Protocols for the Assessment and Repair of Bridge Foundations

Course No: S08-006
Credit: 8 PDH

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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	■
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 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
■	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)

LIST OF ABBREVIATIONS AND SYMBOLS

ADOT	Arizona Department of Transportation
CALTRANS	California Department of Transportation
CCFRPM	Centrifugally cast, fiberglass-reinforced, polymer mortar
CPT	Cone Penetration Testing
DelDOT	Delaware Department of Transportation
FHWA	Federal Highway Administration
FDOT	Florida Department of Transportation
GPS	Global Positioning System
HASP	Health & Safety Plan
INDOT	Indiana Department of Transportation
L/D	Length to diameter ratio
LiDAR	Light Detection and Ranging
MDOT	Michigan Department of Transportation
MnDOT	Minnesota Department of Transportation
NYDOT	New York State Department of Transportation
NDT	Non-destructive testing
NCDOT	North Carolina Department of Transportation
ODOT	Ohio Department of Transportation
PennDOT	Pennsylvania Department of Transportation
CPTu	Piezo-cone Penetration Testing
SCDOT	South Carolina Department of Transportation
THEA	Tampa Hillsboro (Toll) Expressway Authority
VDOT	Virginia Department of Transportation
WisDOT	Wisconsin Department of Transportation

1. INTRODUCTION

1.1. Background

1.1.1. Project Need

In August 2015, the bridge carrying I-65 northbound over Wildcat Creek between Indianapolis and Chicago experienced nine inches of settlement at one pier location over a period of a few days as a result of piping sand when adjacent pile driving penetrated an artesian aquifer. This movement resulted in an emergency closure of the northbound bridge that lasted one month. In June 2014, the bridge carrying I-495 over the Christiana River in Wilmington, Delaware experienced major lateral movement of four piers as a result of increased lateral pressure caused by a stockpile of soil adjacent to the bridge. This movement resulted in an emergency closure of the bridge that lasted two months on the southbound side and nearly three months on the northbound side. In September 2013, the bridge carrying I-43 over the Fox River in Green Bay, Wisconsin experienced a sudden two feet of settlement at one pier location as a result of pile corrosion. This movement resulted in an emergency closure of the bridge that lasted three months. These three recent incidents involving foundation movement and emergency bridge closures have highlighted the need for the development of protocols and best practices to address emergency conditions arising from unexpected foundation movements. In all three cases, the bridges were required to be closed to traffic until the cause of the movement was identified and assessed with regard to the safety and capacity of the bridge and until repairs were implemented. These incidents resulted in disruption to traffic on heavily traveled Interstate highways with consequent inconvenience to motorists and commerce. Developing best practices to respond to incidents of this type will help lessen the impact of the incident. This report provides best practices for responding to emergency conditions of foundation movement that result in the need to close bridges until repairs can be made.

1.1.2. Failure Definition

The word "failure" as used herein includes foundation movements and/or corrosion beyond the design norms for the structure that result in the need to close a bridge or portion thereof for any period of time. The movements and/or corrosion may or may not cause the bridge to be unsafe, but are considered significant enough to close the bridge. The catastrophic failure or collapse of a main load carrying member of the bridge is not included in this definition. A catastrophic failure would result in the need to replace the entire bridge or at least the failed portion. This report focuses on restoring the load carrying capacity of the failed foundation so that the bridge can be put back into service.

1.2. Purpose

1.2.1. General

The purpose of this document is to develop best practices for emergency repairs to bridges that have experienced events resulting in bridge foundation failures as defined above. The protocols emphasize safely returning the bridge to service as quickly as possible. The protocols that were developed are based upon the experience of transportation agencies with similar type events.

Information regarding these events was acquired through interviews and review of published accounts of emergency response to bridge foundation failures. Response techniques and lessons learned are documented relative to widely applicable repair protocols in order to assist local jurisdictions in the response to bridge foundation failures with the intent to return the bridge to service as quickly as possible.

1.2.2. Focus

Protocols presented herein are intended to be used to design and implement the foundation remediation necessary to bring the bridge back into service as quickly as possible. The protocols focus on foundation failures that do not result in a catastrophic collapse of any portion of the bridge.

1.2.3. Exclusions

- *Superstructure:* The protocols presented in this report assume that the superstructure, although possibly in need of additional repair or remediation, will be put back into service after the foundation remediation has been completed.

- *Slopes:* Slope failures are also causes of disruption and safety concerns, but are not included except to the extent that they can be contributing factors to bridge foundation failures.

- *Forensic Investigation:* Consistent with a focus upon returning the bridge to service as quickly as possible, a study of the mechanisms of failure in support of claims and/or litigation is not included except to the degree needed for design of remedial foundation elements. The root cause of the failure should be determined so that the repair will not be subject to the same conditions that caused the original failure.

- *Compromised Foundations:* Compromised bridge foundations that have not experienced movement associated with failure, such as scour exposure, are not included, unless the bridge was closed to traffic on an interstate or primary system highway as a result of such condition.

- *Operations:* Maintenance of traffic, development of detours, road closures, and communication with the traveling public, government officials, news agencies and other outreach are not specifically included in the best practices.

2. LITERATURE REVIEW

2.1. Information Sources and Approach

Publicly available sources from conference proceedings, presentations, technical journals, newspapers, and industry magazines were researched to identify relevant case histories that included the following general information.

- Cause or causes of failure
- Extent of damage to substructure and superstructure
- Foundation repair solutions implemented
- Concept plans for emergency repairs
- Lessons learned

For each identified case history, the available sources were reviewed, synthesized by failure type, and summarized.

2.2. Literature Review

2.2.1. General Trends

Nine case histories of bridge foundation failures or partial failures were discovered in the literature review. Causes of foundation damage relate to a combination of factors including the original bridge design and construction, subsurface conditions unique to the mode of failure, and nearby construction or external load influence that precipitated a failure. Among the eleven case histories, the causes of failure included:

- Corrosive soil conditions,
- Downdrag effects due to highly compressible soils beneath the approach embankment,
- Lateral squeeze effects due to stockpiled soil placed adjacent to the bridge foundation,
- Loss of lateral support due to scour effects,
- Subsidence induced by karst geology and/or insufficient pile embedment,
- Densification settlement due to adjacent construction,
- Artesian conditions.

Although not specific to the case histories included in the literature review, extreme weather events or geohazards that result in sudden bridge foundation failures, such as hurricanes or earthquakes, are likely to impose damage on the superstructure and are discussed in more detail within Chapter 3.

The most common repair methods, used in 8 of the 9 reviewed cases, involved transferring the existing bridge foundation loads to new drilled shafts or micropiles. The new foundations were typically designed to bear on or within a deeper, more competent bearing stratum than the existing foundations, due to either insufficient resistance within the original bearing layer, or the need for higher resistance to replace the existing foundations with fewer or smaller foundation elements.

Post-tensioned foundation caps were typically constructed to transfer column loads to the new foundations. At locations where existing bridge footings could be reused, micropiles were installed through the footings. Larger foundation elements (i.e., drilled shafts, or H-piles) were installed by cutting through the existing bridge deck. This is the repair technique employed for both the Wilmington, DE I-495 Bridge and the Route 17 overpass in Chesapeake, VA.

2.2.2. Case History Findings

Brief descriptions of failure type and repair methods employed are included in Table 2-1for each of the nine case histories. Detailed summaries are included in Appendix A.

Table 2-1: Summary of Bridge Foundation Failure and Repair Methods

Failure Mechanism	Bridge Location (Year of Failure)	General Description of Failure	Foundation Repair Methods
Corrosion	I-43 Leo Frigo Memorial Bridge, Green Bay, WI (2013)	Corrosion of piles from industrial by-product fill. Sudden 2-foot settlement of one pier.	Loads transferred to new drilled shafts
Lateral Squeeze	I-495 Bridge, Wilmington, DE (2014)	Soil stockpile placed adjacent to bridge. Lateral squeeze on piles resulted in tilting of bridge piers.	Stockpile material removed, structure loads transferred to new drilled shafts
Adjacent Construction (Artesian Induced Soil Migration)	I-65 Bridge, Lafayette, IN (2015)	Construction of replacement bridge penetrated artesian sand layer causing soil loss. Existing bridge settled 9 inches.	Loads transferred to new micropiles
Inadequate Resistance (Karst)	Lee Roy Selmon Expressway, Tampa, FL (2004)	Insufficient bearing resistance on highly weathered rock in karst setting. Bridge pier settled 11 feet during construction, followed by other piers over the next few months.	Affected pier foundations retrofitted with new drilled shafts or micropiles
Adjacent Construction (Vibrations)	Flagler Memorial Bridge, Palm Beach, FL (2012)	Vibratory hammer used to install drilled shaft casings for an adjacent replacement bridge. Original bridge settled 2-inches likely due to densification of sand underlying the [thin rock] bearing layer for timber piles during construction of adjacent new bridge.	Loads transferred to new micropiles. Subsequently, bridge closed for duration of drilled shaft installation for the new bridge.
Deficient Pile Bearing	Birmingham Bridge, Pittsburgh, PA (2008)	Bridge settled 8 inches due to steel rocker bearing failure. This led to further investigation which revealed that piles were not driven to design elevations and required retrofitting.	Loads transferred to new micropiles
Corrosion	I-35 Bridge, Duluth, MN (2013)	Steel piles damaged from corrosion in low-drainage, high-chloride environment.	Concrete collars placed around damaged piles
Down Drag (Embankment Settlement)	Route 17 Overpass, Chesapeake, VA (2003)	Abutments were constructed before completion of primary settlement. Continuing movement failed the pile connections in tension.	Loads transferred to new steel pipe piles
Adjacent Construction (Artesian Induced Soil Migration)	I-94 over Riverside Drive, Battle Creek, MI (2009)	Construction of replacement bridge penetrated artesian sand layer. Existing bridge on footings settled ±12 inches.	Emergency micropile retrofit

3. INTERVIEWS

3.1. Purpose

The primary purpose of conducting interviews was to gather information from states that had experienced emergency bridge closures due to foundation failures. State representatives were asked about the repair techniques as well as the administrative processes that were utilized to initially close and then reopen the closed bridge. Also discussed during the interviews were major obstacles to the implementation of the repairs, such as procuring engineering and contracting services, public involvement, and availability of materials or equipment. Interviews were focused on repair techniques, lessons learned, protocols, lines of communication, contracting, and design in the overall process of returning the bridge to service without consideration of future claim resolution or litigation. With the knowledge that many failures also involve litigation, all of the interview summaries presented herein represent a general synthesis of conversations with one or more persons familiar with specific failure events and should not be considered direct quotes representing the official position of specific transportation agencies.

3.2. Interviewees and Relevant Projects

State transportation agencies were contacted by phone based upon known recent bridge failures and/or so as to incorporate a variety of geologic settings, the potential for different external environmental factors, and differences in design and construction methods for bridges associated with different geographic regions of the country. Participating states are shown Figure 3-1.

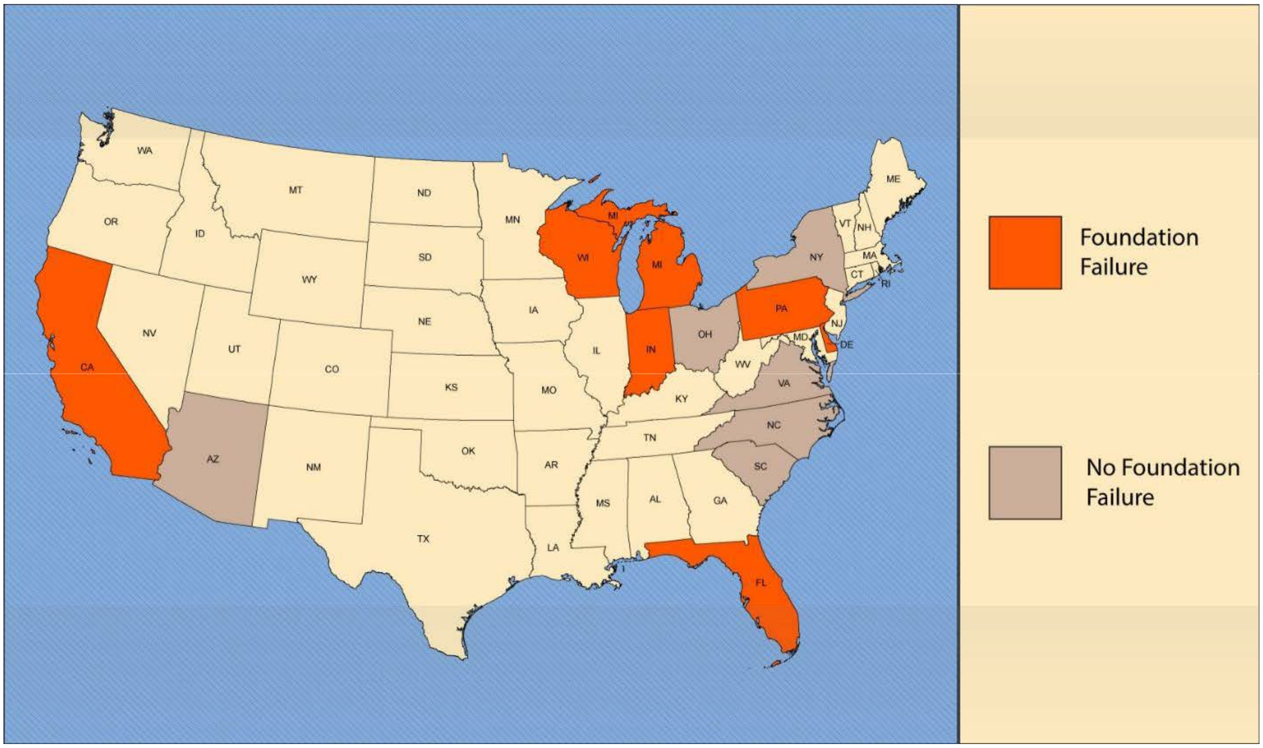


Figure 3-1: Participating States

3.2.1. Arizona (ADOT)

ADOT has not experienced any foundation failures that meet the criteria for this study, as defined in Section 1.1.2. Typical practice and experience in Arizona are as follows:

- ADOT has in-place an expedited process for procuring design and construction for emergencies.
- In-state bridge foundation failures have typically been scour related, exacerbated by piles that were installed short of the depths required for protection against scour.
- Failures of this type have not occurred since the mid-1980’s, but at that time, the affected bridges were entirely washed away leaving no option for restoration of the superstructure to normal service.
- Other events have included erosion related abutment movements caused by undetected artesian conditions. Detection of movement was revealed through the normal inspection process, but did not involve roadway closure.

3.2.2. California (CALTRANS)

California has experienced several emergency response situations for bridge foundation failures due to scour, earthquakes, and long-term settlement. Examples of each are briefly described below:

- I-10 Tex Wash Twin Bridges over a typically dry riverbed near Desert Center, CA: The eastbound bridge collapsed and the westbound bridge was undermined as the result of heavy rain and associated flooding in the typically dry riverbed. The cause of the collapse and undermining was scour. Caltrans' Structures Group designed a replacement for the collapsed eastbound bridge and the Structures Maintenance & Investigation Group designed a retrofit for the undermined westbound bridge, using large diameter drilled shafts for support of the abutments and bent.

- I-5 Bridge over San Mateo Creek at the north boundary of Camp Pendleton, CA: Bridge inspections revealed that the bridge foundations had been undermined by scour. The repair involved underpinning of tie-in structure with 30" diameter drilled shafts designed as columns without lateral support from the surrounding soil. The drilled shafts were designed as columns to a 23-foot scour depth as revealed by the presence of asphalt debris (8-feet deeper than the scour depth of 15-feet that was used in the original design). Drawings were developed and delivered to the contractor who mobilized three drilled shaft rigs to the site one day after receipt of the drawings. An order from the director of Caltrans facilitated the quick, emergency response to the project. Work in the stream was permitted for a 24 hour period.

- Hwy 1/Hwy 156 interchange in Castroville, CA (Long-Term Settlement) – One abutment settled 1.8 feet over a period of 15 years. The bent adjacent to the abutment (Bent 2) shortened, but Caltrans did not know the total settlement until it was underpinned. Underpinning consisted of all new pile foundations which were 90 feet long with an innovative splice at 45 feet, which was required to allow underpinning piles to be installed through the existing bridge deck. Portions of the bridge deck were removed to provide paths for each pile installation. Caltrans used a new diaphragm and jacked the bridge to install new bearing pads to correct for the settlement.

- I-5/Hwy 14 Interchange in Santa Clarita, CA (Northridge Earthquake) – Emergency response involved relocation of twin 30" gas lines and moving an estimated one million cubic yards of material to fill a canyon in 1.5 days and then re-excavating it a day later. Innovative contracting and intergovernmental cooperation were cited as contributing to early completion and success of the 80-foot high Gavin Canyon Bridges. Emergency replacement bridges were almost entirely federally funded. Incentive payments ($150,000/day up to 30-days for early completion) and penalty clauses were built into the contract. Also cited was the effectiveness of combining skilled engineers with a well-qualified contractor.

Fundamental preparation measures for emergencies within the Caltrans system are as follows:

- As-built plans and annual bridge inspection records for all structures are maintained within the Bridge Inspection Records Information System (BIRIS).

- Archives of geotechnical information for all 12 districts are maintained electronically, including boring logs, geophysical data, laboratory test results, and geotechnical reports, which can be located via geographic information system (GIS) databases.

- A listing of pre-approved contractors with a proven record of performance is maintained by headquarters.

The chain of command in response to failures is initiated up notification from the public or Caltrans Maintenance office of a problem, which will typically pass through the District Office first for immediate attention. A Director's Order issued on the Governor's declaration of a disaster allows the process of contracting to proceed on force account from the pre-selected contractor's list, or similarly on a design-build delivery mode without adhering to normal permitting and procurement processes.

Federal funding for major earthquake damage needs to be expended within the first six (6) months after the earthquake. For the Loma Prieta Earthquake the work was done within the six-month time frame. Incentives of $80,000 to $90,000 per day have been built into contracts to encourage early completion of critical infrastructure restoration.

3.2.3. Delaware (DelDOT)

DelDOT officials were aware of only one major incident in recent history, the tilting of the pier on the I-495 Bridge in Wilmington, meeting the definition of failure, as defined in Section 1.1.2. This project is included amongst the case histories listed in Chapter 2. Some of the lessons learned from that major emergency were as follows:

Maintain a system to effectively transfer incoming information to the proper department: The reported observations of passing motorists can provide invaluable lead time on a developing emergency condition. In this case, failure was in-progress gradually over the course of about 6 months. A driver notified DelDOT that something did not look right in April 2014, but that message was not communicated to the Bridge Department. A DelDOT inspector was dispatched to the site over a month later based upon notification from an independent engineering firm conducting an inspection on an oil pipeline that had experienced movement, by which time the bridge pier had rotated 2 feet out of position and the piles had buckled.

