soils with MEMS embedded
Foundations	• Strain gauges • Load cells • Survey • Inclinometer • Settlement points at depth • Laser scanning • Maintenance records • Quality geotechnical data • In situ geotechnical testing • Tiltmeters • Bridge response WIM • Crack meters • TDR cables embedded in foundation • Settlement of foundation	• Smart foundation elements • Technique to measure existing load on foundation • Laser/radar interferometry monitoring of deflection	• Earth pressure cells • Energy piles/geothermal heating for heating of decks

Geotechnical Performance Issue	Tools Currently Available	Short-Term Technology Development	Long-Term Technology Development
	• Load test data • Embedded GPS reference points in foundations		
Deterioration	• Half cell potential • Resistivity • Sacrificial steel and inspection • Concrete coring • Concentrations of chloride and sulfate in concrete • Concrete cover measurements • Ultrasonics	• Optical TDR • Laser/radar interferometry monitoring of deflection	• Shear/p-wave velocity (for elemental stiffness) • Smart paint/coating (to measure stress, corrosion) • Self-healing steel • Self-healing concrete • Maintaining compatibility of strains in repair materials • Embedded biosensors
Earth-retaining structures	• Strain gauges • Load cells • Survey • Inclinometer • TDR moisture sensors • Settlement points at depth • Laser scanning • Airborne LIDAR • Maintenance records • Quality geotechnical data • In situ geotechnical testing • Tiltmeters • Crack meters • Piezometers • Inspect drains • TDR cables	• Smart concrete/ structure members to capture loading • Electro-conductivity of wall	• Earth pressure cells • New technique to measure water height behind wall face • Smart soils • Harnessing movement on bridge to capture energy to power sensors

Geotechnical Performance Issue	Tools Currently Available	Short-Term Technology Development	Long-Term Technology Development
Hydraulics (scour)	• Sonar • Plumb bobs • Float out device • TDR vertical and horizontal • Sub-bottom profiler • Ground-penetrating radar • Flow monitoring • Visual inspection/diver • Embedded GPS reference points in countermeasures	• In-place sonar • Float out device attached to structure • Vibrations of pier structure	• Smart particles • Satellite/airborne imagery to detect scour holes

GPS = Global Positioning System.
MEMS = Microelectromechanical systems.
WIM = Weigh in motion.
LIDAR = Light detection and ranging.
TDR = Time domain reflectometry.

SUMMARY OF THE SECOND PLENARY SESSION: GEOTECHNICAL AND HYDRAULIC HAZARDS AND IMPACTS

INTRODUCTION TO THE PLENARY SESSION

Session 2 of the workshop consisted of presentations on the hazards and impacts of geotechnical and hydraulic features from the perspective of FHWA and State transportation department personnel. The session was moderated by Dr. Phil Yen, Principal Bridge Engineer at the FHWA Office of Bridge Technology, who began the session with a discussion of the importance of seismic hazards by posing the question: What is the situation after an earthquake? Dr. Yen emphasized the need to quickly estimate the capacity and integrity after an extreme event, with post-hazard evaluation being a key issue.

NATIONAL BRIDGE INSPECTION PROGRAM: THE UNKNOWN FOUNDATION AND HYDRAULIC SCOUR QUESTION

Mr. Dave Henderson, Senior Bridge Engineer (Scour) at the FHWA Office of Bridge Technology, provided an overview of the national bridge inspection program. He began the presentation with a graphic showing the relationship between foundation characterization, unknown foundations, and hydraulic scour (see figure 7), then asked the question: How does it all fit?

He described the components of the national bridge inspection program and the FHWA scour program. He explained that the national bridge inspection program has three fundamental components: the NBI, the National Bridge Inspection Standards (NBIS), and the National Bridge Inspection Program (NBIP). The inventory, standards, and program provide the database of information available for over 600,000 bridges nationwide. The performance of bridges is measured by 23 metrics.[9] Metric 18 measures scour.

The FHWA Scour Program consists of the following key elements: scour evaluations, scour critical bridges, unknown foundation bridges, plan of action bridges, and scour countermeasures. In 2011, FHWA implemented the risk-based and data-driven NBIP oversight process. The risk-based component provides a strategy of prioritizing vulnerable bridges based on bridge importance and consequences of failure. The data-driven component provides the key operational characteristics of the facility. These two strategies were further elaborated as they relate to unknown foundation elements. Mr. Henderson offered the following three important takeaways:

1. The bridge owner must develop prioritization and decision making strategy, which is consistently applied and easily replicated.
2. Low risk bridges Coded “U” (unknown foundation) in Item 113 can be “low hanging fruit” and owner’s resources may be focused on bridges with highest risk.
3. The term “Unknown Foundation” for bridge owners is a performance measurement of compliance with NBIP.

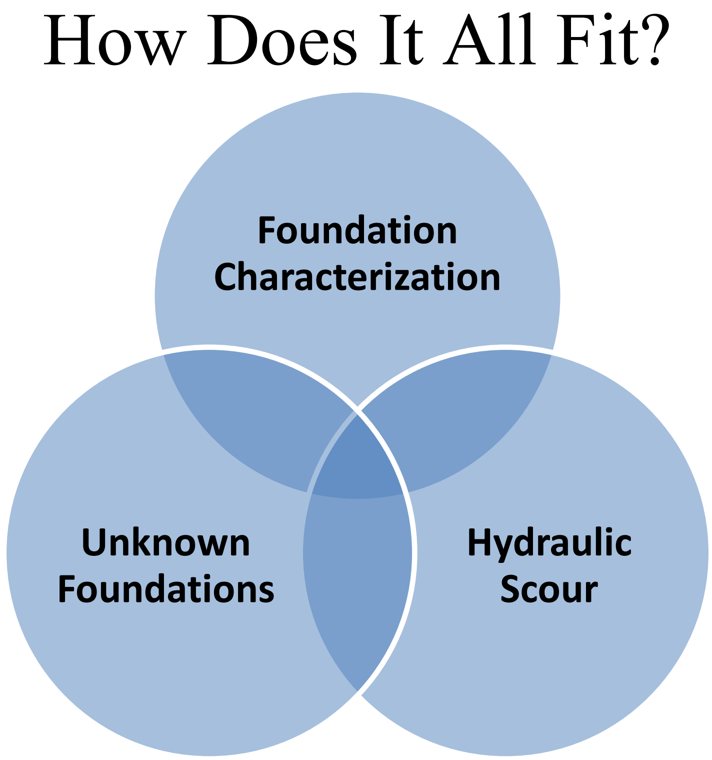
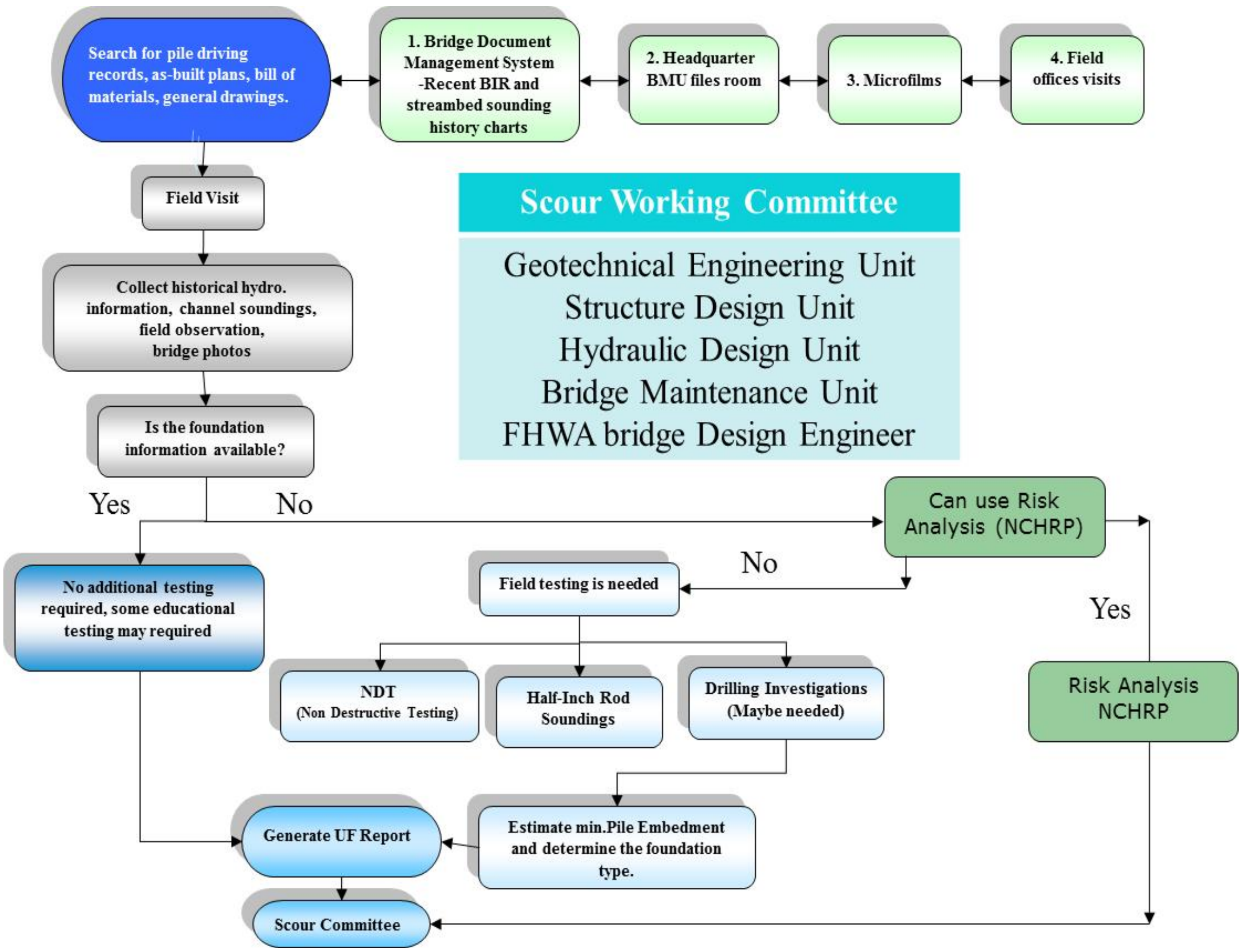


Figure 7. Diagram. Interrelationship of Characterization, Unknown Foundations and Hydraulic Scour.