Maintain availability to resources with proven emergency response experience: DelDOT was able to access a proven engineering firm through an open-end contract to immediately begin the process of assessing options for stabilizing the bridge foundation. Two drilling contractors were added to the team in order to be able to conduct round-the-clock subsurface investigations during a 2-week period. Expertise was also brought to bear from FHWA and the University of Delaware.

Maintain protocols to quickly declare a state of emergency: The immediate response involved all departments – bridge, geotechnical, construction, environmental, hazardous materials, and traffic. Protocols were in place to contact the Governor's office for an emergency declaration. The Secretary's office held a press conference on the first day following the declaration and DelDOT set up a website to provide updates to the public. DelDOT does not have on-call contracts with contractors, except maintenance contractors, so the emergency declaration allowed DelDOT to hire an experienced contractor on a sole-source selection. This enabled the contractor to collaborate with the response team in the plan development. Work was performed on a time and materials (force account) basis, which was deemed appropriated to the situation and worked well.

Maintain flexibility to change methods: After consideration of options, which included a complete replacement of the bridge, the repair that was implemented involved installation of drilled shafts to rock (approximately 160 feet deep) and jacking of the bridge superstructure. The methods took into consideration not only the low overhead clearance, but also material availability from regional construction projects underway that could be requisitioned to shorten the lead time associated with ordering materials. Materials were acquired from the NYSDOT Tappan Zee Bridge Project, which already had fabricated steel casing and reinforcing steel cages available for 4-foot diameter drilled shafts. Initially, installation of casing was being performed by the oscillation method due to concern about vibrations. The oscillation method proved to be time consuming. The contractor changed to the vibratory installation and monitored vibrations. Vibrations were measured to be within tolerable limits. Concern over potential ground movements resulting from the removal of the soil stockpile that caused the foundation problem lead to monitoring of ground movements as the stockpile was removed. Monitoring revealed that removal of the stockpile did not result in detrimental ground movements.

3.2.4. Florida (FDOT)

Flagler Memorial Bridge in the FDOT system and Lee Roy Selmon Expressway, owned by the Tampa Hillsboro Expressway Authority, are the most notable foundation failures in recent history meeting the definition of failure, as defined in Section 1.1.2. Both of these foundation failures are included among the case histories in Chapter 2.

FDOT has established emergency response teams through the District Structure Maintenance Offices, which take the lead on all bridge emergencies.

3.2.5. Indiana (INDOT)

I-65 over Wildcat Creek, which failed in August 2015, is the most prominent in-state foundation failure in recent history that meets the definition of failure for this study, as defined in Section 1.1.2. The project is detailed in the case histories in Chapter 2. The failure is a unique case due to the occurrence during execution of a design-build (bridge widening) contract. The bridge was being widened at the time of the incident. The existing bridge experienced dislocation of bearings at a pier and settlement and rotation of one of the piers. Some of the lessons learned were associated with preventative measures specific to construction adjacent to an existing bridge supported on spread footings where artesian conditions in sandy soils are present. For instance, due to the higher risk of uplift and/or piping sand, extra care in proximity to existing bridge foundations should include monitoring of bridge foundation elements in association with pre-determined alert level and action level thresholds relative to temporary excavation and pile driving. Similar to other emergencies, the conditions that led to failure developed gradually, in this case during the course of construction, and clues were missed, such as substantial relaxation of the capacity of the newly driven piles between initial driving and restrike. There were no inspections, instrumentation or monitoring of the existing bridge during the early stages of bridge widening construction, therefore the magnitude of the movement was not noticed until the bearings on the existing bridge fell out following pile driving. Monitoring would have provided irrefutable advanced notice of a developing emergency prior to the visual evidence that an existing pier had settled and rotated several inches. Some of the lessons learned from the emergency closure were as follows:

<u>Establish immediate coordination with F</u>HWA: The FHWA's geotechnical engineer was contacted early in the process, was closely involved in the evaluation and selection of repair alternatives, and the execution of the repairs. FHWA's representative contributed knowledge of similar past failures in Michigan, and shared perspectives on the need for reliable structural underpinning approaches. Federal involvement increased the oversight effort, i.e., the number of people involved with reviews, however, INDOT indicated they would have utilized FHWA for technical reviews anyway.

<u>Resist pressure to reopen prematurely:</u> Following the August 4 closure to reset the bridge bearings that had fallen out, the bridge was reopened to service on August 5 in order to alleviate the traffic disruption. However, difficulties were experienced while jacking the bridge for reinstallation of the bearings that lead to questions as to whether the operation was actually jacking the foundation downward. Monitoring revealed continuing settlement, i.e., the foundation was being pushed downward, so the bridge was closed again on August 7. A protocol for reopening the bridge to service should have been developed based upon evidence that the cause of the movement had been corrected.

<u>Conduct investigations and repairs while pursuing all available funding options:</u> Initially INDOT assumed no federal funding would be available, but later determined that there was some federal money in the project. FHWA involvement was to be expected on the interstate system, but does entail additional documentation requirements for the Contractor.

<u>Declaration of a state of emergency and contracting</u>: A state of emergency was not declared, which may have allowed additional flexibility specific to procurement requirements. Despite no declaration of a state of emergency, other state agencies worked with INDOT to expedite reviews and approvals. As a result, the repair work was performed as quickly as possible. If a DOT has the ability to expedite procurement through their Contracts group, as is the case at INDOT, then there may be no need to declare a state of emergency, particularly if state emergency funding is available. INDOT has emergency response on-call contracts, but does not see the need for emergency response on-call construction contracts due to the difficulty in predicting the specific needs.

<u>Establish a single point of contact</u>: Communication through a single point of contact avoids conflicting messages with the public and facilitates coordinated, expedited implementation of remedial measures. INDOT does not have a formalized protocol for emergency response, but learned from previous emergencies that authority needs to be vested in a single point of contact, related to the management structure. INDOT created the Bridge Division to have a single line of authority amongst what had previously been separate bridge groups, e.g., design, inspection, construction.

Establish a spirit of cooperation: In a design/build environment, both contractor and consultant are readily available. Mobilizing resources is easily accomplished. Fostering a spirit of cooperation is essential to a quick response and resolution. Strong leadership is required. The leader should have decision making authority.

For this project, cooperation was the key to success. State resources were highly responsive, including interest from the Governor's office. Technical support from FHWA included advising INDOT on the design and installation of micropiles. Administratively, the contractor was directed to investigate and correct the problem, with issues regarding payment to be settled at a later date. Other than penalties already included in the contract for lane closures, there were no incentives or penalties to encourage completion of repairs on any specific schedule.

3.2.6. Michigan (MDOT)

Similar, but prior to the I-65 Wildcat Creek emergency in Indiana, the Michigan DOT experienced a foundation failure during a bridge replacement project on I-94 in Battle Creek, as detailed by the case history in Chapter 2. Notably, both of these failures were associated with driving piles through glacial lacustrine soils where artesian conditions exist. Emergency response was coordinated through the MDOT Regional Office's geotechnical and bridge disciplines. The Regional Engineer handled coordination between the State Police and MDOT traffic personnel, and initiated further steps to advise the governor's office, as well as the mayor of Battle Creek and the FHWA. Even though both the eastbound and westbound bridges were closed for emergency repairs, a state of emergency was not declared. There were no specific permitting restrictions and federal funding was made available for the repair.

Since settlement on the order of one foot had already occurred in conjunction with pile installation, initial attention was directed toward preventing more extensive damage. As such, MDOT rejected suggestions for driving additional piles and shimming the bridge. The Regional Office set up an emergency contract with a specialty contractor to consider non-driven deep foundation alternatives, such as micropiles or augercast piles. A soil dynamics expert from the University of Michigan, who had led NCHRP research on pile driving vibrations, was also added to the team. He captured the timeline of events by interviewing inspectors and reviewing reports which was very helpful to developing a response and repair program. A micropile alternative, designed by MDOT, was ultimately selected and constructed by the specialty contractor on an emergency contract mode of delivery.

There were no alert level or action level thresholds for movement established for the project as originally bid. Upon identification of the initial failure, survey monitoring of the existing substructures and bridge decks was initiated using traditional survey practices and tiltmeters. The monitoring was later supplemented by a web-based automated monitoring system that uses motorized total station technology with automatic target acquisition with an accuracy of ± 1 mm (0.04 inch) at 300 feet distance.

The entire process to put the bridge back into service took about 2 months. MDOT considered the ability to use an experienced contractor with whom the department had confidence to be a key to successful resolution and would be inclined to use the same process for future similar situations.

3.2.7. North Carolina (NCDOT)

NCDOT did not have experience with bridge foundation failures in recent history that met the definition for this study, as defined in Section 1.1.2.

3.2.8. New York (NYDOT)

NYDOT has not experienced any foundation failures that meet the definition of this study, as stated in 1.1.2. However, the state has experience with scour failures and slowly developing failure conditions. Following the scour related Scoharie Creek Bridge collapse in 1987, NYDOT developed a scour watch list for vulnerable structures. Additionally, the NY state legislature established a unified code for bridge inspection to inventory and assess vulnerabilities. NY has had a number of imminent failure conditions that have developed gradually over time. Examples of these include, corrosion of MSE straps and abutment piles due to cinder backfill materials (I-990 Lockport Expressway, Amherst, NY), complete bridge replacement with an at-grade crossing due to high fill downdrag (Route 37, Ogdensburg, NY), and faulty backfill drainage causing erosion at the toe of an MSE abutment (Route 11 over Shattagay River). Even though these conditions were service failures that resulted in a complete replacement and/or a foundation rehabilitation, the remediation actions occurred prior to movements that provided cause for closure of the bridge.

3.2.9. Ohio (ODOT)

ODOT has not experienced any foundation failures that meet the definition for this study, as defined in Section 1.1.2. The state does not have on-call contracts with consultants or contractors for emergency response, but if the Governor declares an emergency, specific contractors can be compensated on a time and materials basis.

3.2.10. Pennsylvania (PennDOT)

PennDOT has experienced two foundation failures in recent times that meet the definition of this study, as defined in Section 1.1.2. The Birmingham Bridge in Pittsburgh, PA (reference the case history in Chapter 2) experienced a rocker bearing failure due to the excessive (9-inch) settlement resulting from piles not having been driven to rock. The Route 33 Bridge over Bushkill Creek in Nazareth, PA experienced an estimated 20 inches of settlement due to a sinkhole collapse. Both of these failures occurred while the bridges were in service and the DOT was notified by the public. The Bushkill Creek Bridge is included in a joint study with Caltrans and WisDOT to detect bridge movement using high resolution imaging from satellites.

PennDOT has protocols in-place for addressing emergency situations. Police close the roadway, public notification is handled by the PennDOT Communications Department, and a state of emergency is declared by PennDOT through the emergency authorization procedure to enable procurement of a contractor to start repairs. PennDOT has since put in place on-call contracts for emergency response, both for consultants and contractors. Test borings were available in the archives for both bridges, but the as-built driven depth of the piles were not in the archives.

PennDOT has since implemented requirements to show the depth of test piles on the plans. This is consistent with a Louisiana DOT protocol.

Both bridges were remediated using micropiles through a design-build delivery mode and federal emergency funding. Work had to be completed within six months of the incident to utilize federal emergency funding, but there were no incentives or penalties imposed for early or late completion. Overall, it took 4 months to return the Birmingham Bridge to service and 6 to 8 months to return Bushkill Bridge to service.

3.2.11. South Carolina (SCDOT)

SCDOT has not experienced any foundation failures that meet the definition for this study, as defined in Section 1.1.2. Nonetheless, a major storm event (1000-year flood) in October 2015, brought 24 inches of rain to a focal point along a 35-mile segment of I-95 in Clarendon County, shutting down the interstate. Even though there was no evidence of foundation movement / failure, by inspection and analysis 13 out of 18 bridges had major scour losses in this coastal plain setting, with some piles estimated to have only 2 to 3 feet of penetration remaining. SCDOT mobilized staff to inspect scour critical structures immediately following the storm, but had to wait 2 to 3 days to make assessments due to high water. Protocols were in place to declare a state of emergency and immediately shut down the interstate to all traffic except emergency vehicles with escorts. Initial efforts were coordinated through the Director of Maintenance and the Director of Construction, with notices to the media and law enforcement issued from the SCDOT Public Relations office. The Public Relations office was also tasked with keeping the governor’s office informed.

SCDOT does not maintain on-call contracts with consultants or contractors for emergency response, but based upon the governor’s declaration of a state of emergency in October of 2015, three contractors were contacted to submit bids for the remedial work, as required by state procurement laws. SCDOT also contracted directly with a consultant with whom the department had experience, to sound the exposed piles, i.e., perform pile integrity testing (PIT), to determine in-place pile lengths. The soundings were compared with as-built records and existing subsurface data to assess the remaining embedment and bearing. A threshold of 10-feet of embedment was considered the minimum for serviceability.

Initially, the contractors provided next-day bids to place Class B riprap, but the 2-week estimated construction time was considered unacceptable in light of pressure from the governor’s office to return the interstate to service as quickly as possible. Contractors provided alternative bids in about 6 hours to place tremie concrete underwater for approximately the same volume of riprap. Contract delivery mode was design-build. The initial 4000 psi mix design, which included a retarder was not setting up properly. It had to be changed to a low slump 5000 psi mix under direction from SCDOT. Overall, the emergency response worked well because the Department was prepared to rapidly assess the condition of scour critical structures expected to be affected by the on-coming storm, prior to the onset of the storm, and had state funds available to respond immediately under a declared state of emergency. This allowed bypassing the normal permitting processes, allowing construction to start immediately. As a result, I-95 was returned to service within two weeks of the inception of flooding. The state is applying for reimbursement through FEMA.

3.2.12. Virginia (VDOT)

VDOT was not aware of any recent failures that would meet the definition for this study, as defined in Section 1.1.2. Emergency foundation failures would typically be addressed on the District level by the Bridge and Structures office, in combination with the Geotechnical Division. Most issues experienced by VDOT are maintenance related or not serious enough to close the bridge. District offices can respond quickly. For major emergencies, the contracting mechanism is design-build. VDOT identifies three firms with the proper qualifications and solicits bids from all three firms.

3.2.13. Wisconsin (WisDOT)

WisDOT has had some smaller bridge (non-interstate) foundation failures, but the I-43 Leo Frigo Memorial Bridge, as referenced by the case history in Chapter 2, is the best example meeting the definition of failure for this study, as defined in Section 1.1.2. Two independent corrosion specialty consultants, one with forensic experience, determined that the foundation failure was caused by corrosion. Initially there was no certainty that the bridge could be put back into service, but the settlement associated with foundation failure was eventually stabilized. The first notification of the failure came from the public following the development of a two (2) foot dip in the bridge vertical alignment. The emergency response included a combination of Regional District personnel (traffic and community outreach), FHWA, the WisDOT Bureau of Technical Services, the WisDOT Bureau of Structures, and the WisDOT Geotechnical Section. The two corrosion consulting firms, both of which were under contract for other work, were brought on to the team, but not under indefinite delivery on-call contracts. Following the declaration of emergency, WisDOT was able to issue additional task orders to these firms under their existing contracts. There were no contractors on the emergency response team.

A protocol was in place for closing a major structure through the chain of command and for notification of the public, coordinated through the regional district office. As-built and inspection records were available for use, along with geotechnical data, which was supplemented by additional borings, core sampling, test pits, and physical / chemical testing performed after the failure occurred. A Health & Safety Plan (HASP) for working beneath the bridge was developed and put into action prior to any field work. The usual state permitting requirements were invoked, but an expedited process was followed due to the emergency nature of the situation.

Options for remediation were developed. A constructability review was performed to vet the options. Drilled shafts, post-tensioned through the existing footing, was deemed the most feasible and lowest risk solution. Procurement for the construction included two contracts: an initial design-build contract to support the existing bridge deck, followed by a competitively bid (design-bid-build) Permanent Foundation Repair contract using an Expedited Letting Process with three bids. Concepts for the stabilization contract were presented to three invited contractors to bid over a 2-day procurement. The Stabilization contract was approximately $1.5M. The Permanent Foundation Repair design was developed by the consultants and WisDOT. The contract amount was $7.5M to $8M. Federal funding was involved, and FHWA made an outreach to other states. The overall time period to return the structure to service was about 5 months.

4. SUMMARY OF LESSONS LEARNED

4.1. Introduction

The literature review and state DOT interviews revealed a degree of common nationwide experience with foundation failure repairs, but also differences reflective of the geographic size of the state, frequency of naturally occurring disasters that lead to foundation failures, and state-specific regulations governing procurement. The following is a compilation of the most salient findings related to the agencies' initial response to a foundation failure, the remedial foundation types most often used, and the contracting mechanisms employed to construct the repairs.

4.2. Initial Response

4.2.1. Records and Documentation

4.2.1.1 Existing Data

- Archived and readily accessible inspection records are an invaluable resource in emergency response. States, such as California, have organized records into a Bridge Inspection Records Information System for rapid access.

- As-built plan records are essential to emergency response. Some DOT as-built plans do not include the driven depth of production piles and test piles. This information is invaluable in assessing the foundation. This information is worthy of inclusion within a protocol for submitting as-built records.

- Geotechnical and geophysical data in a geographic information system accessible from GIS database further enables rapid access to information used to assess a failure. This could save time during an emergency response.

- Even though every bridge under state control is not on the federal system, FHWA is able to provide information from other states that may have encountered the same type of failure under similar conditions. FHWA early involvement can open up access to resources and experience that can speed the evaluation and resolution of the situation.

4.2.1.2 Event Documentation

- The indications of failure do not always develop suddenly, but rather over a period of time, and the leading causes may be less than obvious (e.g., corrosion, breaching of an artesian layer, or karst activity). As such, developing a detailed chronology of events leading up to failure may be as important as documenting the observed conditions at the time of failure. This is particularly important with respect to avoiding implementation of temporary or permanent emergency measures that may worsen the existing condition.

- Executing the immediate requirements for safety, such as closing an interstate highway, may require involvement from FHWA, state police, and the governor's office. To avoid confusion and enable decisive action, concise reporting of existing conditions must be quickly conveyed through a lead point-of-contact. Reporting should be through a clearly understood, non-redundant chain of command within the DOT that vests full authority of the DOT within the lead position.

- Additional testing or instrumentation and monitoring that may be useful will likely depend upon enactment of safety provisions to stabilize the structure, such as the installation of temporary shoring towers, as shown by the DelDOT I-495 case history. Temporary shoring was also used by WisDOT on the Leo Frigo Bridge. The response team should be prepared to render a preliminary assessment of the potential for collapse of the bridge based on the movement that has already occurred. The response team should be able to recommend safeguards necessary to allow work to occur beneath the structure. This could be implemented through a Health and Safety Plan (HASP) developed for the project. This plan could be established ahead of time in a generic nature and modified for the specific conditions to be encountered at the site each failure. Information regarding the development HASP's along with tools to assist in their development can be found on the United States Department of Labor, Occupational Safety and Health Administration website: https://www.osha.gov/.