UNKNOWN FOUNDATION INVESTIGATION PROGRAM IN NORTH CAROLINA

Mr. Mohammed Mulla, Assistant State Geotechnical Engineer at the North Carolina Department of Transportation (NCDOT), provided an overview of the unknown bridge foundation program in North Carolina. Early efforts focused on records searches and field testing to identify the foundation type, with estimates of minimum pile embedment or footing size and depth, and an evaluation of the foundation with respect to scour using soundings. By 2005, a rigorous unknown foundation process had been developed (see figure 8). Mr. Mulla detailed the process used for unknown foundations in the bridge management system, including the sorting of microfilms. The non-destructive testing (NDT) was conducted by consultants and in-house staff. The testing procedures were reviewed in detail, with examples shown of their use on bridges and foundations in the State. In 2010, the use of risk-based management guidelines for scour was suggested to evaluate remaining unknown foundation low risk bridges.[(10)] By November 2012, review of all unknown foundation bridges had been completed. Mr. Mulla concluded by asking a series of questions regarding NDT and asset management, with an exhortation to think outside the box and communicate.

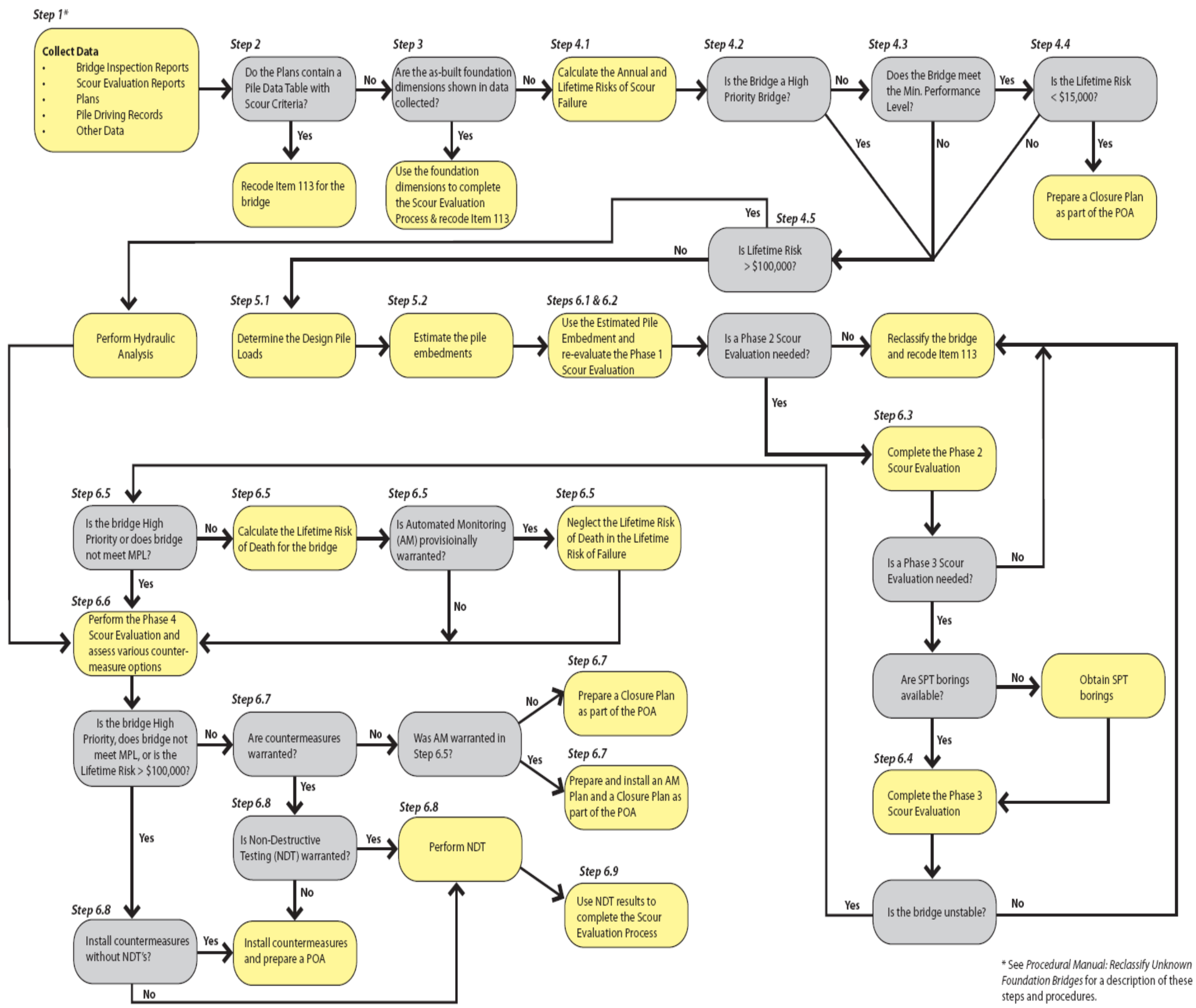


Source: NCDOT

Figure 8. Diagram. Flowchart for North Carolina Unknown Bridge Foundation Process.(11)

FLORIDA DEPARTMENT OF TRANSPORTATION'S APPROACH TO RESOLVE UNKNOWN FOUNDATIONS

Mr. Larry Jones, Assistant State Structures Design Engineer and State Geotechnical Engineer at the Florida Department of Transportation (FDOT), provided an overview of FDOT's unknown foundation program. The FDOT unknown foundations process is summarized in figure 9. Based on 2010 statistics, Florida has determined that the majority of unknown foundation bridges are on local roads, with only nine percent on principal arterials. FDOT has developed an assessment plan to sequence the effort into phases. The unknown foundations process involves data gathering, risk assessment, embedment prediction, and Phases 2 through 4 scour evaluations. The National Cooperative Highway Research Program (NCHRP) Web Only Document 107 procedure is followed with some modifications for Florida costs, failure rates and tidal bridges.(7) Risk thresholds are based on lifetime risks tied to specific dollar amounts. Embedment predictions are based on artificial neural network or geotechnical analysis methods. The results of the Florida processes were detailed with comparisons of predicted versus measured embedment depths by the various methods. An extensive summary for the statistics of Florida's program was presented. Of some 2,500 bridges, only 160 were determined to be scour-critical, with about 400 not reported. Mr. Jones closed by characterizing some issues for thought regarding MSE walls and service limit versus strength limit states, particularly that proof loading of unknown foundations addresses the service limit state, but not the strength limit state.



Source: FDOT

Figure 9. Diagram. FDOT's Unknown Foundation Process.[12]

WASHINGTON DEPARTMENT OF TRANSPORTATION FOUNDATION EVALUATIONS FOR GEO/HYDRAULIC HAZARDS AND DESIGN PURPOSES

Mr. Jim Cuthbertson, Chief Foundation Engineer at the Washington State Department of Transportation (WSDOT), provided an overview of WSDOT's history of emergency bridge issues over the past century. Seventy bridges (out of 3,500 State bridges) have been damaged beyond repair or collapsed in that time, for a 2.0-percent failure rate, 43 of which did so under flood conditions (1.23 percent) and only 2 with unknown reasons (0.06 percent).[13] Thus, of those that failed, slightly more than 60 percent did so under flood conditions. Earthquakes and landslides have not yet caused collapse or complete replacement. Except for flood/scour causes, foundation issues have not been a primary cause of structure failure or replacement.

Mr. Cuthbertson showed a slide on Geotech Emergency Response that highlighted the key issues to be addressed under time and money constraints (see table 4). Foundation evaluation procedures for scour, flood, and seismic causes were presented. Earthquakes have mainly caused structural damage and the primary response thus far has been by the Structures Preservation Unit. Mr. Cuthbertson closed with thoughts on reuse of foundations in widening efforts.

Table 4. Geotechnical Emergency Response (Regardless of the Event).[13]

Emergency Response	Issues for Asset Management Discussion
• Gather structure information. • Prioritize response if necessary. • Put boots on the ground and go look. • Talk issues/solutions/risks with other interested parties: Hydraulics, Structures, Traffic, FHWA, Federal Emergency Management Agency. • Manage risk to public and property by making emergency field decisions based on engineering judgment or limited calculations; close road, take lanes, or implement emergency stabilization. • Back in office. • Reprioritize (structure triage). – Gather available data, plans, subsurface info, and loads. Get new info if necessary. – Evaluate: global stability, settlement, bearing, lateral resistance – Talk issues/solutions/risks with other interested parties: Hydraulics, Structures, Traffic. – Develop repair/replacement. – Fix/replace.	• We have embraced the digital age. So, no power = no data. • Not in office = no data, as it is behind firewalls. • Travel can be issue. Roads have been closed. May not be able to inspect structures. • Cellular communications may be down so we may have to act autonomously. We do have statewide radio, but Geotechs don't have access. • Big response—Limited staff and support services; surveying, drilling, air photos, etc. • Political pressure/public perception affecting or overriding engineering. • Time—Never enough. • Money—Especially never enough.

EVALUATION OF EXISTING FOUNDATIONS WITH NON-DESTRUCTIVE METHODS

Mr. Khamis Haramy, Senior Geotechnical Engineer, FHWA Central Federal Lands, provided a brief overview of existing NDE methods used for foundation characterization and foundation material integrity evaluation. At the outset, Mr. Haramy stipulated that the objective of nondestructive evaluation of bridge foundations was twofold: (1) determine unknown bridge foundation characteristics for scour vulnerability concerns, and (2) assess conditions and integrity of unknown and known bridge foundations for increasing bridge structure design life and foundation reuse. A brief description of the existing NDE methods, their applicability and limitations was provided. Mr. Haramy indicated that the FHWA manual "Application of Geophysical Methods for Highway Related Problems" and the associated searchable, web-based e-manual contain a summary of the methods and their limitations. Mr. Haramy demonstrated the use of the e-manual for determining the most reliable methods for a certain application (figure 10). He indicated that, in his opinion, these methods provide a useful way to characterize bridge foundations; however, a combination of methods may be required to best characterize some sites. He also indicated that advanced technologies used in medicine and oil exploration—3D full waveform tomography—may significantly improve foundation characterization if adapted by the transportation field. He recommended that funds be allocated for the development of advanced methods and by utilizing newly developed algorithms for improving image clarity.

Figure 10. Picture. Screen capture of Geophysical "Webmanual."[14]

SUMMARY OF THE THIRD PLENARY SESSION: CHANGES IN SERVICE LOADS AND FOUNDATION REUSE

INTRODUCTION TO THE PLENARY SESSION

Session 3 of the workshop consisted of presentations on changes in service loads and foundation reuse from the perspective of FHWA and State transportation department personnel. Mr. Khalid Mohamed, Geotechnical Engineer with the FHWA Office of Bridge Technology, moderated the session.

EVALUATING FOUNDATIONS FOR REUSE: LOOKING AHEAD

Mr. Ben Rivers, Geotechnical Engineer at the FHWA Resource Center, provided a look ahead at the evaluation of foundations for reuse. The drivers for foundation reuse are that existing foundations are assets with a functional value. Reuse enhances preservation efforts, cost and time savings, and minimizes impacts to mobility. Mr. Rivers emphasized that reuse designs must meet or exceed current design standards. The issues boil down to costs and managing risks.

Relationships between factor of safety and annual probability of failure based on actual engineering projects was shown (figure 11) to illustrate the interrelationship between the level of engineering and risk of failure.(15) Mr. Rivers briefly described when it is appropriate to consider foundations for reuse; the obstacles for reusing existing foundations; and, current needs in considering reuse of foundations. The foundation reuse needs include evaluation of the integrity of the foundations; understanding nominal resistance and load-deflection criteria for all design loads; and quantifying reliability and establishing acceptable risk thresholds for bridges.
Mr. Rivers concluded by reviewing opportunities with the use of new and existing methods for in situ determination of soil properties and structural integrity, and listed some of the challenges facing foundation reuse.

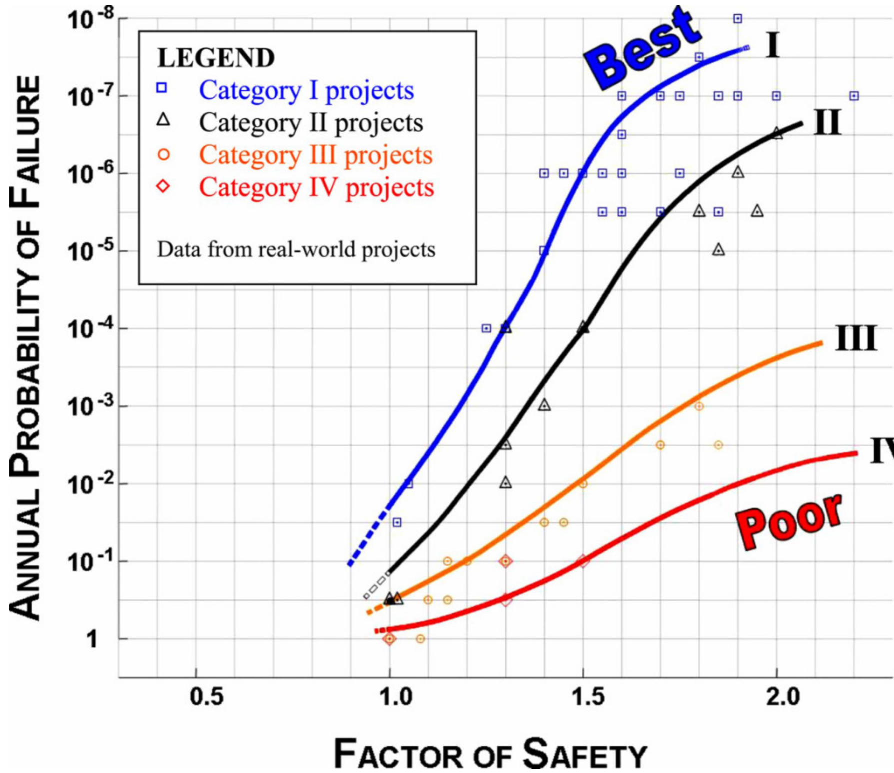
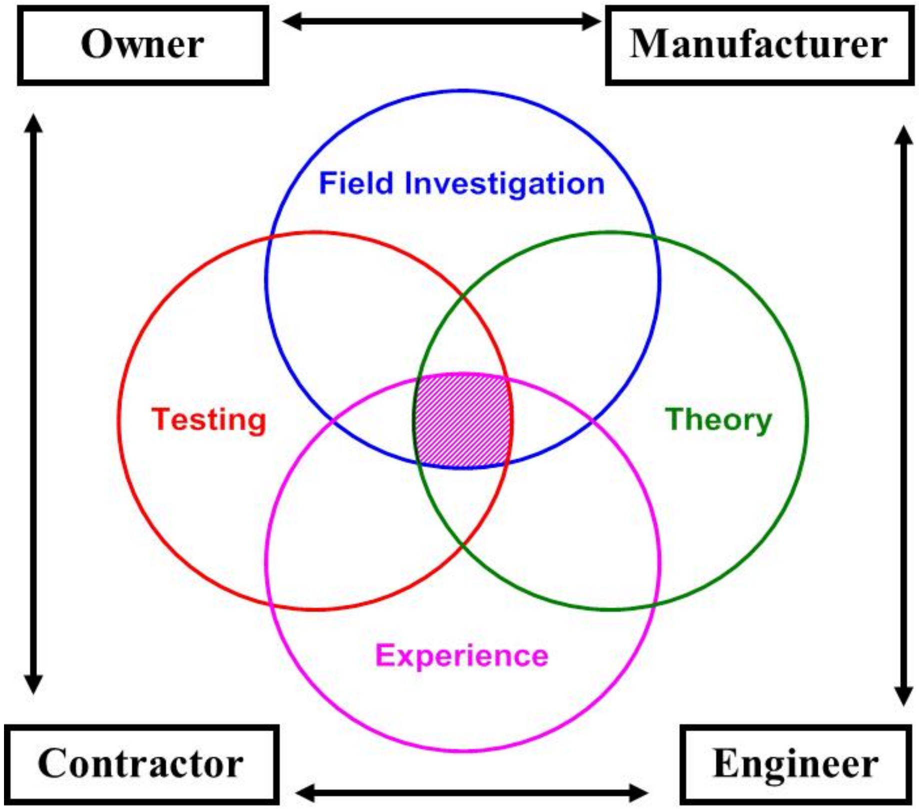


Figure 11. Graph. Probability and risk of slope failure.[(15)]

EXPERIENCE WITH EVALUATION AND REUSE OF BRIDGE FOUNDATIONS AT THE MASSACHUSETTS DEPARTMENT OF TRANSPORTATION

Mr. Peter Connors, Geotechnical Engineer at the Massachusetts Department of Transportation (MassDOT), provided an overview of the MassDOT experiences with evaluation and reuse of bridge foundations. Foundation reuse is written into the Massachusetts bridge manual. Reasons for reusing foundations include replacement of structurally deficient bridges, good performance of foundations, accelerated bridge construction, cost/time benefit, historic nature of bridges, and superior quality. Conditions that require further evaluation for reuse include bridge widening with spread footings or arches, prior reuse, or when foundations are of poor quality. Above all, one should not force a reuse solution on a project. Reuse is not different from new construction; one still needs field investigation and testing and engineering with both theory and experience (figure 12). Mr. Connors provided a detailed review of the evaluation process culminating in a preliminary structure report, the existing foundation types, subsurface/substructure investigation methods, and the use of engineering judgment.



Source: MassDOT

Figure 12. Diagram. Is reuse of a foundation different than new?

ILLINOIS DEPARTMENT OF TRANSPORTATION (IDOT) PAST AND PRESENT POLICES ON DETERMINATION OF EXISTING FOUNDATION CAPACITY FOR REUSE

Mr. William Kramer, State Foundations and Geotechnical Engineer at IDOT Bureau of Bridges and Structures, provided an overview of Illinois' past and present policies on foundation capacity for reuse. Illinois has a formal policy on reuse because: (1) it has been difficult to prove bridges designed under old American Association of State Highway Officials (AASHTO) codes meet current code, (2) it is difficult to justify the expense to replace when no evidence of poor performance exists, (3) consultants often prefer to make conservative judgments to protect liability, and (4) the public demand to stretch limited tax dollars and provide consistent judgments required IDOT to develop formal policy for foundation reuse.

Illinois has an elaborate methodology for evaluating foundation reuse. Mr. Kramer provided background on the past practice, the need for change, and an overview of the new policy issued in 2008. The new policy allows for an abbreviated analysis when the substructure is in a good or repairable condition and the dead load increase is less than 15 percent. A summary of the new policy for capacity tables for spread footings and piles is shown in figure 13. A detailed analysis is required when the dead load will increase more than 15 percent. Details of the procedures are shown in Mr. Kramer's presentation.

Existing Spread Footing Capacity Determination Table

R_a	No Borings Available (**2 ksf**)	Mixed soils with N >15 (**4 ksf**)	Clay soils with Q > 3.0 (**6 ksf**)	Very Dense Granular with N>50 (**8 ksf**)	Hard Clay Till with Qu > 4.5 tsf (**10 ksf**)	Sandstone or Shale (**15 ksf**)	Limestone or Dolomite (**30 ksf**)

Example: Obtain the footing plan dimensions and base elevation from the existing plans. Calculate the existing and proposed footing loading to obtain the maximum applied service bearing pressure ($\mathbf{Q}_{MAX}$) and resultant eccentricity. If the proposed Q max is more than 50% above the existing loading, the footing can not be reused. If founded on soil, calculate the proposed equivalent uniform bearing pressure ($\mathbf{Q}_{EUBP}$). Using new or existing boring data, locate the footing base elevation and evaluate the soils/rock within a depth of 1½ times the footing width to determine the allowable **service bearing capacity** $\mathbf{R}_a$ from the above table.
The proposed applied bearing pressure ($\mathbf{Q}_{MAX}$ for rock or $\mathbf{Q}_{EUBP}$ for soil) must be less than the allowable service bearing capacity $\mathbf{R}_a$ and the proposed resultant eccentricity must be within the Middle third (for soil) or middle half (for rock) of the footing for the existing foundation to be considered adequate.