4.2.1.3 Assessment of Needs

- A preliminary plan for monitoring should be developed during the initial response phase. Monitoring will determine if movement is on-going, and if so, the rate and direction of movement. Simple initial monitoring using traditional survey methods can be followed up by installations for monitoring with more sophisticated instruments such as tiltmeters, inclinometers, piezometers, and other instrumentation at a later time.

- If the bridge has experienced a failure that warrants closure to traffic, temporary underpinning may be needed immediately to stabilize the structure until a permanent repair can be made.

- If as-built records and geotechnical data are insufficient to assess pile lengths or subsurface conditions, additional borings, in-situ probes, or soundings may be needed. This need should be assessed as part of the initial response.

- The conditions of a failure may immediately suggest the need for specialized expertise and/or specialty contractors that are not available through existing contracts or conventional procurement means. The initial response should consider the resource requirements in concert with the available procurement methods. The declaration of a state of emergency through the governor's office may be a necessary consideration to expedite the response to the emergency depending upon state procurement laws and the availability of open-end contract resources.

- Relaxation or a waiver of environmental permitting requirements may be necessary to expedite stabilization or to enact remedial repair methods in a timely manner. Initial response should consider the environmental procedures relative to the expediting the environmental process that could be made by the declaration of a state of emergency.

4.2.2. Communication

4.2.2.1 Notifications and Advance Warning

- Thorough review of inspection reports at the proper level is essential to revealing conditions that may presage the development of a failure. Protocols for assessing information collected during inspections that could foretell a problem prior to reaching a state that requires a bridge closure should be developed. These protocols should determine the type of information collected during each inspection cycle and how the information is analyzed and compared to previous cycles.

- The motorists using the bridge are often the first source of notification that a failure has occurred or is in the process of occurring. Improperly routed incoming calls are a lost opportunity to gain valuable lead time.

4.2.2.2 Initial Responders

- States with large geographic areas commonly respond to emergencies from the District office level, at least initially, whereby forces can be deployed rapidly to the site. This mode of response appears to be effective for the states that were interviewed.

- To the degree that can be anticipated, emergency response should include representation from all departments that would be involved in remediation, e.g., bridge, geotechnical, construction, environmental, hazardous materials, traffic, and the public relations office.

- Involvement of the FHWA early in the event will provide access to FHWA's experience and expertise with foundation failures nationwide. FHWA will provide technical advice with regard to assessment of the bridge and the development of repair strategies. Additionally, the pursuit of available federal funding sources concurrent with response efforts can increase the potential for federal funding assistance. FHWA funding does not rely on a declared state of emergency, however, federal funding review and reporting requirements must be followed. . FEMA funding may also be available for scour related damages.

- The DOT command structure in-place prior to the incident should establish the lead position of authority who is empowered to make decisions, foremost of which is assuring safety and assessing whether the combined conditions of the failure, the site of the failure, and the requirements for procurement warrants recommendation to the governor to declare a state of emergency.

- Anticipate pressure to return critical infrastructure to service. In the absence of temporary support structures, resist putting failed foundations back into service until the corrective measures have re-established full confidence in the safety of the bridge.

4.2.3. State of Emergency

4.2.3.1 Declaration Decision

- Procurement of services can be accomplished by a variety of means, depending upon the circumstances of the failure and the laws of the state. Declaration of a state of emergency is not, however, a standard operating procedure for all DOT agencies, even in the event of a mandated bridge closure on the interstate system. Early involvement of the governor's office and appropriate state agencies will assist in determining the need to declare a state of emergency. If there are no impediments to contracting with the needed resources or a perceived need to streamline permitting processes to accomplish a repair, the declaration of a state of emergency may not be necessary.

- Amending an agreement with firms that are already under contract at the time of failure is one method of procurement, albeit restricted by the available open contracts (and the scope thereof) at the time of failure.

- Bidding amongst multiple pre-approved contractors can be performed on an expedited schedule, even within the limited time-frame of an emergency response. SCDOT used this process to respond to storm damaged interstate bridge foundations under a design-build contract delivery mode. In South Carolina, limiting the invitation to bid to three pre-selected firms, however, requires the declaration of a state of emergency through the state governor's office. Familiarity with individual state procurement rules can expedite the response process.

- In California, where earthquake disasters are anticipated, Caltrans maintains a list of pre-selected contractors with proven capabilities that can be mobilized on a force account or design-build delivery mode upon a Director's Order issued after the governor's declaration of a state of emergency. The declaration also allows Caltrans to streamline permitting processes that are otherwise mandated by law. Understanding a state's law with regard to permitting requirements under emergency conditions can expedite the response process.

4.2.3.2 Potential Benefits of a State of Emergency Declaration

Understanding a state's laws and regulations is beneficial to making a decision to declare a state of emergency. Based on the information received from various states, the potential benefits of the declaration of a state of emergency are summarized below. These benefits may not be realized in every state due to variations in the laws of individual states.

- <u>Expediting mobilization of law enforcement in coordination with DOT Traffic Department</u>-
  Engaging law enforcement to assist in managing traffic and motorists during the initial and longer term phases of a bridge closure improves the safety of the situation and releases DOT resources to deal with the issues associated with re-opening the bridge.

- <u>Provide immediate access to state emergency funding</u> -
  Access to state emergency funds can provide a means of financing the necessary temporary stabilization measures while the permanent bridge foundation repair options and other forms of federal funding are being pursued.

- <u>Relaxation or waiving of mandates for Buy America provisions</u> -
  If repair work is to be performed in association with an on-going construction project, for instance using a force account to procure the services of a specialty foundation contractor under an existing general contractor, a waiver on certain contract provisions, such as Buy America provisions, can be helpful in expediting response time.

- <u>Relaxation or waiver on restrictions for sole source procurement of technical resources</u> –
  In addition to allowing for procurement of services from specific consulting firms or, for instance, subject matter experts within a narrow technical field, some states, such as South Carolina, have provisions within the engineering licensure law to allow for a waiver of in-state licensure under a declared national or state public emergency. The waiver in South Carolina permits engineers licensed in other jurisdictions having like standards meeting NCEES Model Law standards to render services in-state for a period not to exceed 90 days.

- <u>Relaxation or waiving restrictions on limited or sole source procurement of contractors</u> -
  Engaging with a general contractor or specialty foundation contractors of known ability early in the process of foundation repair design has the advantages associated with developing the design based upon the availability of material resources and equipment, and specific expertise related to the selected means and methods of construction, such as casing installation.

- <u>Expediting or waiving permitting processes</u> -
  For river, stream and wetland crossings in particular, environmental permitting processes can be streamlined by a declared state of emergency.

- <u>Public information dissemination in coordination with DOT Public Communications Department</u> -

  Engaging the governor’s office in public communications under a declared state of emergency provides an alternative means of communicating information to elected governmental officials, possibly improving the flow of information to the public, and assisting the DOT with the best use of department resources.

4.2.4. Foundation Remediation Types

Interviews conducted with state DOT's that experienced bridge foundation failures revealed that the most common remediation technique utilized was micropiles. However, several remediation techniques are available. These techniques are described in the following paragraphs. These techniques should be assessed in light of the specific conditions that accompany a bridge failure. The response team should evaluate the myriad of variables associated with a specific incident and select the remediation technique that provides the best solution to the emergency.

4.2.4.1 Micropiles

The case histories in Section 2 confirm that micropiles are a preferred method for remediating failed foundations where the existing footing or pile cap remains intact. Since the foundation failure implies that the load carrying capacity of the foundation has been comprised, micropiles are designed to support the entire load on the existing foundation. Micropiles have the advantage of a high capacity, comparable to H-piles, with a more limited and symmetrical cross sectional area. Micropiles can be installed through the exposed tops of footings or pile caps and fixed in-place with non-shrink grout, or around the perimeter of the existing footings or pile caps, with bracketed connections. Micropiles are suitable for rapid installation with very low vibration impact in a variety of settings, including low overhead clearance locations with as little as 8 feet of head space clearance. The elements can be post-tensioned to reduce movements upon transfer of the load. Case histories (MDOT and INDOT) indicate that micropiles were suitable for use under artesian conditions, using duplex drilling with water. To help mitigate the influence of artesian pressure, INDOT used a low mobility grout.

4.2.4.2 Drilled Shafts

At locations where the bridge substructure is deemed unsalvageable, drilled shafts, positioned outside of the limits of the existing substructure, are commonly used to restore failed bridge foundations to service. Drilled shafts have the advantage of being able to accommodate large axial and lateral loads with a single element, while also being suitable for installation with relatively low vibratory impact. Commonly they are installed adjacent to the existing substructure. Constructing the drilled shafts adjacent to existing substructure requires a transfer beam to be constructed to transfer the loads from the existing substructure to the new drilled shafts. The drilled shafts and the transfer beam can both be post tensioned to limit deflection. Where drill casings are necessary for the installation of drilled shafts, casing oscillators may provide for a low vibration installation. DelDOT found the process of using casing oscillators to be slow, and opted for the use of a vibratory hammer in conjunction with vibration monitoring.

4.2.4.3 Driven Low-Displacement Piles

Open-end steel pipe piles driven outside the substructure limits or through the bridge deck and adjacent to existing foundation, were used for remediation of failed foundations in two of the case histories. Similar to the drilled shaft alternative, the pipe piles were driven plumb and required the additional step of constructing a post tensioned transfer beam or an abutment/backwall replacement. The need to closely monitor for vibration or displacements during driving is a disadvantage associated with the use of driven piles. This disadvantage may be offset by the speed of installation, the ability to quickly verify resistance of the new piles by dynamic testing (PDA/CAPWAP) and the higher cross sectional area for lateral load resistance. The higher lateral load resistance is beneficial where battered pile arrays are not possible due to space constraints or are inappropriate due to on-going settlement of the in-situ soils.

4.2.4.3 Other Methods

- Concrete Jacketing: One case history involving the closure of I-35 in Minnesota was remediated by jacketing highly corroded steel pile connections with concrete.

- Tremie Grouting: When a major storm event resulted in closure of I-95 in South Carolina, tremie placed concrete was used to restore lateral confinement to exposed pile lengths as an expedited alternative to placing approximately the same volume of riprap.

- Ground Improvement: Although not used in the reported case histories, jet grouting, permeation grouting, deep soil mixing, controlled modulus columns, and other ground improvement techniques may have application for temporary or permanent remediation of poor ground conditions.

4.3. Contracting

4.3.1. Failure Occurrence during Construction Activity

4.3.1.1 Monitoring

- Construction contract provisions establishing monitoring requirements near adjacent existing structures and the associated alert and action level thresholds are not always provided, but should be considered as part of a protection program for existing structures. Parallel bridges and nearby structures should be monitored for impacts due to vibrations or heave to provide early warning of a potential problem. This should be done at vulnerable site locations. Vulnerable locations include those where artesian conditions exist or where deep foundations or temporary shoring will be installed near structures founded on shallow foundations. Other vulnerable locations include deep foundations with embedment depths less than the depth of the adjacent excavation, or founded in soils that are susceptible to densification from vibrations.

- Establishing a monitoring program immediately upon discovery of a failure provides real time information on bridge movements. This allows for a determination about the continued movement of the bridge, and may help in assessing the cause of the structure displacement. Monitoring data can be used to determine specific needs for stabilization of the bridge to ensure the safety of crews working to assess and/or repair the structure. Monitoring will also provide information regarding the effectiveness of the repair.

4.3.1.2 Spirit of Cooperation

Regardless of the contract delivery mode (design-build, design-bid-build, force account, etc.), when a foundation failure occurs, it is important to recognize that it is in everyone's best interest to cooperate toward the primary objective of returning the bridge to service as quickly as possible, without focusing on assigning fault. All parties should agree that compensation issues need to be deferred until after the emergency situation has been resolved.

4.3.1.3 Contractual Relationships

Case histories revealed a variety of contractual relationships when failure occurred during construction. The three cases for which the contracting mechanisms were revealed all involved micropile foundation repairs.

In Indiana, INDOT, which was in a design-build construction contract when the failure occurred, indicated that working with the existing contractor was preferable, even if specialty subcontractors need to be employed for specific foundation repair efforts. The success of directing the design-build contractor to pursue corrective measures in that instance was based upon the cooperation that was established between the contractor and the DOT during the early phases of the construction.

On a design-build contract under construction in Florida, FDOT contracted with an engineering firm under an on-call task order to evaluate the failure, and subsequently used a design-bid-build delivery mode to install the micropile foundation repairs.

In Michigan, MDOT was executing a design-bid-build construction contract when failure occurred and ultimately contracted directly with a specialty foundation contractor to install micropiles under a design-build contract.

In general, the contracting method for executing the emergency repair was dependent upon a number of variables. These include the availability of on-call designers and contractors, established relationships with engineers and contractors, agency preferences for procurement, the nature and urgency of the situation, procurement laws in individual states. Due to the number and complexity of the variables, no clear preference was apparent for the contracting methodology used to procure the evaluation, design and construction services.

4.3.2. Failure Occurrence in the Absence of Construction Activity

4.3.2.1 General Procurement Considerations for Contractors

Aside from general maintenance contracts, DOT on-call contracts are generally not in-place with construction contractors in anticipation of various types of foundation failures. Contracting with the appropriate resources (experienced general contractors and specialty foundation contractors) in response to foundation failures can be a challenge, and often relies upon amending agreements with firms that are already under contract or modifying standard state procurement procedures under emergency contracting provisions to authorize either sole source contracting or expedited bidding amongst pre-approved invited contractors. Arrangements for the latter emergency contracting method are normally handled through the state contracting office or the DOT Director via a declared state of emergency application to the state governor's office. PennDOT has recently put in place on-call contracts for contractors, as well as consultants.

4.3.2.2 General Procurement Considerations for Consultants

On-call contracts with engineering consulting firms are common and provide a reasonable means for DOT agencies to rapidly assemble technical resources. Open-end arrangements are typically in-place for traditional disciplines, such as structures, geotechnical, traffic, but may not include specialty testing, advanced instrumentation capabilities, or the subject matter experts needed for a specific emergency response. After a state of emergency was declared, WisDOT was able to issue additional task orders to firms that happened to be under contract on other projects at the time of failure. These firms were not available under any existing open-end contracts. Administrative provisions need to be in place for the addition of technical resources under expedited subcontract agreements.

4.3.3. Incentives and Disincentives

4.3.3.1 Bonus Awards

DOT interviews did not find incentive clauses to be typical of emergency repair contracts. In California, Caltrans successfully used incentives of $150,000 per day and $80,000 to $90,000 per day for early completion of bridge replacement and restoration contracts following the Northridge and Loma Prieta earthquakes, respectively. Penalty clauses for late completion were also in effect. Case histories revealed that incentive bonuses have also been used in Florida, where FDOT awarded a $675,000 bonus for early completion of the Flagler Memorial Bridge repairs. Incentive clauses can be effective, but must be judicially applied in the context of an individual owner's experience and preference. Incentives should also be balanced with disincentives.

4.3.3.2 Other Factors

Federal rules require that funding for emergency repairs be expended within a six-month time frame. This was achievable by the DOT's that were interviewed, with or without incentives and penalties. Caltrans, which used incentives, cited the success in meeting the six-month time frame, at least in part, to the effectiveness of using pre-approved contractors with a proven record of performance. Similar comments related to the importance of having access to a trusted engineering firm (Delaware), experienced contractors (Michigan), and past experience between the DOT, contractors, and consultants (PennDOT) were attributed to timely completion of repairs without contractual incentive or penalty clauses for early or late completion.

4.3.4. Contract Delivery

4.3.4.1 Influence of the State of Emergency Status

Most of the DOT agencies interviewed cited the declaration of a state of emergency by the state governor's office as a means to expedite contractor selection. However, Michigan and Indiana are not required to declare a state of emergency to sole-source with a pre-selected contractor in an emergency. INDOT and MDOT both nevertheless maintained a high level of communication with their respective state and local government offices regarding the status of repairs and returning the bridge to service.

4.3.4.2 Contract Type

The contract type for delivery of emergency services varies between states and the circumstances of the emergency response. For instance, force account may be more suitable to managing a general contractor's efforts on a complex failure, while temporary support and permanent repair designs are being developed concurrently under one or more DOT open-end contracts. From the sampling of DOT interviews and limited number of case histories, design-build is the implied preferred mode of contract delivery, but force account and design-bid-build have also been used. State practices for delivery of emergency services that have either been used in a foundation failure emergency or were conveyed as a likely mode of response based on the interviews were as follows, but are not necessarily limited to these contracting modes:

- Sole source design-build emergency contract following the governor's declaration of a state of emergency – California, Pennsylvania

- Sole source emergency contract on force account following the governor's declaration of a state of emergency (with separate design services procurement) – California, Delaware, Ohio

- Sole source design-build emergency contract without declaration of state of emergency – Indiana, Michigan

- Design-build emergency contract with expedited bidding process amongst three pre-selected contractors following the governor's declaration of a state of emergency – South Carolina, Virginia, Wisconsin (Note: Wisconsin Leo Frigo case history had 2 contracts: a.) design-build for temporary support, and b.) design-bid-build with expedited bidding process (3 bids) for permanent repairs

- Design-bid-build with incentive for early completion -- Florida

5. RECOMMENDED BEST PRACTICES

5.1. Introduction

Interviews with a select sampling of state DOT agencies across the country revealed that the procedures for responding to bridge foundation emergencies have similarities, as well as regional differences that are ill-suited to a standard protocol relative to all states. Some of the differences are naturally due to the considerable differences in state size and DOT organizational structure, the frequency of specific geo-hazard events that are experienced by, for instance, earthquake prone regions, and the differences in state-specific criteria for declaring a state of emergency, as well as the benefits derived from the governor's declaration. Accordingly, this section addresses the response to foundation failure emergencies in the form of best practices common to the aspects of advanced preparation and planning, initial response to a foundation failure event, documenting the event, instrumentation and monitoring, development of the repair plan, and contracting.

5.2. Advance Preparation and Planning

5.2.1. Organizational Structure

5.2.1.1 Routing of Notifications

Agencies possess different means for communicating incoming alerts from the public, whether it is through 911 call-ins or direct call-ins to the DOT. Procedures for routing alerts from the public need to follow a chain of command consistent with the DOT organizational structure that mirrors the chain of authority in-place for responding to bridge foundation emergencies. However, the protocol for routing incoming alerts should be streamlined to avoid delays in evaluating and responding to such alerts.

Protocols should be in place for DOT staff (maintenance and operations) as well as for consultants (bridge inspectors, construction inspectors, etc.) to initiate a response to an event discovered during field work.

5.2.1.2 Command and Control Authority

Whereas some agencies vest the authority for emergency response at the district office level, e.g., District Structures Maintenance, states with smaller geographic areas are more inclined to vest authority with the central office. Procedures for establishing the authority for leadership associated with emergency response should be in-place prior to an event to help mitigate confusion with the necessity for rapid decisions.