Existing Pile Capacity Determination Table

C_s	**Existing Pile Capacity Source**	Existing Driving Records (**0**% Capacity Increase)	Existing Plans Pile Data (**10**% Capacity Increase)				
C_b	**Low Capacity Formula Bias**	Pile Capacity > 40 tons (**0**% Capacity Increase)	Pile Capacity < 40 tons (**6**% Capacity Increase)				
H_e	**Hammer Efficiency Correction**	Closed End Diesel, Drop or Unknown Hammer (**0**% Capacity Increase)	Open End Diesel Hammer (**4**% Capacity Increase)	Air-Steam Hammer (**8**% Capacity Increase)			
P_e	**Pile Effect on Hammer Efficiency**	Precast Concrete or Timber Pile (**0**% Capacity Increase)	Metal Shell or Steel H-Pile (**4**% Capacity Increase)				
P_l	**Pile Length Formula Conservatism**	Driven or Estimated Length < 60 ft. (**0**% Capacity Increase)	Estimated Plan Pile Length > 60 ft. (**2**% Capacity Increase)	Driving Records Driven Length > 60 ft. (**4**% Capacity Increase)			
S_m	**Borings Indicate Main mode of Support**	No Records Available (**0**% Capacity Increase)	End Bearing in Soil or Shale (**4**% Capacity Increase)	Friction in Granular Soils (**8**% Capacity Increase)	Friction in Cohesive Soils (**16**% Capacity Increase)	End Bearing in Sandstone (**16**% Capacity Increase)	End Bearing in Limestone or Dolomite (**20**% Capacity Increase)

Example: Existing plans pile data indicate timber piles, estimated to be 62ft long, with a design capacity of 24 tons. The pile driving records indicate that a MKT 11B3, a Closed End Air-Steam hammer, was used and on average the piles were driven 57ft with a final bearing of 30 tons.

The allowable resistance available $\mathbf{R}_a$ can be determined by the following formula $\mathbf{R}_a$ = **Existing Capacity** x $(1+\mathbf{C}_s+\mathbf{C}_b+\mathbf{H}_e+\mathbf{P}_e+\mathbf{P}_l+\mathbf{S}_m)$. The Exist Cap = 30 tons, from driving records, $\mathbf{C}_s$ **=** 0.00, since we have driving records, $\mathbf{C}_b$ **=** 0.06, because the Exist Capacity is below 40 tons, $\mathbf{H}_e$ = 0.08, due to the use of an Air-Steam Hammer, $\mathbf{P}_e$ = 0.00, because timber piles were used, $\mathbf{P}_l$ = 0.00 due to the driven length being less than 60 feet, and $\mathbf{S}_m$ = 0.00 as no borings are available. The factored resistance available $\mathbf{R}_F$ is determined by multiplying by the factor of safety which is assumed to be 3.0 and the resistance factor with is taken as 0.5.

R_a= 30 tons x (1+0+.06+.08+ 0+0+0) = 30 tons x (1.14) = 34.2 tons 14% < 50% so Ok.
R_F = R_a x (Safety Factor) x (Resistance Factor) = 34.2 x (3) x (0.5) x (2 kips/ton) = 102.6 kips

The new factored strength group pile loading must not exceed the factored resistance available of 102.6 kips.

Source: IDOT

Figure 13. Diagram. Foundation capacity tables for spread footings and piles.[16]

POTENTIAL OF STRUCTURAL IDENTIFICATION FOR CHARACTERIZING EXISTING BRIDGE FOUNDATIONS

Professor A. Emin Aktan of Drexel University provided a presentation on structural identification in reusing bridge substructures. Professor Atkan provided background on the six steps of structural identification, which entails an integration of analysis and experimentation to reduce uncertainty by calibrating a finite element model of a bridge (see figure 14).[17] The process was detailed in an example. This process is being applied in the LTBP Program and is also detailed in the American Society of Civil Engineers (ASCE) book, *Structural Identification of Constructed Systems*.(17) Some key takeaways from the presentation are that reality is always 25 percent removed from our idealization of global behavior, and different time periods provide different behavior perspectives.

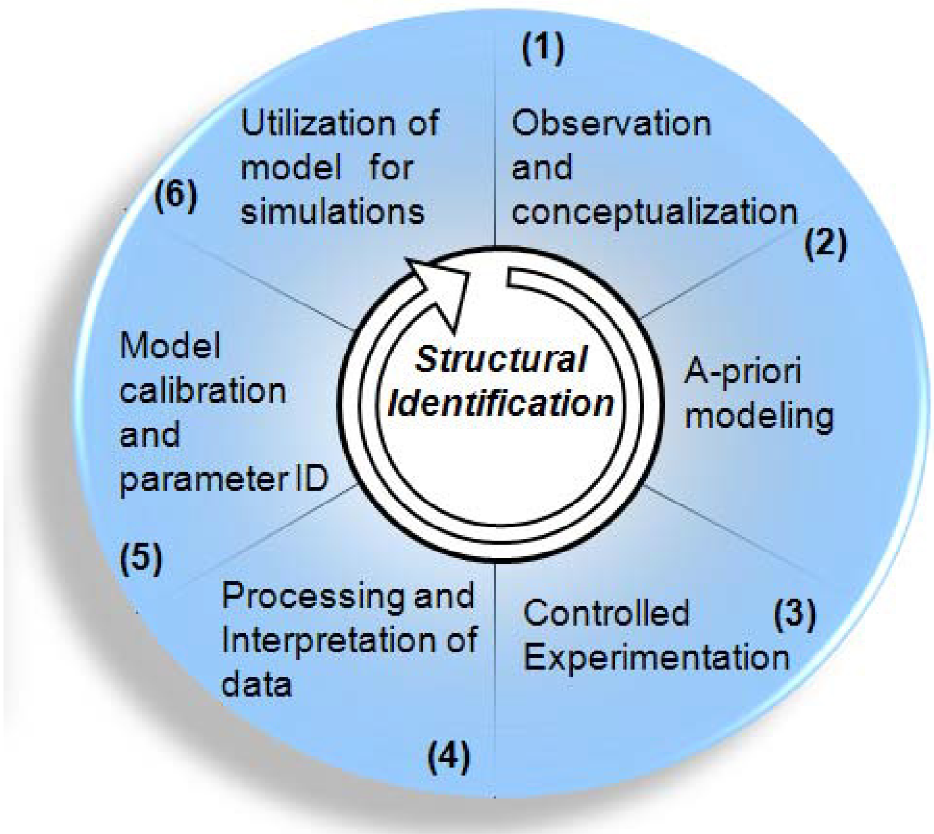


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Figure 14. Diagram. Six steps of structural identification.(17)

LOAD RATING OF PILE-SUPPORTED BRIDGES

Dr. Hisham N. Sunna of Ayres Associates, Inc., provided a review of the load rating of pile-supported bridges. The available load rating methodologies for the superstructure and the substructure were reviewed, indicating that structural bridge load rating is traditionally based on the superstructure components with the substructure being ignored. The presenter reviewed geotechnical performance factors and elaborated on settlement considerations. Dr. Sunna showed an application of settlement considerations to case histories for Allowable Stress Rating (ASR) for determining the allowable live load that can be carried by the bridge (figure 15).(18) Load rating for different bridges was conducted to compare substructure load rating and superstructure load rating and demonstrate dependence of substructure based load rating on the amount of scour at the site. The presentation was concluded that all bridges over waterways should be analyzed for a substructure load rating considering the existing mudline and potential scour; a bridge load rating based only on the superstructure could cause either catastrophic or functional failure.

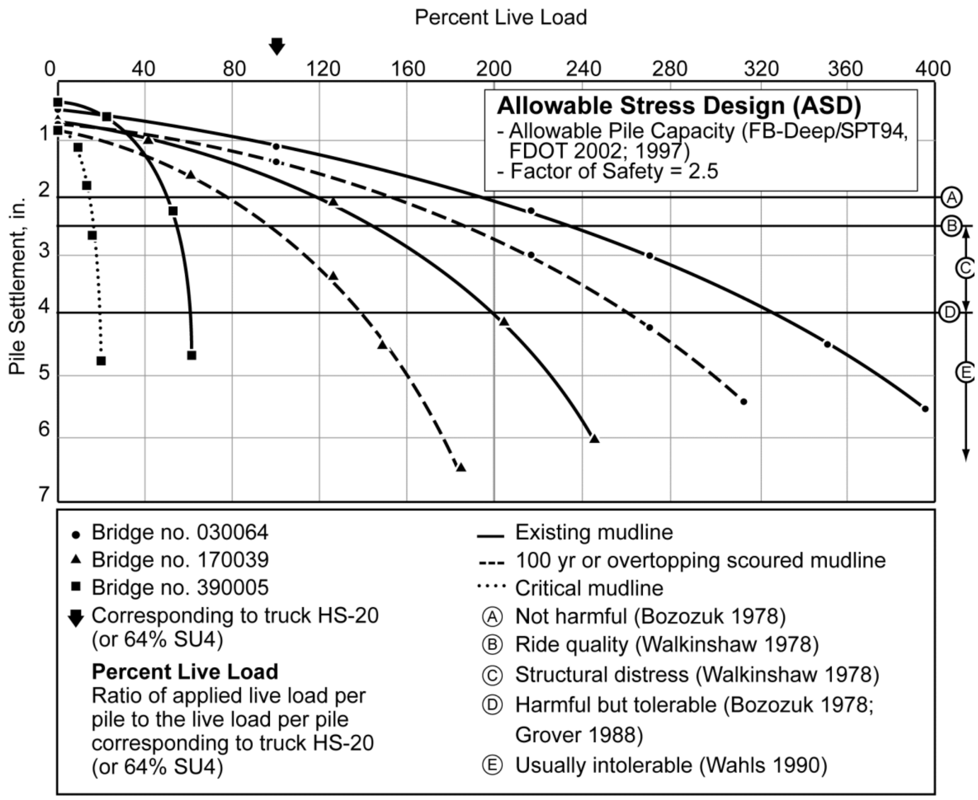

Figure 15. Diagram. Allowable Stress Rating (ASR).[18]

OTHER PARTICIPANTS IN THE WORKSHOP

In addition to the presenters, the following also participated in the workshop:

- Professor Ivan Bartoli, Assistant Professor, Drexel University.
- Ms. Sheila Duwadi, Team Leader (Hazard Mitigation), FHWA Office of Infrastructure R&D.
- Dr. Lubin Gao, Senior Bridge Engineer (Load Rating), FHWA Office of Bridge Technology.
- Mr. Khalid Mohamed, Geotechnical Engineer, FHWA Office of Bridge Technology.
- Mr. Silas Nichols, Senior Bridge Engineer (Geotechnical), FHWA Office of Bridge Technology.
- Mr. Benjamin Oltmann, Structural Engineer, FHWA Eastern Federal Lands.
- Dr. Sayed M. Sayed, Principal and Director of Engineering, GCI Inc.
- Dr. Jerry Shen, Program Manager, FHWA Hydraulics Laboratory, Genex Systems.
- Dr. Phil Yen, Principal Bridge Engineer, FHWA Office of Bridge Technology.