5.2.1.3 Chain of Communication

DOT agencies do not all possess the same chain of command, but at a minimum each emergency response team, as well as all authorities up the command structure, should be aware in advance of the communication chain for notifying the state police (roadway closure), office of the governor (declaration of a state of emergency), and technical discipline leadership (assembly of resources) in advance of a foundation failure emergency. Some of the questions that should have scripted procedures in advance of an emergency are as follows:

- Will the DOT communications office handle public notifications or another state agency, and under what circumstances will the standard protocol for public notification be different?
- Will the state police handle rerouting of traffic or the DOT Traffic Department, and under what circumstance will the protocol be different?
- Who will be the lead contact with the governor's office for dissemination of information, recommended declared state of emergency, or state police assistance?

5.2.2. Decision Basis for Technical Resource Allocation

5.2.2.1 Availability of In-house Resources

Depending upon the DOT size and the magnitude of the foundation failure, in-house resources may be suitable to respond to all of the engineering needs of an emergency without the necessity for supplemental outside consultants or testing agencies. Upon an initial assessment of need, the response team should have a documented means of immediately assessing the available in-house resources that can be dedicated from each respective discipline within the DOT. Each department within the DOT should document capabilities within the department and the means to supplement the in-house resources where necessary.

5.2.2.2 Access to Outside Resources

Major emergencies often require some form of outside technical or specialized testing assistance. Procurement procedures vary between states, particularly amongst locations that have a historical need to respond to disasters and those where the need to respond to major emergencies is infrequent. Recommended best practice procedures to consider in advance of an emergency relative to procurement of supplemental testing services, consulting engineering, or subject matter experts are as follows:

- Maintain a listing of subject matter experts, are accessible under current open-end contract agreements, along with the agreement expiration date.
- Maintain a listing of consulting firms, are accessible under current open-end contract agreements, along with the agreement expiration date.
- Maintain a listing of specialized testing firms for tasks such as in-situ testing, geophysical testing, or pile integrity soundings that may be needed in an emergency, accessible under current open-end contract agreements, along with the agreement expiration date.

- Document state-specific policy and procedures for accessing subject matter experts, consultants, or specialized testing firms on the listings that are not currently under contract with the DOT and the typical time requirements for approval.

- Document the state-specific policy and procedures to expedite the addition of technical resources to existing contracts and the typical time requirements for approval.

If state policy and procedures require the declaration of a state of emergency to access technical resources that are not already under contract with the DOT, the mode of contract delivery will influence the accessibility to technical resources, or potentially limit the DOT influence upon the remedial foundation design effort. Consideration should be given to the following general contractual issues in advance of an emergency:

- The design-build contract delivery mode may be preferred for emergency response in the event of foundation failures within states that have infrequent major emergencies. However, even under a state of emergency, competing bids from three pre-selected contractors may be required. The DOT should maintain a listing of general contractors and specialty foundation contractors possessing design-build experience. A process should be developed to allow firms to apply for inclusion on this listing.

- Pre-qualification of contractors is more important for states that frequently require emergency response to foundation failures. Provided that the DOT maintains the technical capacity to respond to foundation engineering requirements in-house or through open-end agreements, the ability to activate a sole source emergency contract on a force account basis with a pre-qualified contractor can significantly expedite response time.

- In the event of a foundation failure in proximity to an adjacent design-build construction contract, directing the existing contractor to pursue remedial repair is preferable, provided that a spirit of cooperation exists to address the emergency as the top priority and that the policies and procedures of the state will permit the DOT to add subcontractors to the design-build team, e.g., micropile or drilled shaft specialty contractors.

- In the event of a foundation failure in close proximity to an adjacent design-bid-build construction contract, working under force account (time and materials) is preferable, however, the DOT may have a greater need to access other technical resources to develop a remedial foundation design.

- For foundation failures that require shoring towers to temporarily support the existing structure, while permanent repairs are being designed, the DOT may choose to employ a separate design-build contracting mode for installation of the shoring, while the design is in progress for the permanent foundation remediation under a different contract delivery mode.

- Regardless of the contract delivery mode, the DOT should maintain the means to quickly procure expertise from sources outside of the normal contractual vehicles, e.g., from academia or from firms with which the department has developed a high level of confidence.

5.2.3. Availability of Records

- *Inspection Reports* -- Archive inspection records into a Bridge Inspection Records Information System for rapid on-line access.

- *As-built Plans* -- Maintain access to as-built plans for use by first responders, including the driven depth of production piles and test piles.

- *Geotechnical and Geophysical Data* – Maintain geotechnical and geophysical data in a web based geographic information system to enable rapid access to information from the site or nearby locations during an emergency response.

- *Design Records* – Maintain design calculations and reports for rapid on-line access.

- *Similar Foundation Failure Experiences* – Contact FHWA early in the emergency response to possibly gain experience from other states that may have encountered the same type of failure under similar conditions.

5.3. Initial Response

5.3.1. Response Team Assembly

DOT First Responders – Whether the initial response is led by District or Central office personnel, the first responders for a major emergency should, to the degree possible, include representation from all departments that would be involved in investigation and remediation, including, but not limited to, bridge, geotechnical, construction, environmental, traffic, and public relations. Depending upon the severity of the failure, first response might also include FHWA and consultants that are contractually accessible and known to be suited to the task.

Additional Notifications – In some instances, the first responder may only be a bridge inspector from a district structure maintenance office, dispatched to the site based upon limited alert information. The foremost responsibility, after assuring immediate safety of the motoring public, is to assemble the necessary resources. These might include, but are not limited to, the technical disciplines and entities listed above, the state police and other government authorities from the governor's office on down to the city or town jurisdictional level. Owners of utilities that are carried on the bridge must be notified of the bridge closure and of any restrictions that will be imposed relative to accessing their facilities. DOT first responders should be equipped with contact information to immediately access the chain of command to initiate notifications based upon a prioritized listing of emergency contacts.

Feature Crossed – Consideration must be given to the safety of the feature under the bridge that has experienced a failure. The safety of the individuals who might be using the roadway, open space, developed land or waterway under the bridge has to be assessed in conjunction with assessing the safety issues associated with the bridge that has experienced the failure. Closure of local roads will require coordination with local DOT's and other authorities. Limiting access to open space or developed land will require coordination with adjacent property owners. Under-bridge easements should be identified and easement holders notified of restrictions placed on the easement. If the bridge crosses a navigable waterway, the United States Army Corps of Engineers should be included in the notifications, engaged in the development of remediation measures and kept abreast of developments as the work progresses.

Leadership – Once the DOT team has been assembled, the authority for reporting to higher levels within the DOT should be clearly vested in a response team leader based upon the established DOT organizational authority.

News Media – A single point of contact should be established for news releases and public notification and the team should channel all inquiries through the lead for public information.

Consultants and Specialty Testing – Based on a preliminary assessment of the requirements relative to available resources, consultants or subject matter experts should be added to the team at the earliest possible time, preferably from existing open-end contracts. Special requirements that entail the need for services from firms that are not under existing open-end contracts with the DOT may require sole source procurement. Policies and procedures, such as may be allowed under a declared state of emergency, should be in-place to expedite sole source contracting, either by addition to an existing contract and/or by directly contracting with the firm.

Pre-Qualification of Contractors – If the mode of failure and remedy is reasonably well understood at the outset, the involvement of contractors in the remedial foundation repair design phase can provide significant advantages with regard to knowledge and limitations of various construction methods, local availability and limitations of equipment, and the availability of material sources, such as reinforcement steel, steel casings, and drill pipe. Policies and procedures to pre-qualify contractors for sole source procurement or contracting on the basis of competing bids amongst a limited number of pre-selected contractors can prove very useful in the event of an emergency and should be considered by any size DOT.

5.3.2. Initial On-Site Tasks

5.3.2.1 Safety

Once the bridge has been closed to traffic, the team will need to assess whether the existing condition is sufficiently stable to work beneath the bridge, to what degree movement may be continuing, and whether a means of temporary support is warranted to stabilize the bridge while foundation repairs can be designed and installed. Depending upon the conditions of access, temporary support may simply consist of driven low-displacement piles installed through the existing bridge deck to underpin the girders while permanent foundation repairs are being designed and installed, as depicted by the Chesapeake, VA overpass case history in the Appendix.

Alternatively, more robust jacking towers supported on drilled shafts may allow for a resumption of service prior to completion of the permanent foundation repair, as depicted by the I-495 Wilmington, DE case history in the Appendix. If site and loading conditions allow, temporary support could be as simple as off-the-shelf scaffolding with screw jacks supported on timber mats placed directly on leveled ground below the bridge. Temporary support systems should be designed and detailed to meet the requirements presented by the failure and the site.

If site access restrictions are deemed appropriate due to the risk of collapse, a generic pre-emergency action health and safety plan (HASP) should be amended to convey the limitations of access. DOT protocol should include provisions to expedite mobilization of forces to stabilize a structure under a sole source contract upon a declared state of emergency. A short list of contractors possessing the capabilities to perform such services under a variety of conditions should be available to the emergency response team.

The use of remotely operated robotic systems such as drones can provide a safe method for the preliminary assessment of the condition of the bridge.

5.3.2.2 Additional Notifications

The initial response team will need to assess the need for additional notifications and resources as discussed in Section 5.3.1 regarding the response team assembly. In addition, the failure may require immediate involvement of other stakeholders, including utility owners with facilities supported on the bridge or in close proximity, hazmat personnel, representatives from the U.S. Army Corps of Engineers, in the event of impacts to navigable waterways or Waters of the U.S., state environmental agencies possessing similar or additional regulatory authority, and adjacent property interests, including those of historical significance. Protocols should be in-place to notify utility companies, state, federal or local regulatory authorities, state historical trust, or other potential stakeholders for bridge foundation failures statewide.

5.3.2.3 Records Review

Inspection reports, as-built plans, and subsurface data should be reviewed by the response team for evidence that may help identify the source of failure, such as soft ground (surface load induced lateral squeeze, settlement, pile down drag), deleterious or corrosive fill materials (steel pile damage, ground subsidence), karst conditions (void collapse, groundwater gradient induced soil piping), artesian conditions (soil piping loss), loose sand (vibration or groundwater withdrawal induced settlement).

5.3.2.4 Documentation

Pending consideration for safety precautions, initial responders should attempt to measure and record the movements that occurred as a result of the failure – subsidence, substructure tilt, lateral displacement. Include observation of the surrounding environment as related to the failure and/or ultimately having a possible impact upon equipment access. Examples include stockpiled earth; features of on-going construction, particularly excavations, dewatering, foundation installations, along with details and the means and methods of construction associated with each; utilities supported on the bridge or in proximity to the bridge; wetlands; historical features or adjacent properties that might be impacted by remedial foundation repair efforts. If the failure was in association with on-going construction activities, information should be collected to determine the sequence of events leading up to failure, in order to understand the mechanism that may relate to the efforts to remediate the failure and rapidly return the bridge to service without inadvertently taking actions that worsen the existing condition. Recording existing conditions is further discussed in Section 5.4.

5.3.2.5 Monitoring Plan

Initial baseline measurements and the means for monitoring should be established as quickly as possible to provide an early assessment of whether bridge movements subsequent to the initial failure are still on-going. This may consist of conventional survey monitoring points established on piers and abutments at first, supplemented by the subsequent installation of monitoring points using tiltmeters, inclinometers, crack gauges, or three dimensional coordinate technology, such as Light Detection and Ranging (LiDAR). The frequency of readings may be initiated on intervals as small as hourly at first. To reliably detect the rate and direction of minor movements as early as possible, instruments must possess a high degree of accuracy (degree of correctness) and precision (degree of repeatability). Measurement and monitoring are discussed in more detail in Sections 5.4 and 5.5.

5.3.2.6 Supplemental Subsurface Data

With the goal to return the bridge to service as rapidly as possible, obtaining supplemental subsurface data is not always feasible on the accelerated schedule necessary for implementing a foundation repair. As such, rapid access to archived geotechnical data is essential to emergency response. In-situ testing, specifically Cone Penetration Testing (CPT), and Piezo-cone Penetration Testing (CPTu), provide a means to gather a large amount of supplemental data on an expedited schedule. Depending on conditions, several hundred feet of continuous profiling can be accomplished in one day. Although limited in usefulness in settings characterized by cemented or unweathered rock layers, gravel deposits, or rock inclusions, the cone penetrometer otherwise has wide utility in subsurface settings ranging from soft clay to dense sand, rendering data on soil consistency, inferred soil behavior type, and in-situ stress. In addition, the piezo-cone (CPTu) can provide valuable information about undissipated excess pore pressures associated with on-going consolidation settlement. In-situ testing is generally accompanied by Standard Penetration Test (SPT) borings, which provide an opportunity to obtain samples for visual identification, Standard Penetration Test data to assess the relative density of the subsoils, undisturbed thin wall tube samples for laboratory verification of assumed design strength parameters, and renders an open-hole means to install instrumentation (inclinometers, piezometers, etc.) or to perform downhole testing, such as parallel seismic or induction coil testing as discussed in 5.4.1.5 to determine in-place pile lengths.

5.3.2.7 Non-Destructive Testing

Depending upon the availability of well documented as-built records, the length of in-place piles may be unknown. Non-destructive testing (NDT), such as the acoustic pulse echo method, the electromagnetic induction coil method, or the parallel seismic method may be performed to determine in-place pile lengths relative to a bearing stratum or to assess the remaining embedment of existing piles that have been exposed by scour. NDT methods are further discussed in Section 5.4.

5.3.2.8 Source and Magnitude of Failure

The cause of foundation failures is not always immediately obvious. Nevertheless, the primary mission of the emergency response team is not to perform a detailed forensic evaluation, but rather to gather sufficient information to develop a remediation plan that will return the bridge to service as rapidly as possible without exacerbating the existing failure condition. Various forms of testing may be performed concurrent with design of remedial foundation repairs to confirm suspected causes; however, if the foundation has already failed, the response team needs to assess whether the existing substructure and footing is in usable condition to be incorporated into a remedial design. Typical remediation plans are further discussed in Section 5.6.

5.3.2.9 Declaration of a State of Emergency

Each state DOT has thresholds, which are not necessarily the same, for recommending a declared state of emergency through the state governor's office. A declared state of emergency might allow for sole source contracting with pre-qualified contractors or alternatively, seeking bids from a select shortlist. There are common considerations for this decision that need to be considered by the emergency response team, generally categorized as follows:

- Resource Requirements – Are there specific resources needed immediately that are unavailable through standard means of state procurement, which would otherwise be accessible via sole source contracting under the governor's declared state of emergency? These resources might include technical experts, engineering consulting firms, boring contractors, in-situ or non-destructive testing firms, general contractors for temporary stabilization, or specialty foundation contractors.

- Emergency Funding – If state emergency funding is available, is access to the funds dependent upon a declared state of emergency and to what degree will the state qualify for federal funding from FHWA or FEMA without a declared state of emergency? Seeking alternative funding channels should be concurrent with development of a remedial repair, such that the proper oversight and review is initiated early in the event.

- Bridge Closure – Based on the type of transportation corridor taken out of service by a bridge closure, e.g., a major interstate highway or primary route within a city center, are there reasons to declare a state of emergency to ease the impact on state DOT forces? For instance, will the governor's declaration expedite mobilization of state police to assist the

Traffic Department with maintenance of traffic or further enable the Public Communications Department to route notifications through the governor's office for posting on the state website and other media outlets? If the declaration of a state of emergency is not standard DOT protocol for a major emergency bridge closure, responding personnel should be aware of the specific bridge closure criteria under which such a recommendation is warranted.

- Permitting – Will the environment, such as a navigable river, Waters of the U.S., historic district, etc., or the standard state or federal permitting requirements for construction at this location be a potential impediment to rapid restoration of service in the absence of a declared state of emergency?

- Contractual Restrictions – If the foundation failure occurred in association with an on-going construction contract, are there other contractual restrictions, such as Buy America provisions, that a declared state of emergency will take precedence over?

5.4. Recording Existing Conditions

5.4.1. Measurements

Measurements that document the existing condition of the bridge at the time of the failure should be taken to establish a baseline for monitoring the bridge during the remediation process and to assess the success of the repair. Many measurements require access directly to the foundation element in question. The stability and safety of the structure should be verified prior to accessing areas of the bridge that would otherwise pose a safety hazard to personnel performing measurements.

5.4.1.1 Manual

Basic measurements of the dimensions of specific elements involved in the foundation failure should be obtained on the initial response, as well as a recording the displacement and cracking patterns observed at that time. Equipment for these measurements includes measuring tape, carpenters level, and laser-based tools that can accurately measure distances, lengths, offsets, and crack widths (Figure 5-1a), or tilts of substructure units (Figure 5-1b).

Figure 5-1: Laser-based equipment used to measure: (a) distances and (b) tilts (Bosch™)

5.4.1.2 Surveying

During or immediately following the initial response, survey measurements using total station equipment that integrates an electronic theodolite with an electronic distance meter, can rapidly gather baseline failure position data. Total station equipment is capable of measuring angles in both in the horizontal and vertical planes in conjunction with obtaining distance measurements at a high degree of accuracy. In addition, modern equipment can be controlled robotically by a single operator who can change the target area for measurements without returning to the total station, or they can be automated. The Michigan DOT reported an accuracy of ±1mm at 300 feet distance using an automated target acquisition system, as indicated in 3.2.1.6. The equipment can also record high resolution images. Optical leveling to establish a baseline for assessing settlement that may be continuing following a foundation failure should be performed on at least a second-order basis. Dunnicliff (1993) defines second-order leveling as limiting sight distances, balancing foresight and backsight readings, carefully plumbing the rod, and reading on well-defined marks and stable turning points. Monitoring points for survey measurements are discussed in more detail in Section 5.5.

5.4.1.3 Global Positioning System

In the absence of as-built plans, mobile global positioning system (GPS) equipment provides a useful tool to record photographic records by geographic coordinates with constant updates to GIS mapping. For example, the photographic records for a foundation failure involving a multi-span structure, such as the Tampa, FL Lee Roy Selmon Expressway case history in the Appendix, can be tagged to GPS coordinates (northing and easting) using wearable GPS receivers (Figure 5-2) or GPS devices built into mobile cell phones or tablets.

Figure 5-2: Wearable GPS receiver (Garmin Foretrex™)

5.4.1.4 Light Detection and Ranging

Light Detection and Ranging (LiDAR) is a laser scanning technique for rapid, non-contact data acquisition. The technology is based on sending and receiving laser pulses to build 3-D coordinates of a scanned surface. LiDAR is suited to environments where health and safety conditions limit immediate access to target locations and can also be used to produce topographic maps, penetrating through vegetation to provide a detailed view of the bare landscape. The topographic mapping capability may be particularly useful in quickly establishing baseline failure conditions relative to mass earth movements. In either instance, there is a sacrifice of accuracy relative to a total station survey. Research indicates that georeferenced (tripod based) accuracy of LiDAR data is generally better than 2 cm; airborne topographic LiDAR data is typically no better than 10 cm (Iavarone and Vagners). Standards for LiDAR and other high quality digital photography are periodically published by FEMA.

5.4.1.5 Non-Destructive Testing

Non-destructive testing (NDT) techniques such as pulse echo, induction coil, or parallel seismic may be useful to determine unknown pile lengths in the absence of as-built plans. Each method has advantages and limitations that need to be considered relative to the application and the time available to return the bridge to service.

Pulse Echo – The pulse echo method, which employs a small hand-held hammer to create a compression wave in the foundation element, as shown by Figure 5-3, can be used on all types of solid section foundation elements (concrete, concrete filled pipes, drilled shafts, timber), but has limited application to unfilled steel pipes or H-piles. A compression wave from a hammer strike applied to the exposed pile or shaft head is reflected from the toe, or in some cases, a change in the cross-sectional area or material quality of the foundation element, and returns to the head of the pile or shaft at a time interval relative to the wave speed for the foundation material type. Data from the test can be used to evaluate pile integrity and physical dimensions of both length and cross sectional area. Likens (2015) indicated that the length to diameter ratio (L/D) may be limited to about 30, less in strong soils or possibly greater than 50 in weaker soils. The method conforms to ASTM D5882 "Standard Test Method for Low Strain Impact Integrity Testing of Deep Foundations," and was successfully used in South Carolina to quickly assess in-situ pile lengths relative to scour impacts, as discussed in Section 3.2.11.

Figure 5-3: Pile Integrity Tester (Pile Dynamics, Inc.)

Induction Coil – The induction coil method is based on impressing an AC current into the head of a steel pile or the reinforcing steel in a concrete reinforced pile, which then couples with a return electrode on an offset (either another pile or a driven reinforcing steel section), thereby creating a magnetic field that can be detected by a receiver coil or magnetic field sensor suspended in a nearby PVC cased borehole. The test is only applicable to foundation elements with continuous (electrically connected) steel accessible at the head of the foundation element. The test can be complicated by the presence of high groundwater, ferrous materials in the bridge structure, or other conductive materials buried in the ground. Induction coils can, however, bear advantage over pulse echo methods for very long piles. The method can also be performed in conjunction with parallel seismic, which also requires an adjacent cased borehole. The induction coil method was successfully used in Pennsylvania to assess unknown pile tip elevations for the Birmingham Bridge case history, as shown in the Appendix.

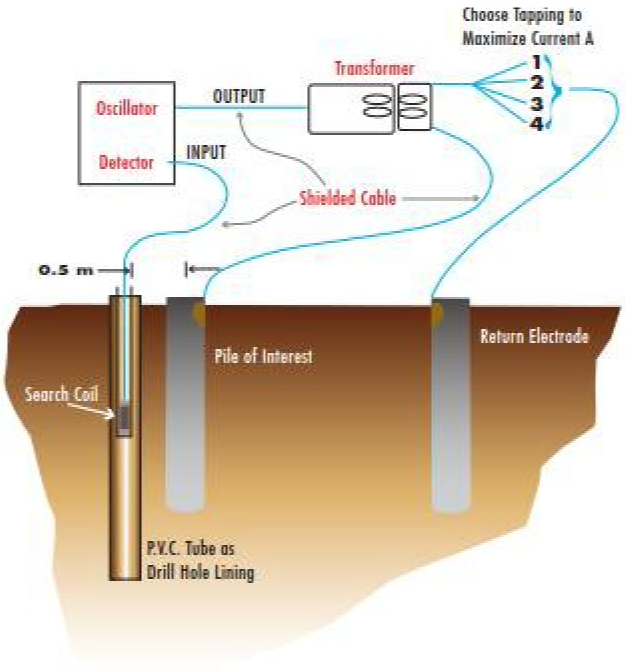


Figure 5- 4: Induction Field Method (Olsen Engineering, Inc.)

- Parallel Seismic – The Parallel Seismic Method is the sonic analog to the electromagnetic induction coil test method. A PVC cased borehole is installed alongside of the foundation element and hammer strikes on the foundation relative to geophone receivers suspended in the borehole are used to assess first arrival (compression) wave speeds. The method depends upon the borehole being deeper than the pile or shaft toe in order to detect a change in the compression wave speed arrival, as shown by Figure 5-5. Access to the pile head is not essential to the parallel seismic method.

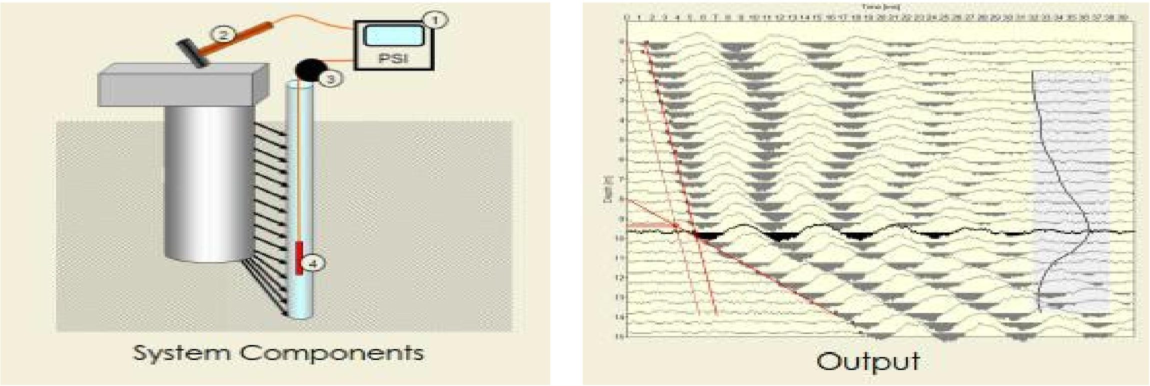


Figure 5-5: Parallel Seismic Test Method (PileTest)

5.4.2. Photographs

Modern digital cameras have resolution and zoom capabilities that enable collection of high quality data. Where possible, photographs should include objects of known size, such as rulers and tape measures, to provide scaling reference. In the absence of camera equipment linked to a GPS tracker, as discussed above, consider using a clip board to enable labeling of bridge pier numbers and the location of specific features. Video clips should also be considered, particularly if government officials will need to be briefed relative to a DOT recommendation for a declared state of emergency.

5.5. Instrumentation and Monitoring For Changing Conditions

5.5.1. Program Development

- Purpose - The instrumentation should have a defined purpose based on the questions that need to be answered, e.g., Is the structure still moving? If so, what is the rate of movement relative to immediate safety of personnel working on the remediation? Is temporary shoring needed to salvage the superstructure before a permanent repair can be designed and installed? If so, at what locations is the temporary shoring needed and on what priority basis? At what point will the restored foundation support be deemed sufficient to return the bridge to service?

- Criteria – Monitoring serves no useful purpose without an action plan. The basis for action should be decided in advance, for instance, upon additional movement of “x” mm in the “y” direction at any two adjacent monitoring points, evacuate all personnel from beneath the bridge and install additional temporary supports per direction of the engineer.

- Planned Redundancy – Redundancy should be built into any monitoring program to account for the limitations of accuracy and the inevitable loss of some monitoring points and instrumentation platforms.

5.5.2. Typical Instrumentation Installations

- Monitoring Points – Amongst the first instrumentation to be considered are fixed points on the structure and possibly the ground, depending upon the circumstances of failure, in order to establish baseline horizontal and vertical positioning at the time of failure. This is normally accomplished by traditional surveying methods as discussed in Section 5.4. If conditions are deemed too unsafe to establish targets, consider a tripod based LiDAR survey while pursuing temporary shoring measures to stabilize the superstructure. At first, typical monitoring points may only consist of spray paint, PK nails, and other very simply points of reference. Typical measuring point details are shown by Figure 5-6 through Figure 5-8 for more refined measurements following the initial response.

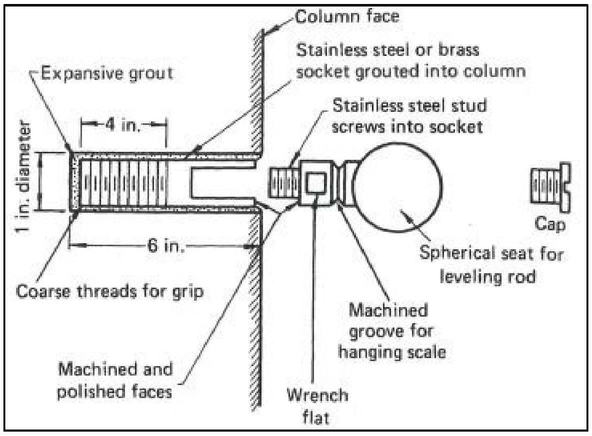


Figure 5-6: Measuring Point on Structure for Precise Work (Dunnicliff)

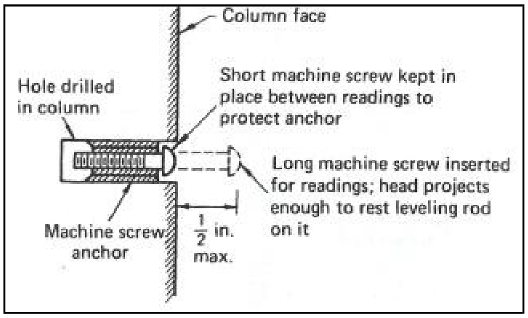


Figure 5-7: Measuring Point on Structure for Less Precise Work (Dunnicliff)

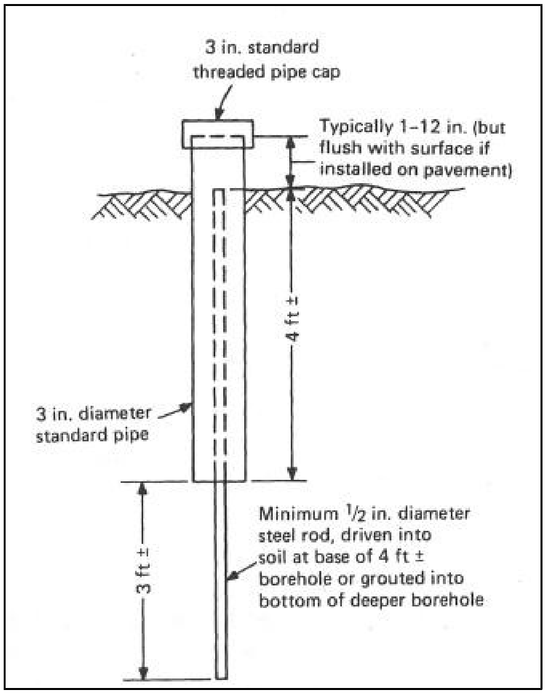


Figure 5-8: Measuring Point on Ground Surface (Dunnicliff)

- Inclinometers – Concurrent with boring investigation, inclinometer casings can be installed in SPT boreholes if lateral ground movement is relevant to the failure condition, such as a landslide or lateral squeeze related failure. Inclinometer casing is special purpose, with grooved tracks to accommodate the inclinometer probe. Casing is available in various diameters, the larger diameters, such as SINCO 85 mm, being more suitable for use where failure is in progress and large ground movements may be occurring. Periodic inclinometer readings will enable detection of shear zones, and establish whether movement is constant, accelerating, or responding to remedial measures.

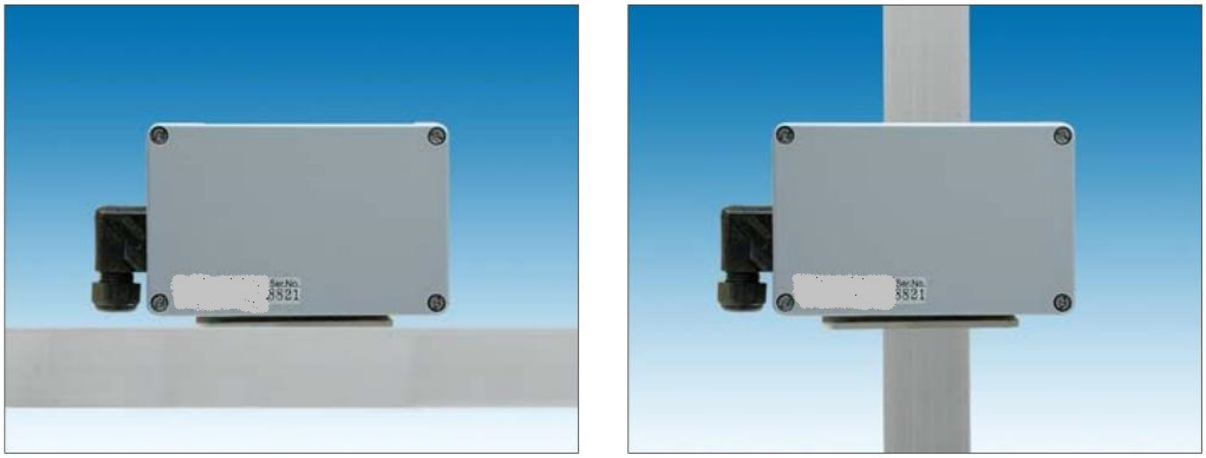
Figure 5- 9: Inclinometer Probe (Slope Indicator Company)

- Tiltmeters – Tiltmeters are used to monitor changes in the inclination of a structure. They are commercially available as both permanently mounted and portable units. The permanently mounted units, as shown in Figure 5-10a, can be attached almost anywhere on a structure with an L-bracket. Readings can be obtained on-site using a portable readout device. An automated data logger can also be used to monitor readings remotely. Portable tiltmeters, as shown in Figure 5-10b, can be used on multiple face mounted tiltplates.

(a) (b)

Figure 5-10: Tiltmeters: (a) Permanent (b) Portable (Slope Indicator Company)

Beam Sensors – Similar to tiltmeters, beam sensors are high resolution electrical instruments that are mounted on horizontal or vertical beams to monitor differential movement and rotation in structures.



Horizontal Beam Sensor Vertical Beam Sensor

Figure 5-11: Beam Sensors (Slope Indicator Company)

- Crack Gauges – Instrumentation monitoring in the aftermath of a bridge foundation failure is less likely to derive meaningful benefit from monitoring the movement of individual structural cracks. Crack gauges are, however, a simple and inexpensive means to assess the continuation of differential movements within a failed structure. Crack gauges consist of two-part overlapping transparent plates with a superimposed grid calibrated in millimeters. The gauges can be attached across cracks using lag screws or an adhesive.

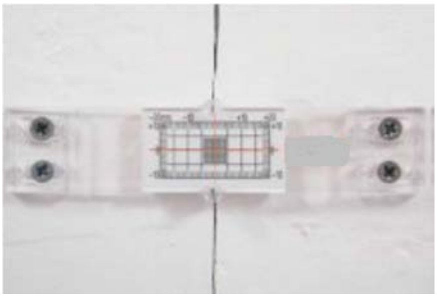


Figure 5- 12: Crack Gauge
(Avongard Products USA)

5.6. Development of Repair Plan

5.6.1. Identification of Options

5.6.1.1 Failed Foundation

If a bridge foundation has failed and the priority is returning the bridge to service as rapidly as possible, fundamental options for repair generally fall into two categories, regardless of whether or not the precise mode of failure is completely understood: a) situations where the substructure unit is reusable, and b) situations where the substructure is not reusable.

- <u>Reusable Substructure Units </u>– Footings or pile caps, abutments or piers are intact and can be utilized in a permanent repair to restore the bridge structure to service. There is a strong precedent for the use of micropiles drilled through or around the perimeter of existing foundations. Since the original foundation element has been comprised, the micropiles or other new foundation element should be designed to support the entire load from the existing substructure unit.

- <u>Unusable Substructure Units </u>– Displacement or damage precludes the inclusion of existing substructure units in a permanent repair. This condition suggests drilled shafts or driven pile piles should be installed adjacent to the existing foundation limits with a post tensioned cap beam used to transfer loads from the superstructure to the drilled shafts. The drilled shafts should be designed to support the entire load from the original substructure unit.

5.6.1.2 Impending Foundation Failure

Closing of a major interstate highway due to an impending failure is typically associated with a loss of structural section, e.g., corrosion, as per the I-35 Duluth, MN case history, or a loss of confinement revealed by inspection, such as the I-95 Clarendon, SC scour case history. In either instance, the remedial action entails restoration by means of encasement or restoration of confinement around the piles, generally without the immediacy of considerations for replacing the existing foundation support. Assessment of the existing condition may be critical to establishing priorities. The non-destructive testing (NDT) methods described in Section 5.4 may be considered in the absence of reliable as-built foundation tip information.

5.6.2. Reusable Substructure Units – Micropile Option

If the substructure is reusable, micropiles offer a distinct advantage over other foundation options due to the light weight and high maneuverability of the typical micropile rig, the speed and low vibration impact of installation, and the full-depth cased drilling method that is capable of penetrating the full spectrum of geo-materials. Due to the performance-based means and methods for developing the bond zone, specialty contractors typically possess design capabilities to, for instance, meet a specified minimum pile resistance requirement, based upon fundamental foundation design criteria. A percentage of the micropile elements can easily and quickly be subjected to either performance testing or proof testing. Typical schematics for foundation repairs using micropiles are included in the Appendix case histories for the Lee Roy Selmon Expressway in Tampa, FL, Flagler Memorial Bridge in Palm Beach, FL, and I-94 over Riverside Drive in Battle Creek, MI. Other important design and construction considerations for the use of micropiles in the permanent repair include, but are not limited to, the following:

- Availability of specialty contracting capabilities within an appropriate range possessing a proven record of performance in the locality
- Design build capability of available contractors
- Site constraints relative to equipment availability – Low-overhead clearance, etc.
- Material availability – Drill casing sizes and wall thicknesses, high-strength reinforcement steel
- Special drilling techniques, pre-grouting, or low-mobility grout specifications warranted under artesian conditions
- Installation configuration (footing penetration or bracketed on perimeter) – existing reinforcement and pile pattern, exposed top of footing dimensions and access, conflicts with existing batter piles or utilities.
- Post tensioning requirements to reduce elastic compression of the micropile element upon load transfer
- Connection details

For guidance on the design of micropiles refer to FHWA Report Number FHWA-NHI-05-039: Micropile Design and Construction (Reference Manual for NHI Course 132078).

5.6.3. Unusable Substructure Units

5.6.3.1 Drilled Shafts

Drilled shafts are cast-in-place deep foundation elements constructed in a drilled hole that is stabilized to allow for placement of reinforcing and concrete. Drilled shafts have a minimum diameter of 30” to 36”.