BREAKOUT SESSION I: GEO/HYDRAULIC HAZARDS AND IMPACTS

BRAINSTORMING GEO HYDRAULIC HAZARDS AND IMPACTS

The first breakout session focused on identifying the geotechnical and hydraulic hazards and impacts associated with unknown foundations and characterization issues. The goal of this session was to solicit high priority input for new research and to prioritize listed high priority items. The workshop participants were divided into two groups to ensure a mix of disciplines and FHWA offices and discussed the session topic on the afternoon of April 30. Following the discussion, the participants reunited on Wednesday morning to summarize the group findings.

A list of preliminary topics for discussion at the breakout session was provided to attendees as a starting point for discussion topics. The topics included performance issues, engineering problems, tools and technology, proposed test plan, numerical modeling, research products, risk-based analysis, outreach and other funding mechanisms. An expanded list of topics is shown below.

Agenda Items for the Geo/Hydraulic Hazard and Impact Breakout Session.

1. Performance Issues—What are some of the main issues that required foundation characterization?
   - Brainstorm performance issues and rank them.
     - Pre-event vulnerability evaluations (scour, seismic, etc.)
     - Post-event assessment (flooding, post-seismic, ship impact, etc.). Can the foundation still perform? Damage to the foundation? And so forth.
   - Data needs and gaps.
2. Engineering Problems—What are the key engineering problems that need to be researched?
   - Foundation type (shallow/deep).
   - Foundation geometry (dimensions (L,W, D), pile tip elevation, pile distribution).
   - Foundation material (concrete, steel, timber, masonry, stone).
   - Foundation integrity (condition assessment).
   - Load carrying capacity.
   - Others.
3. Tools and Technology.
   - Geophysics.
   - NDT.
   - Remote sensing.
   - Destructive testing.
   - Load testing.
   - Numerical modeling.
   - Risk-based analysis, statistical procedures.
   - Others.

4. Proposed Test Plan.
    - Existing bridges—geometry, type material.
    - Decommissioned bridges—load testing.
    - Test bed—with defects. Integrity testing. Baseline evaluation and technology validation.
    - Other test sites—National Geotechnical Experimentation Sites (NGES), Reuse of Foundations for Urban Sites, German Federal Institute for Materials Research and Testing test site.
5. Numerical Modeling.
6. Research Products.
    - Guidance documents.
    - Reports and Tech Briefs.
    - Web portal.
    - Foundation database.
7. Risk-Based Analysis.
8. Outreach—Other events: TRB 2014 workshop, Geo-Institute.
9. Other Funding Mechanisms We Can Leverage—Pooled funds, NCHRP, Research and Innovative Technology Administration, National Science Foundation, etc.

The participants in Group 1 were as follows:

Mohammed Mulla (NCDOT), Chair
Jennifer Nicks (FHWA)
Jerry Shen (FHWA/GENNEX)
Dave Henderson (FHWA)
Frank Jalinoos (FHWA)
Khalid Mohamed (FHWA)
Larry Jones (FDOT)
William Kramer (IDOT)
Benjamin Oltmann (FHWA)
Sayed Sayed (GCI, Inc.)
Emin Aktan (Drexel University)

The participants in Group 2 were as follows:

Khamis Haramy (FHWA), Chair
Vern Schaefer (Iowa State University)
Kornel Kerenyi (FHWA)
Ben Rivers (FHWA)
Steven Lottes (TRACC/ANL)
Jim Cuthbertson (WSDOT)
Peter Connors (MassDOT)
Hisham Sunna (Ayres Associates)
Phil Yen (FHWA)
Lubin Gao (FHWA)
Ivan Bartoli (Drexel University)
Silas Nichols (FHWA)

Each group approached the discussion in a different way. Below are summaries of their discussions.

GROUP 1

The following items were highlighted during the Geo/Hydraulic Hazard Impact breakout session.

Performance Issues—The key performance issues were super/substructure compatibility, strength and service limits, scour, load rating criteria, integrity, and environmental issues. Participants highlighted the importance of maintaining super/substructure compatibility as a key performance issue to prevent distress in either. It was pointed out that both strength and service limits should be considered in performance. The depth of embedment of the foundation must be defined in regards to scour performance. The load rating criteria based on the NBIS guidance must be further explored to better describe performance. Integrity after of the structure after extreme events is an important issue, with ship impact being raised as an example. Environmental issues, in particular corrosion, are also important to address.

Engineering Problem—The key engineering problems identified were load rating capacity in terms of risk-based criteria, the depth to satisfy stability, integrity of components, and corrosion or degradation of components.

Products—The key products identified as needed were guidelines for NDT selection, including cost information and rankings, and best practices for determination of foundation integrity and capacity.

Tools and Technology—Currently available tools and technologies are considered to be adequate and reliable. However, the integration or use of multiple tools to enhance their use should be explored, including risk-based decision making. Guidelines on the use of time and cost effective methods need to be developed. The use of tools from other fields (for example from medical, mining/oil exploration and aerospace industries) that could be utilized for foundation characterization should be explored. Continued and expanded use of finite element and other numerical modeling is encouraged, particularly when combined with field data.

Proposed Test Plan—Discussion on a proposed test plan focused on the possibility of testing decommissioned bridges in which an incentive is provided to the contractor to allow research tests to be conducted prior to removal. It was emphasized that both current and new technologies should be tested. Also discussed was the development of model tests at a Federal or academic facility.

GROUP 2

The following items were highlighted by Group 2 in the Geo/Hazard Impact breakout session.

Develop Guidelines for Evaluating/Characterizing Foundations—The development of guidelines for evaluating and characterizing foundations was deemed very important. The guidelines should include type, geometry, and materials of the foundation, as well as methods for determining the integrity of the foundation and the existing load capacity. Guidelines for reuse of foundations were deemed particularly important.

Develop Performance Indicators for Foundation Elements—In terms of performance indicators for foundation elements, the capacity of the foundation and its remaining service life were considered key performance indicators. Development of indicators quantifying reliability and post-extreme event capacity and integrity were also thought to be important.

Tools—The group felt that enhancement of existing tools through refinement in use and increasing resolution would be a particularly fruitful line of effort. Present numerical tools were considered to be in reasonably good state. New tools for determination of integrity and foundation life cycle analysis are needed.

Scour—There is a need for better prediction of the risk from scour hole development and for the risk placed on a bridge's performance in general. Better delineation of countermeasures to reduce scour risk was also considered an important issue.

SUMMARY

Following the group discussions, the participants reconvened, and each group presented their findings (summarized above) with discussion following. There was agreement that we need performance/reliability indicators and guidelines to evaluate the performance of the foundation. Scour is a key hazard, but other hazards such as earthquakes also need to be considered. A focus should be on improving existing test methods to make them more reliable. It was noted that the transportation departments have developed unique ways to assess foundations.

The group felt that no one tool/instrument/product would answer all questions about foundation and scour issues. In general, the current equipment is regarded as good, but that methodologies and protocols need to be improved. The group felt that numerical codes can be of benefit to the bridge community but that additional development, calibration and verification is needed.

The lack of a load rating requirement for foundations was pointed out. There was discussion of the need to add/develop criteria of when a foundation load rating is required. Further, the means of obtaining this rating needs development work. This discussion raised the issue of risk and there was general agreement that risk needs to be assessed.

A possible test plan was discussed, with details about potential bridges that could be used for the program, bridges that are scheduled to be demolished, or construction of a scaled bridge system under more controlled conditions.

BREAKOUT SESSION II: CHANGES IN SERVICE LOAD AND FOUNDATION REUSE

BRAINSTORMING CHANGES IN SERVICE LOAD AND FOUNDATION REUSE

The second breakout session focused on identifying changes in service load and foundation reuse. The goal of this session was to solicit high priority input for new research and to prioritize listed high priority items. The workshop participants were again divided into two groups and discussed the session topic on the morning of May 1. Following the discussion time, the participants reunited to summarize the group findings.

A list of preliminary topics for discussion at the breakout session was provided to attendees as a starting point for discussion topics. The topics included changes in service loads, foundation reuse, load testing, test plan, numerical modeling, research products and risk-based analysis.

An expanded list of topics is shown below.

Agenda Items for the Changes in Service Loads—Foundation Reuse Breakout Session

1. Changes in Service Loads.
   - Brainstorm performance issues and rank them.
     - Use of heavy loads (military, industrial, mining).
     - TS&W—proposed use of higher truck loads by the trucking industries and changes in truck route.
   - Data needs and gaps
2. Foundation Reuse—Bridge widening, rehab, and replacement.
   - Brainstorm performance issues and rank them.
   - Data needs and gaps.
   - State policies.
   - Technology development.
   - Effect of adding new foundation elements on scour calculations.
   - New Load and Resistance Factor Design (LRFD) requirements.
3. Load Testing.
   - How to load test foundation system of an existing bridge?
   - Load testing of bridges with unknown foundation—No specific guidance. NCHRP recommends doing proof load testing.
4. Test Plan—Proposed load testing and structural analysis using decommissioned bridges.
5. Numerical Modeling—Development of numerical simulations to model the complex soil structure interaction and to calibrate field test results.
6. Research Products.
   - Web portal.
   - Guidance documents.
   - Reports.
7. Risk-Based Analysis.

Participants in Group 1 were as follows:

Khalid Mohamed (FHWA), Chair
Benjamin Oltmann (FHWA)
Frank Jalinoos (FHWA)
Larry Jones (FLDOT)
William Kramer (IDOT)
Jerry Shen (FHWA/GENNEX)
Peter Connors (MassDOT)
Kornel Kerenyi (FHWA)
Hisham Sunna (Ayres Associates)
Lubin Gao (FHWA)

Participants in Group 2 were as follows:

Silas Nichols (FHWA), Chair
Vern Schaefer (Iowa State University)
Khamis Haramy (FHWA)
Jim Cuthbertson (WSDOT)
Mohammed Mulla (NCDOT)
Jennifer Nicks (FHWA)
Dave Henderson (FHWA)
Sayed M. Sayed (GCI, Inc.)
Steven Lottes (TRACC/ANL)

Each group approached the discussion in a different way. Below are summaries of their discussions.

GROUP 1

The following items were highlighted in the Changes in Bridge Loads and Foundation Reuse breakout session.