Due to the large steel requirements for the reinforcement cage and the heavy equipment requirements to install drilled shafts, it is particularly important for emergency repair design work to be preceded by a preliminary assessment of available materials and equipment resources, including the resources that may be available from projects under construction. Early coordination with FHWA and local contractors is essential to this pre-design effort. Typical schematics for foundation repairs using drilled shafts are included in the Appendix case histories for the I-43 Leo Frigo Memorial Bridge in Green Bay, WI, the I-495 Bridge in Wilmington, DE, and the Lee Roy Selmon Expressway in Tampa, FL. Other important design and construction considerations for the use of drilled shafts in the permanent repair include, but are not limited to, the following:

- Availability of contractors within an appropriate range possessing a proven record of performance in the locality
- Permitting requirements for over-the-road transport of drilled shaft rigs
- Availability of reinforcing steel of proper size
- Accessibility of site / need for preparations to accommodate an appropriately sized drill rig
- Need for casing and the installation method for same – oscillator, vibratory, telescoped
- Open hole drilling – environmental considerations for use of slurry or bentonite
- Bridge deck penetration options to expedite the reinforcement cage installation or to reduce cap beam span
- Conflicts with existing batter piles or utilities
- Cap beam construction including post tensioning requirements
- Vibrations caused by casing installation and extraction
- Risks of hole collapse or soil loss during drilling operations

For guidance on the design of drilled shafts refer to FHWA Report Number FHWA NHI-10-016: Drilled Shafts: Construction Procedures and LRFD Design Methods; NHI Course 132014; Geotechnical Engineering Circular Number 10.

5.6.3.2 Steel Piles

In some circumstances, driven steel pipe or H piles can provide a viable option for foundation repairs. Driven steel piles are low displacement piles that will have a lower impact on the failed foundations than large displacement piles such as solid section pre-stressed concrete or concrete cylinder piles. Large diameter steel pipe piles have the added advantages of achieving capacities larger than steel H-piles, resulting in fewer piles, potentially less overall installation time and higher bending moment capacity to resist lateral loads and to avoid battered piles. The vibrations associated with pile driving must be considered in conjunction with the condition of the existing bridge to be sure that the installation of the piles does not have an adverse effect on an already compromised structure.

The specific example depicted by the Chesapeake, VA overpass in the Appendix allowed for crane access on the bridge approach in order to drive piles through deck penetrations to replace the damaged abutment support. Caltrans has also used this technique, as indicated in 3.2.2. Notably, both project examples are in association with correcting long-term settlement issues, reflective of the generally less favorable suitability of driven piles for rapid emergency response repairs.

Important design and construction considerations for the use of driven steel piles in permanent foundation repairs include, but are not limited to, the following:

- Availability of contractors within an appropriate range possessing a proven record of performance in the locality
- Permitting requirements for over-the-road transport of pile driving equipment
- Availability of steel piles meeting ASTM pile standards and in the case of pipe piles, required wall thicknesses
- Accessibility of site / need for preparations to accommodate the pile driving rig
- Need for predrilling and risk of encountering obstructions to driving
- Impact of pile driving vibrations on existing conditions
- Bridge deck penetration options to expedite long pile installation through the deck
- Conflicts with existing batter piles or utilities
- Cap beam construction and post tensioning requirements
- Vibrations and potential settlement and ground displacement during pile driving

For guidance on the design of driven piles refer to FHWA Report Number FHWA NHI-16-009: Geotechnical Engineering Circular Number 12 – Volumes 1 & 2 Design and Construction of Driven Pile Foundations.

5.6.3.3 Right-of-Way Considerations

When selecting a repair option, consideration should be given to the existing right-of-way. If the repair option results in a new foundation that extends beyond the right-of-way line, property or permanent easements may have to be acquired. This process may drive the decision of the foundation type used. A more expensive option that fits within the existing right-of-way may be more attractive if property acquisition is expensive or time consuming.

Existing easement through the state-owned right-of-way such as those for utilities or adjacent property access should also be researched and considered when designing the foundation retrofit.

5.7. Contracting

5.7.1. Delivery

The interviews revealed that the contract type (design build, design bid build, force account) for delivery of emergency services varies depending upon the circumstances of failure, e.g., whether the failure occurred during construction or independent of construction activities, and whether the assessment of condition and remedial foundation design effort is being led by the DOT / DOT consultants or by an on-site design-build contractor. Moreover, the benefits of a declared state of emergency have different implications depending upon the state. For instance, a declared state of emergency in California, Pennsylvania, Delaware, or Ohio, will expedite sole source emergency contracting, but sole source contracting is possible within Indiana and Michigan, without a declared state of emergency. By contrast, a declared state of emergency does not equate to sole source selection in other states. For instance, a declared state of emergency in South Carolina, Virginia, and Wisconsin, which to varying degrees are exposed to weather related disasters, will allow for an expedited bidding process amongst three invited bidders.

5.7.2. Technical Resources

On-call contracts with engineering firms are a common means to quickly access outside technical resources, but existing contracts may not include all the resources suited to a particular bridge foundation emergency. Administrative procedures need to be in-place to expedite subcontract agreements under existing contracts.

5.7.3. Incentives and Disincentives

There was no clear consensus that incentive and disincentive clauses are necessary to successful rapid restoration of bridge service, but they have been used successfully in Florida and California. Aside from the urgency of returning a bridge to service, contract incentive and disincentive clauses can be used as a means toward achieving compliance with federal rules for the use of emergency repair funding within a six-month time frame.

5.7.4. Summary

Because states have different organizations, procurement regulations and laws, it is not feasible to develop one comprehensive response protocol that would be applicable to all states. This reports provides information that guide states to prepare and respond to foundation failures. On important aspect is to engage FHWA early in the process. Early involvement of FHWA can provide technical advice gleaned from other incidents from around the country as well as provide access to emergency funding to implement repairs.

Assembling data on existing bridges into an easily accessible database can be invaluable to providing a quick response to a foundation failure. This assemblage of data can also be used the myriad of other functions performed on a daily basis associated with managing a state’s bridge inventory.

Maintaining a current database of contact information to be used in the event of a foundation failure will speed response time.

Innovative techniques for the acquisition of materials and equipment, such as investigating active construction projects within the state or region can reduce the lead time associated with delivering the material or equipment to the bridge site.

A checklist to help in the development of response protocols tailored to an individual state’s organization is included in Appendix B.

APPENDIX A: LITERATURE REVIEW CASE HISTORIES

I-43 Leo Frigo Memorial Bridge, Green Bay, Wisconsin

The Leo Frigo Memorial Bridge, part of Interstate 43, carries an average 40,000 vehicles per day over the Fox River in Green Bay, Wisconsin (Phelps, 2013). The 1.5-mile-long bridge consists of four lanes, two lanes carrying traffic in each direction. The tied-arch bridge was originally constructed in 1981, with 52 concrete piers each supported by 40 steel H-piles (WisDOT, 2015). Piles were driven approximately 100 feet deep, with the pile tips bearing either in limestone or the dense clay above rock. Subsurface conditions consisted of approximately 20 feet of fill, including porous fly ash fill and industrial byproducts, overlying layers of dense clay and sand with rock at a depth of approximately 90 to 120 feet, as shown in Figure A-1 (Williams, 2013). The bridge was inspected in October of 2012 and determined to be structurally sound (NACE International, n.d.).

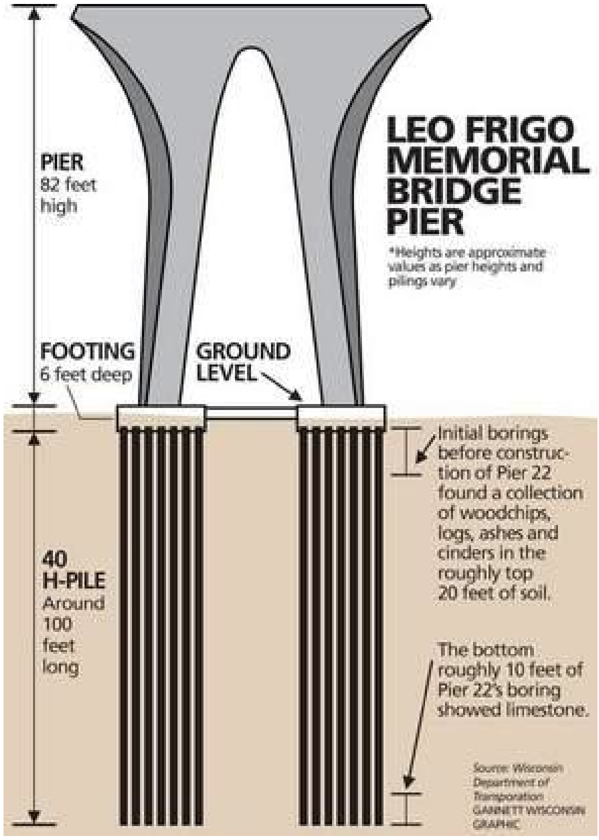


Figure A-1: Existing Conditions of Leo Frigo Memorial Bridge (Williams, 2013)

On September 25, 2013, Pier 22 suddenly settled approximately 2 feet between 3:00 and 3:45 AM. The bridge was closed after motorists called 911 early that morning to alert authorities about the resulting dip in the bridge deck. The vertical displacement of the 400-foot-long span of the bridge deck is shown in Figure A-2 (Phelps, 2013; WisDOT, 2015)

Figure A-2: Sagging Leo Frigo Memorial Bridge (Thompson, 2013)

Wisconsin's Governor declared a state of emergency for the bridge days after the incident, making federal funding available for repairs. The Federal Highway Administration (FHWA) approved federal funding, covering all costs for the first 180 days of the project and 90% of costs after 180 days. Over the next few weeks, WisDOT accepted bids from contractors to complete bridge repairs. The low-bidder was selected and offered an incentive for each day the work was completed ahead of schedule. Literature reviewed for this study did not provide information about procurement for design work. (Luthern, 2013; Thompson, 2013)

Subsurface explorations began on September 28 to investigate the cause of the sudden settlement. Robotic survey instrumentation was also installed to monitor any additional movement of the pier. Investigations revealed corrosion and subsequent buckling of the deteriorated steel H-piles supporting Pier 22 caused the observed settlement. Figure A-3 shows pile corrosion found under Pier 22. Pile corrosion was also found underneath Piers 21, 23, and 25. Investigations determined that the composition of industrial byproduct fill placed in the area of the corroded piles prior to construction interacting with groundwater led to accelerated steel pile corrosion. The porous fly ash fill had high levels of chlorides and sulfides and low resistivity, leading to increased corrosion. A clay layer underlying the fill also led to high differential oxygen levels and chemical concentrations, providing a corrosive environment. Microbial activity also likely played a role in increasing corrosivity. The problem was not detected earlier as checking for pile corrosion is not part of regular bridge inspections. (Phelps, 2013; WisDOT, 2015)

Figure A-3: Pile Corrosion at Pier 22 (Source: Wisconsin DOT)

All piers for the Leo Frigo Memorial Bridge were assessed for pile corrosion and grouped into three categories: tier 1, tier 2, and tier 3. Tier 1 piers showed severe pile corrosion and needed immediate repairs. Tier 2 piers showed some corrosion or potential corrosion, but were not an immediate safety concern. Further monitoring of tier 2 piers was recommended. Tier 3 piers did not show any pile corrosion and had very low potential for future pile corrosion. Piers 21, 22, 23 and 25 were identified as tier 1. Pier 24 was also identified as tier 1 due to its close proximity to other tier 1 piers, even though corrosion was not as severe at Pier 24. Seventeen piers were identified as tier 2. Monitoring instruments were installed on these piers and treatment options were identified should corrosion occur faster than anticipated. No action was required for the tier 3 piers. (WisDOT, 2015)

For tier 1 piers (Piers 21-25), repairs consisted of four 5-foot-diameter drilled shafts installed adjacent to each of the existing pile groups to an average depth of 125 feet, bearing in rock. A post-tensioned extension of each pile cap was constructed to transfer bridge loads to the drilled shafts rather than the steel piles. Buttress walls around the base of the piers were also constructed to transfer loads to the drilled shafts. Centrifugally cast, fiberglass-reinforced, polymer mortar (CCFRPM) casing was placed around the top 30 feet of drilled shafts to resist future corrosion. The new drilled shafts were designed to be capable of supporting the entire pier design load for 75 service years with no contribution from adjacent existing piles. Figure A-4 shows a schematic of repairs to the Leo Frigo Bridge. (Thompson, 2013; WisDOT, 2015)

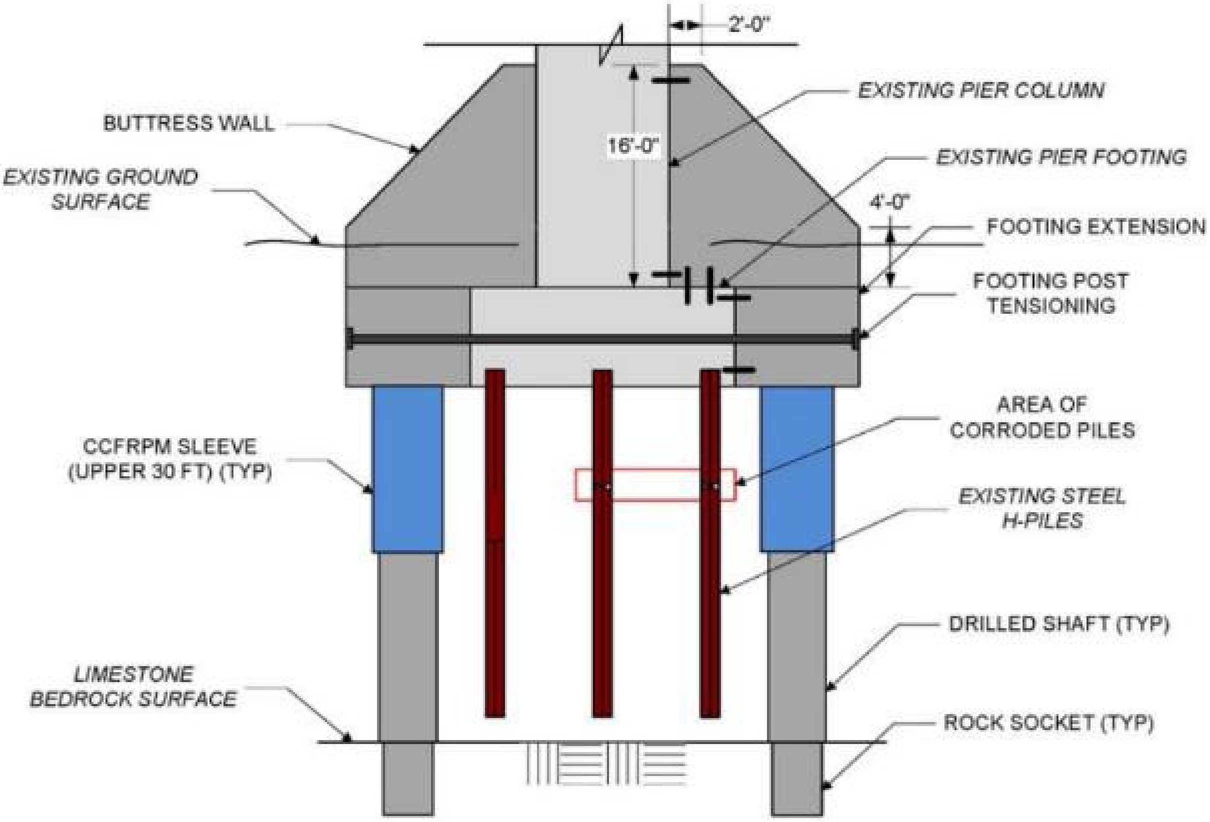


Figure A-4: Schematic of Repairs for Piers 21-25 (Source: Wisconsin DOT)

Repairs were completed and the bridge was re-opened in January 2014, just three months after the initial closing. Round-the-clock investigations and construction led to an ahead of schedule, under budget, and successful repair. The restoration of the Leo Frigo Bridge won an Engineering Excellence award from ASCE Wisconsin, recognizing the dedication of the project team and success of the repairs. Repairs cost $8.45 million, including a $750,000 bonus for finishing early. Costs were completely covered by federal emergency funding. (WisDOT, 2015; Michael Baker Jr. Inc., 2014)

I-495 Bridge, Wilmington, Delaware

The I-495 Bridge over the Christina River in Wilmington, Delaware consists of an interstate highway bridge with three lanes in each direction and carries an average 90,000 vehicles per day. The bridge was originally built in 1973 and consists of parallel structures (for each direction of traffic) supported on single column hammerhead piers. The piers are supported on groups of vertical and battered steel H-piles, approximately 140 feet long. Subsurface conditions consist of up to 100 feet of soft clay overlying more competent dense sand, stiff silty, and bedrock. Piles were driven past the soft clay stratum to bear in the underlying stiff silty clay stratum as shown in Figure A-5. The bridge had been inspected in October 2012 and found to have no deficiencies. (Moffitt and Shelly, 2015; Mohammad and Armfield, 2015)

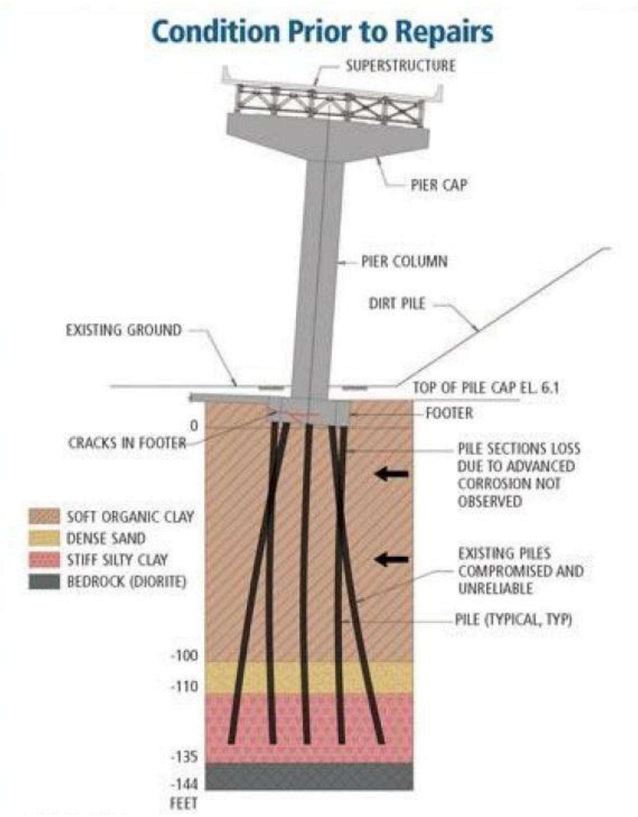


Figure A-5: Subsurface Profile and Observed Damage at I-495 Bridge (O'Shea, 2015)

The bridge was closed on June 2, 2014 after it was observed that 60-foot-high piers on the northbound side were tilting toward the east (Moffitt and Shelly, 2015). The damage was observed by a geotechnical engineer who was working for a third party and was on site to investigate whether a soil stockpile on adjacent private property had caused damage to an underground petroleum pipeline. The stockpile was adjacent to the northbound side of the interstate, specifically in the area of bridge piers 11 through 14. These piers were tilted as much as four percent out of the vertical alignment, resulting in an 18-inch difference in elevation between the median barriers. Subsequent investigations found that the stockpile had caused the bridge foundation failure by inducing lateral loads and deformations (lateral squeeze) into the thick soft clay layer, resulting in lateral displacements of the piles of up to two feet. Figure A-6 shows the soil stockpile adjacent to tilting piers. (Mohammad and Armfield, 2015; Burke and Montgomery, 2014)

Figure A-6: Tilting bridge piers and adjacent soil stockpile (O'Shea, 2015)

On June 3, Delaware's Governor declared a state of emergency and federal funding was made available. Within days, $2 million quick-release Federal emergency relief funding was made available so work could begin. DelDOT immediately began working to find a timely solution to the movements. DelDOT's on-call design consultants were on site the day that the pier tilting was discovered. Geotechnical engineers from FHWA that had experience with foundations repairs of the I-43 Leo Frigo Memorial Bridge were also called in to assist. DelDOT also was able to quickly procure a contractor experienced in emergency bridge repairs. (Mohammad and Armfield, 2015; O'Shea, 2015)

Once the cause of the pier tilting was determined, removal of the soil stockpile by the cooperative owner began immediately and continued 24 hours a day. Just eight days after the bridge closure, removal of 50,000 tons of soil was complete (Burke and Montgomery, 2014).

Subsequent investigations and instrumentation included test pits at pier footings, CPT testing, SPT borings, rock cores, piezometers, inclinometers, and pier tiltmeters. Investigations revealed horizontal cracks at pile caps at Piers 12, 13, and 14 with local buckling of one pile. No pile corrosion was observed. Piers 10 and 15 were determined to not be affected by deformations. CPT testing showed excess pore water pressures well above hydrostatic levels in the soft clay layer under Piers 11-14. This was a concern since surcharge loads are initially carried by the pore water, then transferred to the solid particles as excess pore water pressure dissipates and consolidation occurs. The excess pore water pressures measured in the clay layer corresponded well to the actual surcharge load from the soil stockpile. (Mohammad and Armfield, 2015)

Geotechnical data from a recent investigation for the Wilmington Waterfront Christina River Bridge west of the I-495 Bridge were used in initial repair design, along with historic data, original plans, and adjacent structure foundation investigations. Initial, conservative estimates of geotechnical design parameters for the repair design were developed based on available information. The design parameters were subsequently adjusted once laboratory and in-situ testing results were available. This approach resulted in a repair design that was feasible based on conservative assumptions that was then later refined and optimized based on more accurate data. (Moffitt and Shelly, 2015)

Repairs consisted of augmented foundations for Piers 11-14 and pier replacements for Piers 12 and 13. Drilled shafts were selected for the new foundations due to their high stiffness and lateral resistance compared to the existing steel H-piles. Four-foot diameter drilled shafts were installed to bedrock with depths ranging from 130 feet to 160 feet. The shafts were designed to end bear on the bedrock with no side resistance contribution, but were not socketed into rock in order to minimize the construction schedule. Although excess pore water pressures began dissipating from the time of the removal of the soil stockpile, the initial excess pore water pressures were included in the shaft design for conservatism. (Mohammad and Armfield, 2015, Moffit and Shelly, 2015)

Reinforcing steel cages for the drilled shafts came from New York's Tappan Zee Bridge Project, saving an estimated 10 to 12 weeks. Another time saving technique was to cut 6-foot square holes in the bridge deck over the drilled shaft locations, so that the entire reinforcement cage could be fabricated near the bridge and inserted into the drilled shaft excavation, rather than installing the reinforcement cage in segments and splicing segments together at the drilled shaft location. (O'Shea, 2015; Shemo and Roecker, 2015)

New 8-foot-thick pile caps were installed above the drilled shafts and the existing pile caps. Vertical post-tensioning bars were installed to engage the existing pier footings. The columns and new pile cap were also connected through shear bond and keying. (Shemo and Roecker, 2015)

Using low headroom equipment and averaging a production rate of one shaft per day, 32 drilled shafts were constructed by July 16. Steel casings were used for the entire shaft length to minimize the potential of soil loss during installation. Casing oscillators were initially used to limit vibrations and prevent additional damage to pile groups. However, since the use of the oscillators was very slow, the contractor changed methods to employ a vibro-hammer for casing installation while vibrations and tiltmeters were closely monitored. No additional movements were measured during the casing or shaft installations. (Moffit and Shelly, 2015)

Piers 12 and 13 experienced the most deformations and required replacement. Temporary jacking towers were built to support these sections of the bridge by transferring the load to the new drilled shafts. This enabled replacement of Piers 12 and 13 while the bridge was open to traffic. Figure A-7 shows the methodology used in repairing the I-495 Bridge. (Mohammad and Armfield, 2015)

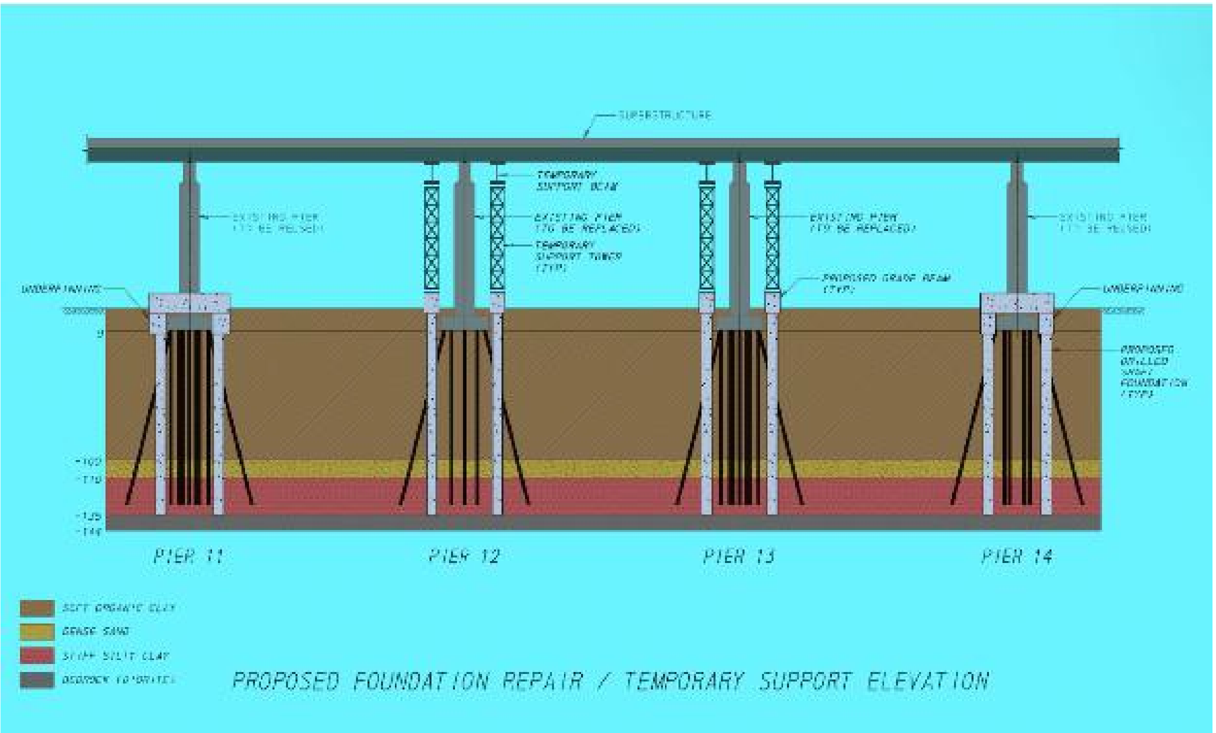


Figure A-7: Repair methods and temporary support (Mohammad and Armfield, 2015)

The southbound lanes of the bridge were opened within 59 days of closure and the northbound lanes were opened 83 days after closure. The total cost of repairs was $40 million. Temporary repairs were paid completely by Federal funding and 90% of permanent repairs were paid for by Federal funding (O'Shea, 2015). Work was done 24/7 to complete repairs in a timely manner. Investigations and initial design were able to occur simultaneously, also saving time and money (Moffitt and Shelly, 2015). Close communication and cooperation of the client, designer, and contractor, along with the clear vision and leadership of DelDOT and assistance from FHWA, led to quick and successful repairs (Mohammad and Armfield, 2015).

I-65 Bridge, Lafayette, Indiana

The Interstate 65 northbound bridge, originally constructed in 1969, carries 25,000 vehicles per day across Wildcat Creek between Indianapolis and Chicago. The five-span, two-lane bridge is 394 feet-long; and the interior piers are supported on shallow foundations with end bents are supported on driven steel H-piles. Subsurface conditions consisted of relatively impermeable glacial till underlain by sand and gravel with artesian conditions. The artesian pressure is about 15 to 20 feet above the lowest elevation in the creek channel, based on post-subsidence piezometer data. (INDOT, 2015)

In January, 2015 INDOT awarded a design-build contract of $82.8 million to widen and rehabilitate I-65 from State Road 38 to State Road 25 in Lafayette. The bridge was being widened to the interior. Foundations for the widened portion of the bridge were to be supported by H-piles. Construction began in July, 2015 and included installation of sheet pile cofferdams adjacent to the existing piers to excavate for pile caps, and driving steel H-piles for support of the widening foundations. (INDOT, 2015a)

Work commenced with driving of sheet piles for cofferdams and pile driving at the north abutment and the two northernmost interior piers, Piers 2 and 3. On August 4, following pile driving, the bridge bearings for the northbound bridge fell out at Pier 3, and the northbound bridge was closed to traffic. The following day the bridge beams were jacked back into place, temporary grillage installed, and the bridge briefly re-opened. The cofferdam at Pier 3 was dewatered in preparation for continuation of construction. However, based on further inspection and measurement, Pier 3 was found to have settled 9 inches on the west, 10 inches on the east, and had rotated 7 inches out of plumb uniformly to the north, and the northbound bridge was closed to traffic on August 7. Investigations found that the settlement was likely due to pile installations penetrating a confined artesian sand layer. The overlying less permeable soils, once penetrated by piles into the aquifer layer likely released water under pressure along with sand, causing subsidence and tilting of Pier 3. Heaving of soil inside the cofferdam excavation may also have contributed to the failure. Instrumentation installation and real-time monitoring were used to assess conditions following the initial settlement. No damage to the southbound bridge was observed. (Vizza and Kiefer, 2015; INDOT, 2015).

Re-establishment of ground support of the footing by compaction grouting or pressure grouting of the artesian layer was considered, but the project team had concerns about the challenges and uncertainties inherent in the grouting operations in the artesian setting. Based on past projects and foundation repair philosophy, FHWA strongly advised against returning a failed bridge foundation to service. A structural solution, with foundation underpinning, was preferred, in order to substitute a deep foundation for the settled spread footing. Drilled shafts were considered, but were not selected due to constructability considerations in artesian conditions.

Repairs to Pier 3 consisted of 12 high-strength, small-diameter steel micropiles installed through the pier's footing to a depth of 67 feet and a steel-reinforced concrete block installed around the existing bridge pier to transfer pier loads to the micropiles. A test micropile was installed near Pier 3 first to verify load capacity. To help mitigate the influence of artesian pressure, low mobility grout was injected during the drilling process. After the piles were installed, the bridge deck was jacked back up to its original position and steel supports were installed (McCoy, 2015). When the structure was jacked up, the contractor used H-piles for temporary support to facilitate rocker bearing restoration. The H-piles were available on-site, facilitating the quick implementation of this emergency repair. Figure A-8 shows the I-65 bridge deck following the failure. (INDOT, 2015; McCoy, 2015)

Figure A-8: Post-Failure View, I-65 Bridge, Lafayette, Indiana (McCoy, 2015)

A fracture critical inspection was performed prior to re-opening the bridge. Load tests were also performed, 24 hours after re-establishment of the final elevations. Load tests were performed with varying configurations of truck traffic on the bridge, to observe performance under maximum vertical load, negative moment on the superstructure, braking loads, and an eccentric loading on the restored pier and foundation. The bridge was instrumented with inclinometers and strain gages to observe performance during the load test program. The design-build bridge engineer, in their role as engineer-of-record, reviewed the design considerations associated with leaving the tilt in the existing pier, and confirmed its acceptability. The bridge reopened September 6, 2015, only a month after observed settlement. Continuous work by Indiana DOT and the contractor made the quick turnaround possible (INDOT, 2015). Construction of the remaining portion of the widening project progressed with continuous bridge monitoring by Purdue University, and with design and construction measures to avoid similar settlement of the remaining piers to be widened.

Lee Roy Selmon Expressway, Tampa, Florida

The Lee Roy Selmon Expressway in Tampa, Florida is an elevated reversible 3-lane highway section constructed from 2003 to 2005 within the median of an existing highway. The existing highway was constructed in the early 1970s and carried an estimated 75,000 vehicles per day, with four lanes in each direction, between Brandon and Tampa. The elevated reversible lanes were meant to provide congestion relief during high volume traffic times. Piers for the elevated reversible lanes were designed to be supported by single (non-redundant) six-foot diameter drilled shafts bearing in highly weathered rock. (Graham et al., 2014; Stein et al., 2004)

Subsurface conditions consisted of 15 to 35 feet of recent sand and silt sediments underlain by 5 to 15 feet of marine clay and highly weathered limestone, as shown in Figure A-9. The geological conditions in this area consist of highly variable materials and strength and karstic limestone. (Dapp et al., 2013; Graham et al., 2014)

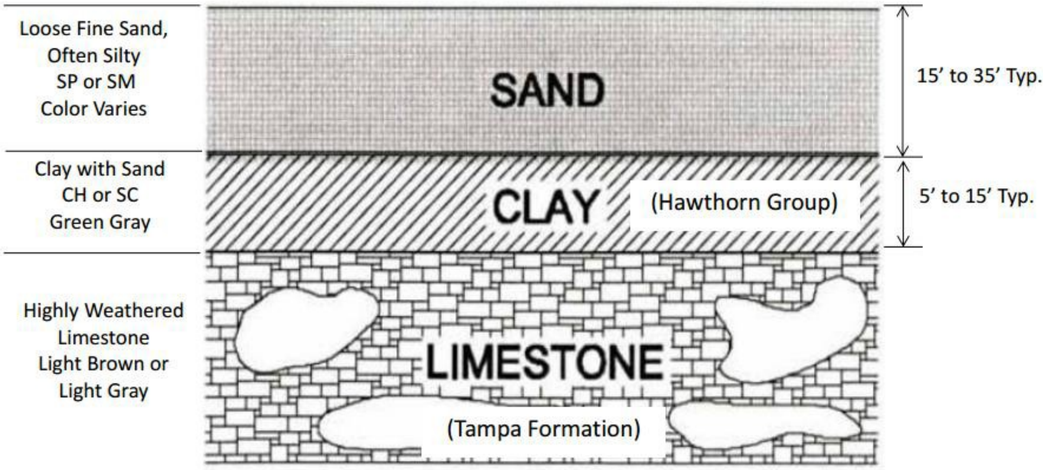


Figure A-9: Subsurface Conditions (Dapp et al., 2013)

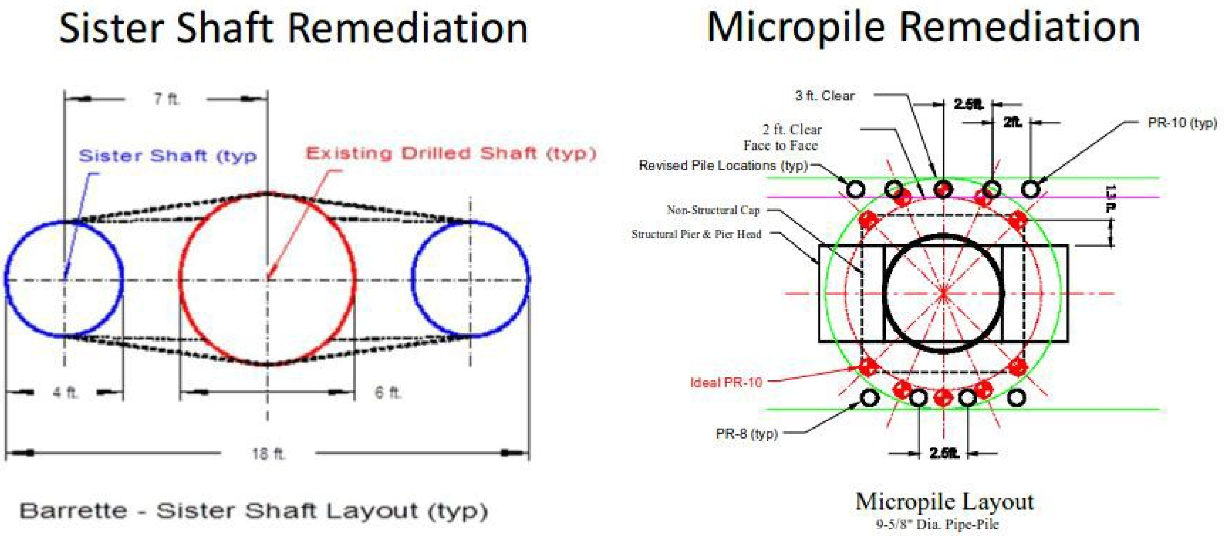
Information about the procurement of the project was not found in the reviewed literature.

In April 2004, approximately 14 months into construction of the elevated lanes, Pier 97 suddenly settled 11 feet (Samuel, 2009). The photograph in Figure A-10 shows the damage from the sudden settlement.

Figure A-10: Collapse of Pier 97 in April, 2004 (Graham et al., 2014)

The 11 feet of settlement was initially thought to be due to an undetected sinkhole beneath Pier 97. However, a few months later in June, 2004, another pier settled a few inches. As more piers began to settle, further investigations found that only 50 of the 204 piers were designed with adequate foundations for the soil/rock strengths present. (Samuel, 2009; Graham et al., 2014).

Repairs were paid for by the owner, Tampa Hillsboro (Toll) Expressway Authority (THEA), but subsequently were the subject of a claim by THEA for recovery of these costs. Specific information about procurement of the repair work was not found in reviewed literature. Depending on geological conditions, the insufficient piers were either retrofitted with micropiles or drilled shafts. Four to ten micropiles, depending on soil conditions, were installed to augment existing foundations at 87 of the piers. Two 4-foot diameter "sister" drilled shafts were installed for support at each of the remaining 67 drilled shafts that needed remediation. Post-tensioned foundation caps were used to connect the existing foundation with the new drilled shafts. Figure A-11 shows schematics of the two different types of remediation. Multiple borings at each pier were taken and correlated to results from full scale dynamic testing previously done for recently constructed piers to determine if/how much additional support was needed (Samuel, 2009; Graham et al., 2014).