Changes in Bridge Loads—Changes in bridge loads is a key issue as the trucking industry is proposing higher truck loads, for example, raising weights from 80,000 lb to approximately 97,000 lb, and there are projections in a doubling of truck traffic in the near future.[2] Key issues related to changes in bridge loads include how to use NDT/modeling to determine effects on bridges, including calibration of such efforts; rapid methods of load testing; guidance for unknown and known foundation characterization and evaluation; and the introduction of risk-based methodologies to reduce/optimize time and cost.

[2] Legislation called the Safe and Efficient Transportation Act was proposed by the Coalition for Transportation Productivity (CTP), which would allow States to raise the interstate weight limits of transport trucks from current 80,000 lb to a maximum of 97,000 lb. CTP states that freight traffic in the United States is expected to at least double by 2035.(19)

Foundation Reuse—For foundation reuse, the highest priority was development of methods and guidance for reusing known and unknown foundations. In particular, risk and reliability methods should be explored. Guidance on methods for increasing load capacity of foundations, determining resistance factors for LRFD design, evaluation of Allowable Strength Design designed foundations in an LRFD platform, and NDT field testing were discussed as needed items in this category.

GROUP 2

The following items were highlighted during the Changes in Bridge Loads and Foundation Reuse breakout session.

End Products—States need end products that can help them characterize changes in bridge loads and foundation reuse. Tools should be developed that help determine what NDT methods are recommended for site and foundation characterization, and for capacity determination. Of particular need is the development of specific guidance for the reuse and assessment of remaining service life of foundations.

Research Needs—Specific research needs were identified to include new tools for integrity of buried structures, refined analysis of holistic structures, synthesis of bridge record keeping, identification of information needed to reuse foundations, and maintenance monitoring for load rating and numerical models.

SUMMARY

Following the group discussions, the participants reconvened and each group presented their findings (summarized above), with discussion following. There was considerable discussion on the push from the trucking industry for higher loads on structures. Although the concerns have primarily been on the superstructure side, there are concerns and risks associated with the substructure also. For known foundations, it may be possible to estimate effects of increased loads, but for unknown foundations, there might be great difficulty. The increased loads issue relates directly to a data need, which is to understand how much additional load will be transmitted to the foundations. This could be determined through short-term monitoring efforts that would measure the extra load applied to the foundation from an extra load on the superstructure.

On the foundation reuse, the discussions focused on the need for a guidance document that outlines when a foundation can be reused and the information necessary to make such a determination. The guidance should provide direction on the exploration methods available for known and unknown foundations, particularly NDT methods. Strategies/methods for strengthening known and unknown foundations for reuse would be valuable. There was agreement that performance/reliability indicators are needed for the reuse of foundations. It was emphasized that a holistic measurement approach was desirable.

At the start of the workshop, there was reasonable agreement on the need for development of test sites. Several possibilities were discussed including decommissioned bridges, existing bridges, and test facilities (likely at TFHRC). The physical testing would be conducted in concert with specific and targeted numerical studies and geared towards understanding the load capacity of the substructure and foundation elements. The discussions throughout the workshop appeared to reduce the enthusiasm for development of test facilities; however, the continued and increased use of numerical studies was endorsed by the group.

Two key interactions were discussed that merit mention. Coordination with the FHWA LTBP Program was encouraged to prevent duplication of efforts. A possible venue for discussion of issues is the upcoming 2014 TRB annual meeting and the 2016 ASCE Structural Engineering Institute/Geo-Institute joint meetings. Of particular interest might be the idea of a prediction challenge of response of the superstructure and substructure to various imposed loads.

SUMMARY OF THE FINAL PLENARY SESSION: RECOMMENDATONS

Based on the one and a half days of presentations and discussions, the following summary and recommendations are made:

1. A key issue with unknown foundations is their characterization.
2. There is much good work being done in the States with the reuse of foundations. States have their own procedure; there is no ready means of assessing the present practice.
3. The main issues for foundation reuse are their condition assessment, their load carrying capacity, remaining service life, and how the reuse of foundations interacts with new codes.
4. Research and development on foundation reuse will also benefit unknown foundations.

In support of foundation characterization and reuse, the following specific recommendations are made:

1. Research is needed for load testing of existing foundations and better methodologies for condition assessment.
2. Research is needed for instrumenting new ("smart piles") or existing foundations for on-demand assessment of condition.
3. A synthesis of common practice on foundation reuse should be developed as soon as possible.
4. Guidelines for field evaluation of unknown and known foundations should be developed to include site investigation, destructive and non-destructive testing or monitoring, numerical modeling, and load testing.
5. Guidance for the reuse of foundations is needed that includes consideration of structural, hydraulic and geotechnical issues in a holistic manner.

In closing, FHWA plans to capitalize on the knowledge shared during this workshop to develop a multiyear research plan and a roadmap and initiate a new CBF program. In support of the workshop recommendations, an open workshop and a separate session on foundation reuse are planned at the 2014 TRB annual meeting.

APPENDIX A—WORKSHOP AGENDA

Characterization of Bridge Foundations Workshop
April 30–May1, 2013
FHWA—National Highway Institute (NHI), Virginia Room
1310 N. Court House Road, Suite 300, Arlington, VA 22201

Workshop Program
Tuesday April 30, 2013
8:00 AM – 4:30 PM

Session 1: Introduction and Federal Research Programs - National Perspective
Moderator: Frank Jalinoos (FHWA) 8:00 AM – 10:00 AM

- Call to Order / Introduction, Frank Jalinoos, FHWA
- "Welcome, Objective of Workshop, FHWA Perspective," Louis Triandafilou, Jorge Pagán-Ortiz, FHWA
- "Overview for FHWA's Characterization of Bridge Foundation Program," Frank Jalinoos, FHWA
- "Hydraulics Research and ANL/TRACC Modeling," Kornel Kerenyi, FHWA, Steven Lottes and Cezary Bojanowsky, ANL/TRACC
- "Overview of Past, Current, and Planned Geotechnical Research at TFHRC in the Fields of Unknown Foundations, Foundation Health Monitoring, Serviceability, and Load Testing of Shallow and Deep Foundation," Jennifer Nicks, FHWA
- "FHWA Long Term Bridge Performance Program (LTBP) – Report on the Workshop on Bridge Substructure Issues and Overview of the GeoTech Tools," Vern Schaefer, Iowa State University

10:00 AM – 10:15 AM Break

Session 2: Geo / Hydraulic Hazards and Impacts
Moderator: Phil Yen (FHWA) 10:15 AM – 12:00 PM

- "National Bridge Inspection Program: The Unknown Foundation and Hydraulic Scour Question," Dave Henderson, FHWA
- "Unknown Foundation Investigation Program in North Carolina," Mohammed A. Mulla, North Carolina Department of Transportation
- "FDOT's Approach to Resolve Unknown Foundations," Larry Jones, Florida Department of Transportation (FDOT)
- "Foundation Evaluations for Geo/Hydraulic Hazards and Design Purposes," Jim Cuthbertson, Washington State Department of Transportation
- "Evaluation of Existing Foundations with Non-Destructive Methods," Khamis Haramy, FHWA

12:00 PM – 1:00 PM Lunch

Session 3: Changes in Service Loads and Foundation Reuse
Moderator: Khalid Mohamed (FHWA) 1:00 PM – 2:20 PM

- "Evaluating Foundations for Reuse: Looking Ahead" (20 min), Ben Rivers, FHWA

- "Experiences with Evaluation and Reuse of Bridge Foundations at MassDOT," Peter J. Connors, Massachusetts Department of Transportation (MassDOT)
- "IDOT Past and Present Polices on Determination of Existing Foundation Capacity for Reuse," William M. Kramer, Illinois Department of Transportation (IDOT)
- "Potential of Structural Identification for Characterizing Existing Bridge Foundations," A. Emin Aktan, Drexel University

2:20 PM –2:30 PM Break

- 2:30 – 2:45 PM Breakout Assignments for Breakout Session I – Vern Schaefer, Frank Jalinoos

Breakout Session I: Geo / Hydraulic Hazards and Impacts

2:45 – 4:30 PM

- Group I – Session Chair: Mohammed Mulla (NCDOT)
- Group II – Session Chair: Khamis Haramy (FHWA)

4:30 PM Adjourn

Wednesday, May 1, 2013
8:00 AM – 8:45 AM

- Report Out from the Breakout Session I (Mohammed Mulla, Khamis Haramy)
- Breakout Assignments for Breakout Session II – Vern Schaefer, Frank Jalinoos

Breakout Session II: Changes in Service Loads and Foundation Reuse

8:45 AM – 10:45 AM

- Group I – Session Chair: Ben Rivers (FHWA)
- Group II – Session Chair: Khalid Mohamed (FHWA)

10:45 AM – 11:00 AM Break

Session 4: Panel Discussion (Identification of Gaps and Opportunities for Collaboration)

Moderator: Frank Jalinoos 11:00 AM – 12:00 PM

- Report Out from the Breakout Sessions II (Ben Rivers, Khalid Mohamed)
- Where Do We Go from Here? Path Forward. – Vern Schaefer
- Summary and Wrap-Up

12:00 PM Adjourn

APPENDIX B—WORKSHOP ATTENDEES

The small invitation-only workshop was organized by the FHWA research office and was attended by 25 members of the bridge community. As shown in table 5, 14 members of FHWA staff from the Research, Headquarters, Resource Center and Federal Lands offices joined 5 stakeholders from State transportation departments and 6 members from academia/industry.

Table 5. Conference attendees by organization.

Organization	Unit	Attendee	Total
FHWA	Research—Turner Fairbank Highway Research Center (TFHRC)	Sheila Duwadi Frank Jalinoos Kornel Kerenyi Jennifer Nicks Jerry Shen (Genex/TFHRC) Lou Triandafilou	14
	Headquarters	Lubin Gao Dave Henderson Khalid Mohamed Silas Nichols Phil Yen	
	Resource Center	Ben Rivers	
	Federal Lands	Khamis Haramy Benjamin Oltmann	
State Transportation Departments	Massachusetts	Peter Connors	5
	Washington	Jim Cuthbertson	
	Florida	Larry Jones	
	Illinois	William Kramer	
	North Carolina	Mohammed Mulla	
Academia/ Industry	Drexel University	Emin Aktan, Ivan Bartoli	6
	Iowa State University	Vern Schaefer	
	ANL—TRACC	Steven Lottes	
	Ayres Associates	Hisham Sunna	
	GCI, Inc.	Sayed Sayed	
		Total	25

The intent was to solicit input from a broad spectrum of disciplines and organizations. As indicated in table 6, the cross-discipline workshop included members from the structural, geotechnical and hydraulics disciplines.

Table 6. Conference attendees by discipline.

Discipline	**Attendees**	**Total**
Geotechnical	Connors, Cuthbertson, Haramy, Jones, Kramer, Mohamed, Mulla, Nichols, Nicks, Rivers, Sayed, Schaefer	12
Structural	Aktan, Bartoli, Duwadi, Gao, Jalinoos, Oltmann, Sunna, Triandafilou, Yen	9
Hydraulics	Henderson, Kerenyi, Lottes, Shen	4
	Total	25

APPENDIX C—WHITE PAPER ON THE UNKNOWN FOUNDATION PROBLEM

By: FRANK JALINOOS
Federal Highway Administration, Office of Infrastructure R&D
frank.jalinoos@dot.gov

SUMMARY

Bridges with unknown foundations potentially pose a significant scour safety problem to the bridge owners. Presented herein is a summary of the unknown foundation problem relating to the hydraulics vulnerability for bridge scour, discussion of other engineering risks with this population of bridges, and the new Federal Highway Administration (FHWA) research initiative to address this national problem.

BACKGROUND

Following the catastrophic collapse of the Schoharie Creek Bridge on the New York State Thruway in April 1987, national attention has been focused on the bridge scour problem. Foundation characteristics are needed for accurate scour analysis—which was nonexistent for the Schoharie Creek Bridge. Therefore, as a result of addressing scour vulnerability of bridges, the unknown foundation also became a national priority.

The loss of support from scour damage can result in increased movement and deformations, which can lead to subsequent failure of the entire structure. To determine the susceptibility of a bridge to scour, information on the foundation type and depth is needed, along with the hydraulic conditions at the site, to perform an accurate scour evaluation of each bridge. To mitigate scouring problems, hydraulics engineers consider numerous scour countermeasure designs. The aim is to control channel instability and to mitigate scour at foundations of abutments and piers. Proper scour prediction is essential for safe design of bridges over rivers, streams, and in coastal areas, both on the National Highway System (NHS) and the non-NHS (NNHS) bridges.

As of December 2012, the National Bridge Inventory (NBI) included 607,380 structures (bridges and culverts) with a span greater than 20 ft (6 m).[(1)] Of those structures, 504,893 (83 percent) have the service under the bridge coded as waterway, or a combination that includes a waterway. 36,076 bridges over waterways (riverine and tidal) in the NBI database were identified as having unknown foundation characteristics.

The number of bridges in the NBI database that are coded "U" under Item 113 (for "unknown foundations") have been reduced considerably over the years. In 1996, 104,000 were quoted in the *NCHRP Research Results Digest 213*, in 2001, 89,000 in the FHWA HEC No. 18, in 2005, over 80,000 bridges were quoted at the Denver "Unknown foundation Summit," and in 2007, the NBI database identified 67,002 bridges. (See references 3 and 20–22.) The main reasons for this reduction can be attributed to efforts by State departments of transportation in finding the lost plans, conducting field evaluations, and performing risk-based assessments such as that recommended in NCHRP Document 107 or the recent 2009 FHWA memorandum, as described next.[(10)]

FHWA GUIDANCE

The National Bridge Inspection Standards (NBIS) regulation 23 CFR 650.313 requires that bridge owners identify bridges that are scour critical (coded 0, 1, 2, or 3 in Item 113) and to prepare a Plan of Action (POA) to monitor known and potential deficiencies. Bridges coded "U" for Item 113 represent a unique subset of bridges that were exempted from being evaluated for scour vulnerability due to the lack of a process and guidance that would have allowed owners to determine the necessary foundation characteristics.

On October 23, 2009, the FHWA issued series of memoranda providing technical guidance for conducting scour evaluation of bridges over waterways with unknown foundations.[4] The FHWA provided example guidance for conducting risk-based assessment noting that other methods exist and the guidance is meant to support ongoing efforts and not to supersede them. FHWA also provided guidance on developing a POA for bridges that will remain coded "U" in Item 113.

Using the example provided in the guidance, FHWA recommended grouping bridges into categories corresponding to risk. For those bridges categorized as having the highest risk, it is recommended that owners establish a means for positively identifying the foundation type, location and depth such that a scour evaluation can be conducted. Positive discovery may include field testing, drilling of borings with field testing, or the use of test pits.

Referencing the example, FHWA recommends high-risk bridges that lack as-built plans to undergo positive discovery of foundation characteristics. For moderate risk bridges, FHWA recommends inferring or assuming necessary foundation characteristics. However, if the degree of confidence for inference or assumption is not high enough, the owner can choose between positive discovery of the necessary foundation characteristics or develop and implement an appropriate POA. For low risk bridges, a risk-based inference method is allowed. However, if the degree of confidence for inference or assumption is not high enough to warrant recoding, a POA would need to be developed and implemented by the owner.

PROBLEM SCOPE

The nature of the problem with unknown bridge foundation is complex. Bridges can be supported by shallow (spread footings) or deep foundations. Footings can be square, circular, or rectangular in shape. They may also be pedestal masonry stone footings or massive cofferdam footings. Piles may be present with or without pile caps and may be battered or vertical. Piles can be made of concrete (round, square, or octagonal), steel (H-piles or round pipe sections), or timber. Deep foundations can be pre-cast concrete piles, drilled shafts, and auger-cast concrete piles. The top of footings or pile caps may be buried underneath riprap, backfill mud and/or channel soils.

The NCHRP Project 21-5 report stated that bridges with unknown foundation are considered to lack the following information:[20]

- Elevation of the base of the foundation (e.g., pile tip elevation).
- Type (shallow versus. deep, or a combination thereof).
- Geometry (width, length, and depth), including checking the accuracy of as-built plans.
- Materials (foundation materials, which can include concrete, masonry, stone, steel and/or timber).
- Integrity (foundation condition such as corroded steel, rotted wood, cracked and defective concrete).

In this report, we expand this definition to include other concerns with a bridge foundation—known or unknown—including the following concerns:

- Load bearing capacity.
- Pile Distribution—Target avoidance for foundation rehabilitation or underpinning.
- Remaining service life.

For scour evaluation, the base of the foundation elevation and the foundation type are considered to be the two most critical items. For other types of evaluations, foundation integrity and bearing capacity can be of prime importance as discussed in the next section.

ENGINEERING RISK WITH UNKNOWN FOUNDATION

As discussed, so far the unknown foundation has been associated only with the population of existing bridges over waterways that cannot be evaluated against the hydraulic vulnerability related to scour. However, many bridges built over land are also expected to have unknown foundations and there are other engineering risks beyond scour that should be evaluated. Many practitioners report that substantial projects involving unknown foundations now involve more than just scour studies and are beginning to focus on structural and geotechnical assessments.

The risk with unknown foundation can be divided into three categories, as described below:

1. **Geo/Hydraulic Hazards.**
    - Hydraulics/Seismic Vulnerability—Scour evaluation, thus far the primary driver.
    - Post-Hazard (Extreme Events) Assessment.
        - Post-Seismic—Post-earthquake assessment of bridges with unknown foundation is a concern as foundation depth and integrity is very important for bridges with visible indication of superstructure damage or movement.
        - Post-Flooding /Hurricane Assessment—Evaluate foundation events after flooding and high water events that can cause large lateral forces.
2. **Changes in Service-Loads**—Currently, there is a lack of guidance for load rating of bridges with unknown foundations. Engineering risk of unknown foundations involving changes in service loads includes:
    - Foundation Reuse—Reuse of foundations for bridge replacement, widening, or rehabilitation projects.
    - Truck Size and Weight (TS&W)—Proposed use of higher truck loads by the trucking industries and changes in truck routes.
    - Heavy Industrial/Mining/Military Loads—Use of the highway infrastructure.
3. **Foundation Condition Assessment**—Age-related decay such as visible degradation or rotted and broken timber piles.

More detail is provided in the next section regarding some of the engineering concerns listed above.

SCOUR VULNERABILITY (PRINCIPAL DRIVER)

As previously discussed, the unknown foundation is considered principally a scour vulnerability issue. Therefore, the term unknown foundation has been traditionally associated only with the population of existing bridges over waterways that cannot be evaluated against the hydraulic hazards related to scour.

At the present, the NBI database does not track bridges built over land with unknown foundations, as this is considered as low risk issue. However, many of these bridges built over land are expected to have unknown foundations and many others lack complete documentation of their as-constructed details (e.g., material properties, continuity and reinforcing details of structural elements) that are needed for engineering analysis, such as load rating and other considerations, as described next.

POST-SEISMIC (EXTREME-EVENT) ASSESSMENT

A survey of available statistics reveals that more than one-third of U.S. highway bridges may be vulnerable to damage and/or failure due to earthquakes.(23) Some of these structures are very old and typically possess non-ductile structural details. Many have either unknown foundations or incorporate lightly reinforced concrete substructures. Bridge foundations, columns, and pier caps are critical when addressing seismic loading because earthquake forces are generated from ground up. Preventing bridge collapse is often accomplished by averting unseating of the superstructure or shear failure of the columns. Foundation integrity is an issue when an earthquake triggers geotechnical hazard such as liquefaction and settlement, slope failure, surface fault rupture, and flooding, which can in damage to the foundations. Soil liquefaction—a loss of shear strength in loose, fully saturated cohesionless (sandy) soil—can cause a loss of bearing capacity resulting in foundation failure, settlement, or tilting of abutments and piers. Examples of foundation failure are shear failure of the pile cap, anchorage failure, pile pullout, and pile shear failure. Therefore, the knowledge of foundation type, geometry, and material are of concern to seismic engineers.

Post-earthquake integrity assessment of substructure elements, such as column, abutment and bearings is a concern to seismic engineers as well as reduced load carrying capacity of the foundation elements. Bridges with unknown foundation have other critical information missing, such as reinforcement detail and material properties.

Post-flooding/hurricane force of bridges with unknown foundation is a concern to hydraulics engineers as foundation depth and integrity is very important for bridges with visible indication of superstructure damage or movement.

Foundation characteristics are also needed to assess bridge vulnerabilities to other extreme event such as ship/barge/truck impact, as well as intentional or unintentional blast events.

CHANGES IN SERVICE-LOADS

As described below, several overload hazard events can result in catastrophic failure or collapse of bridges. In recent years, increased legal load limits on the Nation’s highway have resulted in questions concerning the load carrying capacity of bridges, especially older bridges. Bridge and maintenance engineers are increasingly faced with decisions on accommodating the significantly increased truck weights on their structures. Bridges with unknown foundations carry higher risk as these have unknown/uncertain structural (e.g., reinforcement) details and material properties vitally needed for objective structural evaluation (load rating) determinations.

The overall structural appraisal rating for a bridge is determined based primarily on the safe load carrying capacity. Currently, there is a lack of guidance for load rating of bridges with unknown foundations. The AASHTO "Manual for Condition Evaluation and Load and Resistance Factor Rating (LRFR) of Highway Bridges" states that "bridges which cannot be load rated by computations because of insufficient information on their internal details and configuration need proof testing to determine a realistic live-load capacity. Bridges that are difficult to model analytically because of uncertainties associated with their construction and the effectiveness of repairs are also potential candidates and beneficiaries of proof load testing."[(24)] Neither the AASHTO Manual, nor NCHRP reports—such as NCHRP Digest, "Manual for Bridge Rating through Load Testing"—offer any guidance for performing safe proof-load testing of a bridge with unknown characteristics.[(25)]

Concerns under this category include: (1) increases in service loads such as structural upgrade projects, such as bridge widening or lane increases, (2) proposed use of higher truck loads by the trucking industries and changes in truck routes, and (3) use of the highway infrastructure by heavy mining/military equipment.

Bridge Rehabilitation

Understanding the type and condition of existing foundation are essential for decisions associated with bridge rehabilitation or widening. Without a complete foundation evaluation, it is not possible to assure a rehabilitated bridge will perform adequately for any design life.

Use of Heavy Truck Loads

In the United States, half the shipped freight tonnage moves more than 100 mi (161 km), and 18 percent moves more than 500 mi (805 km).[(26)] Vehicles on Interstate highways must conform to the Federal Bridge Formula (FBF), which is designed to protect bridges from catastrophic overloads. FBF restricts vehicle's axle groupings and vehicle weight to 80,000 lb. The proposals for TS&W liberalization are requesting a switch from the dominant heavy truck—5-axle tractor semitrailer—to trucks that have higher payloads and additional axles. These proposals are requesting the elimination of the FBF's 80,000 lb cap on gross vehicle weight with minimal or no increase in the gross weight of a five-axle tractor semitrailer; but allowing vehicles with additional axles to operate substantially above 80,000 lb. For typical short-twin trailers, for example, the FBF allows 99,500 lb with 7 axles, 104,500 lb with 8 axles, and 110,000 lb with 9 axles.

In evaluating the effects of changes in TS&W limits on bridges, both overstress and fatigue should be considered. Overstress creates the possibility of severe damage and possible collapse caused by a single extreme loading event. Fatigue produces the cumulative damage caused by thousands to millions of load passages. For overstress, as the heavy truck traffic increases, there is a higher likelihood of a "critical" load event in which several heavy vehicles are on the bridge simultaneously.[27]

Use of Heavy Mining and Military Equipment

In the recent years, the U.S. Department of Defense has undergone mission changes that have involved relocating more than 123,000 military and civilian personnel.[28] One of the major initiatives includes the Base Realignment and Closure Act (BRAC) of 2005, which involved base realignment and closure. When personnel from closed bases relocate or commute to another base, the increased defense traffic increases burden on the State and local infrastructure.

The same consideration applies to the use of heavy mining equipment of the State and local infrastructure. As a recent example, in March 2003, the West Virginia legislature passed Senate Bill 583, which established the Coal Resource Transportation System (CRTS) in fifteen southern West Virginia counties.[29] On these designated routes, coal haulers may purchase a permit that will allow for a Gross Vehicle Weight (GVW) of up to120,000 lb (54,430 kg) which are much heavier than regular legal truck loads. The CRTS includes over 600 short to medium span bridge structures, with about 100 posted for live loads less than the allowable CRTS truck loads. Many of the typical reinforced concrete (RC) bridges structures on the CRTS were constructed in the 1920s. Several CRTS bridges have unknown foundation characteristics and many more lack critical information pertaining to material properties, continuity and reinforcing details of the superstructure and substructures, and soil properties critical for proper load testing.

An FHWA-sponsored research team initially selected several West Virginia bridges and conducted detailed inspection and material sampling followed by diagnostic level load tests. However, due to the extremely small levels of response captured, proof-level load tests had to be conducted in order to calibrate the analytical models and forecast capacity. Given the high expense associated with this type of bridge investigation involving unknown foundations (around $100,000 per bridge), the researchers recommended the development of rapid load testing systems.[30]

Bridge Replacement Involving Foundation Reuse

In recent years, the reuse of bridge foundation is being considered for a large number of bridge replacement projects. Foundation characteristics are needed to assess vulnerabilities to site conditions such as settlement or other types of movements. The ASCE Geo-Institute has held several panel discussions and technical session on the topic of foundation reuse.
(See references 31–34.)

In urban settings, the concept of foundation reuse for buildings has been relatively well established.[35,36,37] In October 2006, the Reuse of Foundations for Urban Sites (RuFUS) research project published the best practice handbook, written by a cross-European team of foundation and structural engineers.[37] The handbook provides a sound understanding of the background to foundation reuse and provides advice on investigation, design, and construction issues. One of the big problems foundation engineers face when looking to reuse foundations is that as-built construction records are typically very poor.

THE NEED FOR A FEDERAL RESEARCH PROGRAM

The unknown foundations issue remains one of the most persistent problems facing the bridge engineering community. NCHRP Project 21-5 devoted considerable effort to developing new test methods to address this issue, and some good progress was reported.[20,38] However, there are still concerns on the reliability of the available technologies and associated costs, especially when they require the drilling of a borehole adjacent to the foundation.

In November 2005, FHWA organized the "Unknown Foundation Summit" at Denver, CO, to brainstorm this issue among key stakeholders.[3] After the Summit, FHWA created four internal teams to lead the following initiatives:

1. Policy (Jorge E. Pagán-Ortiz, Lead).
2. Technical Guidance (Ben Rivers, Lead).
3. Research and Development (R&D) (Frank Jalinoos, Lead).
4. Training (Jerry DiMaggio, Lead).

Later on in 2009, FHWA formed a new FHWA Unknown Foundation (UF) team, which resulted in the 2009 FHWA memorandum by the FHWA Bridge Office for reducing the bridges over waterways with unknown foundation population. However, no new effort has been devoted to the R&D needs and specifically research on "positive discovery" methods. (As of December 2012, 36,076 bridges in the NBI database are still identified as having unknown foundation.)[2]

More recently, SHRP 2 devised a research plan for developing technologies to deal with the most urgent requirements for highway facilities. The findings of this project identified unknown foundations as one of the main issues facing the geotechnical community and discussed a need for a national validation test site for unknown foundation research.[39] SHRP 2 estimated $1.5 million is needed for this tier 1 "unfulfilled need" research.[39]

Likewise, the LTBP has identified unknown foundation as a top tier bridge performance priority issue as a result of their March 2010 geotechnical/hydraulic workshop.[8] The program also identified unknown foundation in their assessment for data needs and data gaps related to the geotechnical performance issues.

The European RuFUS project partially funded a validation site for the German Federal Institute for Materials Research and Testing in support of foundation integrity studies.[40,41] This site is located at Horstwalde, 31 mi (50 km) south of Berlin. The test site includes ten small concrete drilled shafts with 24 inch (62 cm) diameter and lengths between 29.5 ft (9 m) and 39.4 ft (12 m) some containing engineered defects. The site consists mainly of sandy soil and the groundwater depth is about 13 ft (4 m). More recently, a pile secant wall was constructed along with a series of boreholes for subsoil investigations.

The U.S. geotechnical field has also successfully used the concept of building designated experimental test sites for the research community. In 1987, the FHWA's Geotechnical Research Program teamed up with the National Science Foundation (NSF) to establish a system of National Geotechnical Experimentation Sites (NGES) devoted to geotechnical research.[42]

Five sites were selected as follows:

1. Treasure Island Naval Station at San Francisco Bay, CA.
2. Texas A&M University at College Station, TX.
3. University of Massachusetts at Amherst, MA.
4. Northwestern University at Evanston, IL.
5. University of Houston at Houston, TX.

These sites are still being used for ongoing research by the geotechnical community. However, there is no experimental test site solely devoted to unknown foundation characteristics.

RECENT FHWA RESEARCH INITIATIVES

In 2013, FHWA proposed a new research program to address the unknown foundation problem. The objective of this research is to develop and/or evaluate new and existing methodologies for characterizing existing bridge foundations.

Initially, a 14-member task force was formed comprised of FHWA and State transportation department stakeholders. The members of this task force met during the January 2013 TRB annual meeting to brainstorm on the steps needed to move forward with a multi-year strategic plan for characterizing bridge foundations. The consensus was to broaden the scope of research from "unknown foundation" to "characterization of bridge foundations" to include multi-hazard concerns. It was also decided to move forward with a workshop to define the research data needs and gaps.

The report herein presents an overview of the "Characterization of Bridge Foundations Workshop" held in Arlington, VA, from April 30 to May 1, 2013. The cross-discipline workshop involved key staff from the FHWA hydraulics, geotechnical and structural disciplines brainstorming with stakeholders. The participants recommended a broad scope of research on foundation characterization with emphasis on foundation reuse, which encompasses all other risks relating to bridge foundations, known or unknown.

ACKNOWLDEGEMENTS

The authors like to acknowledge substantial assistance provided by the members of the Characterization of Bridge Foundation Task Force towards the oversight and organization of the workshop. The members of taskforce included the following:

- Mr. Matt Demarco (FHWA, Central Federal Lands Highway Division)
- Ms. Sheila Duwadi (FHWA, Office of Infrastructure R&D)
- Mr. Khamis Haramy (FHWA, Central Federal Lands Highway Division)
- Mr. Dave Henderson (FHWA, Office of Bridge Technology)
- Mr. Scott Hogan (FHWA, Resource Center)
- Mr. Larry Jones (FDOT)
- Dr. Kornel Kerenyi (FHWA, Office of Infrastructure R&D)
- Mr. Khalid Mohamed (FHWA, Office of Bridge Technology)
- Mr. Mohammad Mulla (NCDOT)
- Dr. Jennifer Nicks (FHWA, Office of Infrastructure R&D)
- Mr. Ben Rivers (FHWA, Resource Center)
- Mr. Roger Surdahl (FHWA, Central Federal Lands Highway Division)
- Dr. Phil Yen (FHWA, Office of Bridge Technology).

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