Sister Shaft Remediation

Micropile Remediation

Barrette - Sister Shaft Layout (typ)

Micropile Layout
9-5/8" Dia. Pipe-Pile

Figure A-11: Remediation techniques selected (Dapp et al., 2013)

Flagler Memorial Bridge, Palm Beach, Florida

The Flagler Memorial Bascule Bridge in Palm Beach, Florida connects four lanes of traffic from the Town of Palm Beach and the City of West Palm Beach over the Lake Worth Lagoon and the Intracoastal Waterway. The original bridge was constructed in the 1930s. The two bascule piers each have two footings originally supported by timber pile groups. As-built timber pile tip elevations were not available, but likely bear on a thin rock stratum. Subsurface conditions include clean sand with intermittent limestone and coquina rock layers. The thickness and elevations of stratums vary significantly throughout the site. For example, out of the borings that encountered rock, the top elevation of the first layer of limestone/coquina rock ranges from -35 feet to -78 feet.

A bridge inspection from 2006 indicated that the existing bridge was structurally deficient, earning a bridge sufficiency rating of 32.4/100. Piles needed repairs, spans were cracked, and concrete beams were deteriorating. The existing bridge also did not meet FDOT design standards. It was decided that a replacement bridge adjacent to the existing bridge was needed. (FDOT, 2012)

FDOT awarded a $94 million design-build contract to replace the Flagler Memorial Bridge. The new bridge was designed to be supported on twenty 5-foot diameter drilled shafts. During the start of drilled shaft construction in October, 2012, the existing bridge settled up to 1.75 inches. At the time settlements occurred, drilled shaft casings were being installed with a vibratory hammer less than 10 feet from the existing bridge in some locations. Settlements resulted in the lock bar of the bascule pier periodically malfunction over the next month. Repairs were made to return the lock bar to an operational level. (Sparks, 2014)

An engineering consultant was called in shortly after settlement occurred to investigate the cause of the settlement and design foundation repairs to prevent any further settlement. It was determined that construction vibrations likely densified sandy layers and caused settlement underneath bearing rock layers supporting the existing timber piles. Loss of material during drilled shaft excavation was another potential contributor to observed settlement, as the ground level inside the casing of the first drilled shaft increased 2 to 3 feet over a one week period in October, 2012 when excavation was paused. However, loss of material was likely not the main cause of settlement.

Options considered for foundation repairs and future settlement prevention included micropile underpinning and grouting of sand layers. It was also considered to change the construction phasing and details of the replacement bridge so that construction activities would be farther away from the existing bridge, but this was rejected due to substantial redesign efforts and schedule impacts that would occur. Micropiles were ultimately selected to underpin the bridge. Design consisted of 68 new micropiles installed to a depth of 80 feet, which was deeper than existing timber piles and construction activities of the new bridge. A plan view of designed micropile underpinning for one of the bascule piers is shown in Figure A-12. Dimensions of designed micropiles consisted of an outer diameter of 9.625 inches, a wall thickness of 0.472 inches, and a 35 foot bond length with a reinforcing bar. Micropiles were connected to existing footings with brackets. A design-bid-build contract was awarded to the lowest bidder to complete the repairs.

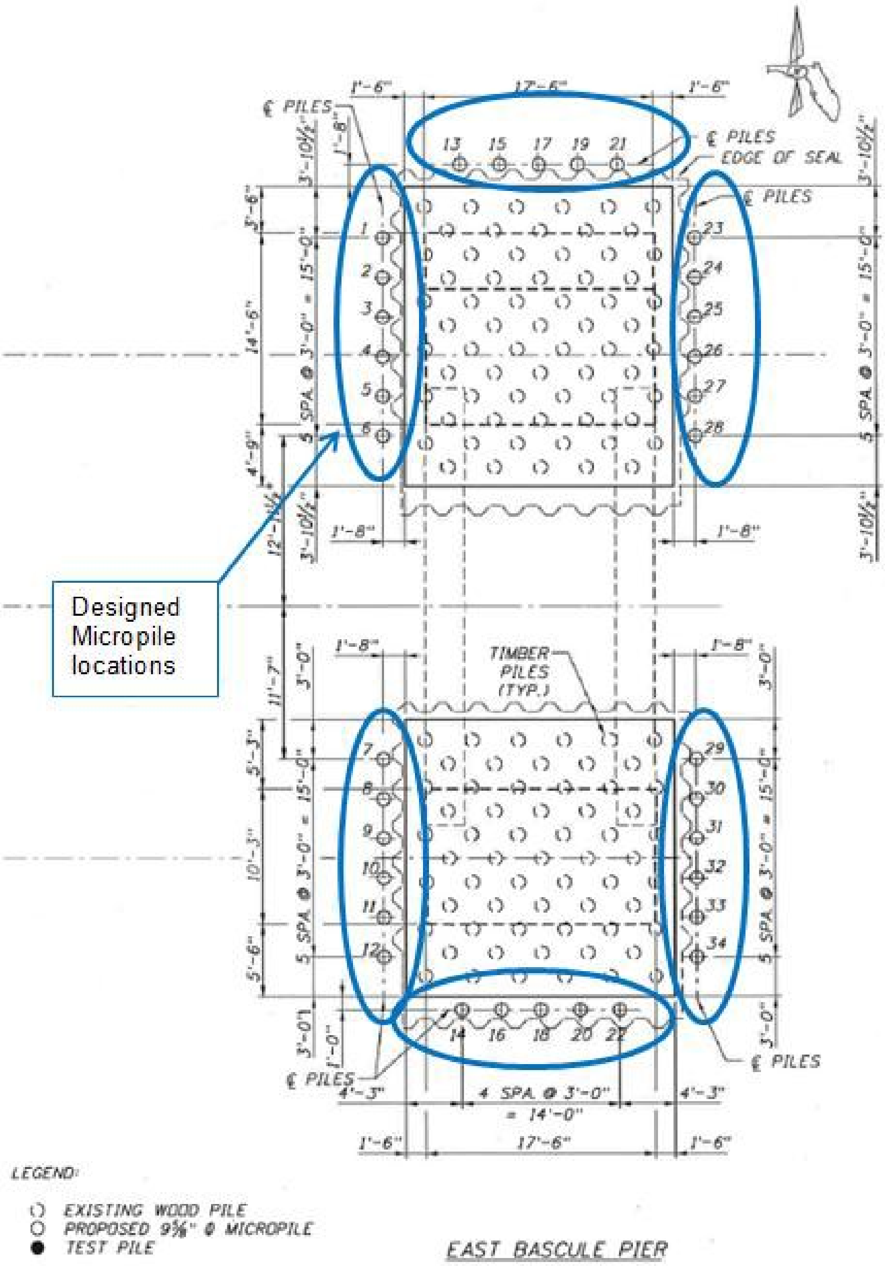


Figure A-12: Plan View of Micropile Locations for East Bascule Pier (Lauckner, 2013)

Construction and installation of new micropiles began in May, 2013 and were completed by November, 2013. The contractor earned a $675,000 incentive bonus for finishing the work early. After repairs were completed and the bridge reopened, approximately ½ inch of additional settlements occurred as the new micropiles took on the full bridge loads and compressed. One complication and potential contribution to this settlement was that it was assumed construction would be in the dry with cofferdam groundwater cutoff; however, the contractor did the work underwater, making inspection and quality control difficult. This additional settlement did not cause the bridge to close again. (Kelly, 2013)

Overall, FDOT has been satisfied with the foundation repairs performed on the older existing bridge. Construction is still ongoing for the adjacent replacement bridge as of October, 2015 and completion is expected in late 2016. (Kelly, 2013)

Birmingham Bridge, Pittsburgh, Pennsylvania

The Birmingham Bridge in Pittsburgh, Pennsylvania carries 10,000 vehicles per day across the Monongahela River. The tied arch bridge was originally built in 1976. Piers were each supported by 48 steel H-piles. Original piles were driven to refusal, which was not always as deep as the design depth to rock due to intermittent layers of hard material and obstructions. Subsurface conditions, shown in Figure A-13, consist of approximately 30 to 40 feet of fill material underlain by layers of shale, claystone, and more competent sandstone. (Oakland Transportation Management Association, 2015; Splitstone et al., 2010)

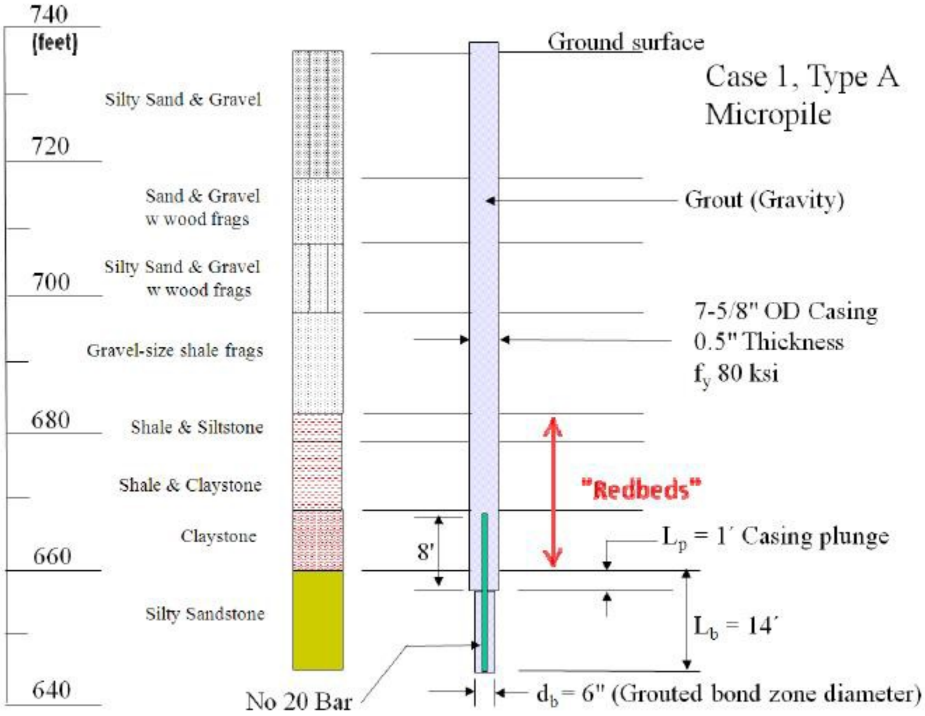


Figure A-13: Subsurface profile and test micropile dimensions (Splitstone et al., 2010)

On February 8, 2008, two spans of the bridge dropped 8 inches overnight. The bridge was closed once motorists called 911 to alert authorities about the movement. PennDOT immediately sent out 25 bridge inspectors to examine the entire bridge structure. A local general contractor and consulting engineer were brought in to analyze the superstructure and substructure and develop temporary supports. Movements were found to be due to steel rocker bearings at Pier 10S over rotating and failing, causing girders to drop onto the pier cap and damage the pier. Pier 10S had horizontal displacements up to 9 inches and cracking at the base of columns. Tiltmeters indicated that pier columns were bending and the pile cap had not rotated. Geotechnical investigations, including inductive coil testing of the two original driven piles, indicated that pile tip elevations were above top of rock elevations and the design elevation. Likely, piles were driven until encountering refusal at a lens of hard material 35 to 40 feet above competent rock. Foundation failure was not necessarily the reason for the steel rocker bearing failing, but evaluation of the foundation system determined that foundation retrofitting was also necessary. (Splitstone et al., 2010)

PennDOT awarded a design-build contract to a team including a general contractor, geotechnical consultant, and geotechnical contractor to develop a deep foundation solution that could be constructed while temporary supports were being used and the bridge remained open to traffic. (Splitstone et al., 2010)

Deep foundation alternatives considered included drilled caissons, driven H-piles, and ground improvement (grouting and micropiles). Drilled shafts were eliminated due to the small available work space and spoil volume produced by drilled shafts. Grouting was eliminated due to unsuitable soil conditions. Micropiles, which would have minimal drill cuttings and spoil, were ultimately selected to retrofit existing foundations. (Splitstone et al., 2010)

Micropiles with a 7.625-inch outer diameter and ½ inch wall thickness were installed though the existing concrete footing while avoiding the existing 48 H-piles of the original pier. Thirty-three micropiles were installed to a depth of 84 feet under Pier 10S. Track-mounted hydraulic drill rig equipment was used to make installation possible in low headroom conditions and confined space. Percussive rotary eccentric duplex drilling techniques with overburden drilling systems were used to advance the steel casing through the original footing, fill, dense layers, and obstructions. Original piles of Pier 10N were also found to bear at an insufficient depth, requiring 22 micropiles for this foundation. The new foundations were connected to the existing pier with post-tensioning bars. (Splitstone et al., 2010)

The southbound deck was reopened on March 3, 2008 to traffic in both directions. The northbound deck was fully reopened on September 8, 2008. Repairs were accomplished quickly through close coordination between all parties involved. Past experience between PennDOT, contractors, and consultants along with knowledge of resources and means and methods made for timely and successful repairs. (Oakland Transportation Management Association, 2015; Splitstone et al., 2010)

I-35 Bridge, Duluth, MN

A 2,100-foot long, low-lying interstate bridge in Duluth, MN carries 5,100 vehicles per day of I-35 traffic. The bridge consists of 38 piers supported by 1,300 steel piles. The piles were driven past soft, mucky soil to bear on bedrock, approximately 40 feet deep. (Kraker, 2013)

In November of 2013, during a scheduled bridge inspection, Minnesota Department of Transportation (MnDOT) inspectors discovered pile corrosion near the connection to Pier 32 of the southbound bridge, where the bridge is just 4 feet off the ground. Figure A-14 shows the observed damage. Excessive moisture and poor drainage were thought to be the causes of the corrosion. Another potential contributor is the high chloride content from salt washing off of the bridge deck during winter, increasing corrosivity. The entire bridge was closed on November 18, 2013 in order to better assess the condition of piles. (Kraker, 2013; Paint Square, 2013)

Figure A-14: Pile corrosion under Pier 32 (Paint Square, 2013)

MnDOT started repair work with its internal maintenance crew before hiring a contractor to complete the work. MnDOT awarded an emergency contract with an accelerated schedule for 24/7 work. Concrete collars were installed around the damaged piles at Pier 32 and the bridge was reopened about a month later. (Kraker, 2013; Paint Square, 2013)

Bridge Overpass, Chesapeake, Virginia

An overpass bridge carrying Route 17 in Chesapeake, Virginia was originally constructed in 1992. The 250-foot-long, 100 feet wide bridge was supported on 12 inch, pre-stressed, pre-cast concrete piles from 70 to 100 feet long. The approach embankments were 35 feet high and 90 feet wide on top. The subsurface conditions consisted of 15 feet of silty sand underlain by a 40-foot stratum of soft organic clay overlying firm sand and stiff clay. Figure A-15 shows original bridge dimensions and subsurface conditions. (DeStephen, 2015)

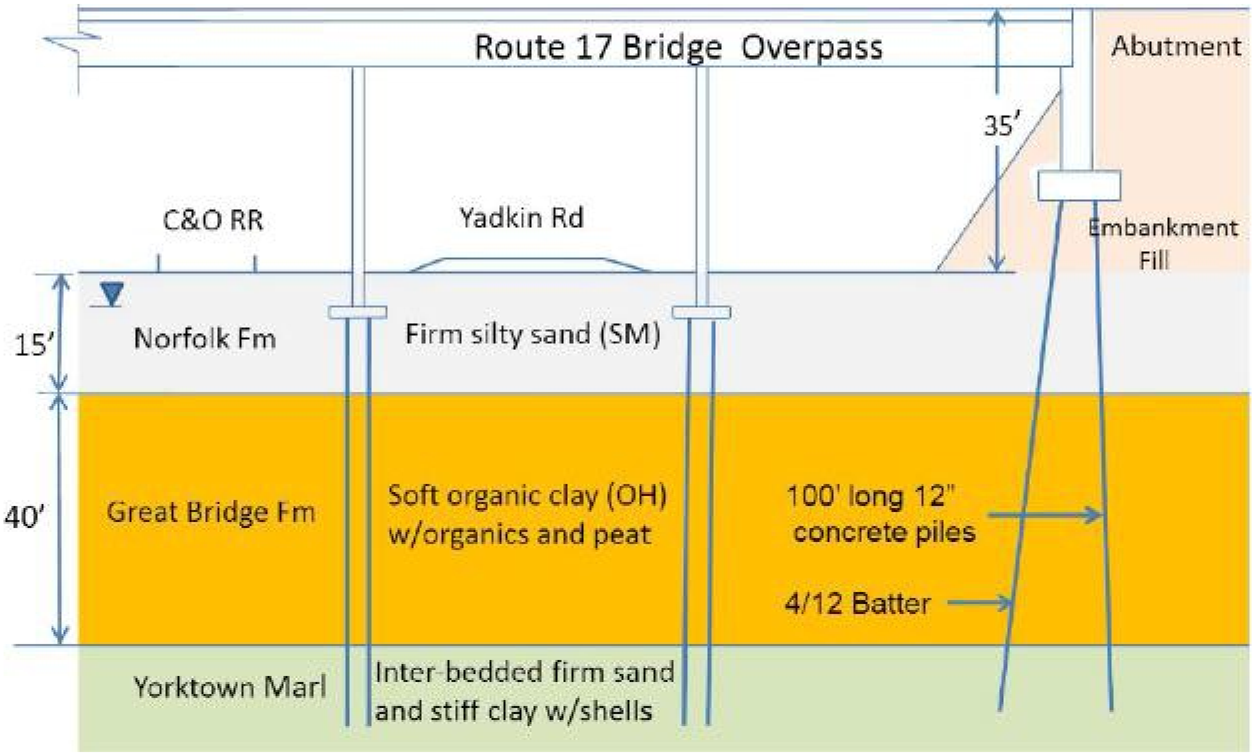


Figure A-15: Bridge Dimensions and Subsurface Conditions (DeStephen, 2015)

Settlements of 2.5 feet to 3.5 feet were expected from approach embankment loading during the original construction of the bridge. Since eighty percent of this settlement was expected to occur over 3 months, so the embankments were constructed and allowed to settle for 3 months before bridge construction began. However, by 2000, additional settlements of up to 2.5 to 3 feet had occurred at the approach embankments after the end of the bridge construction. Figure A-16 shows sagging of the approach at the surface from excessive embankment settlements. A study conducted in 2003 concluded that original analyses did not properly calculate anticipated settlements or account for downdrag effects on the foundation piles. Up to 22 more inches of consolidation of the soft clay layer under the existing embankment load was possible. Damage to the bridge from settlement included cracked beams, buckling of slope protection, and cracked wing walls. Investigation into the abutment foundations indicated that the piles supporting the abutment were severely damaged. Figure A-17 shows the tensile failure of a pile due to downdrag and the void beneath the abutment foundation. (DeStephen, 2015)

Figure A-16: Damage from Settlements (DeStephen, 2015)

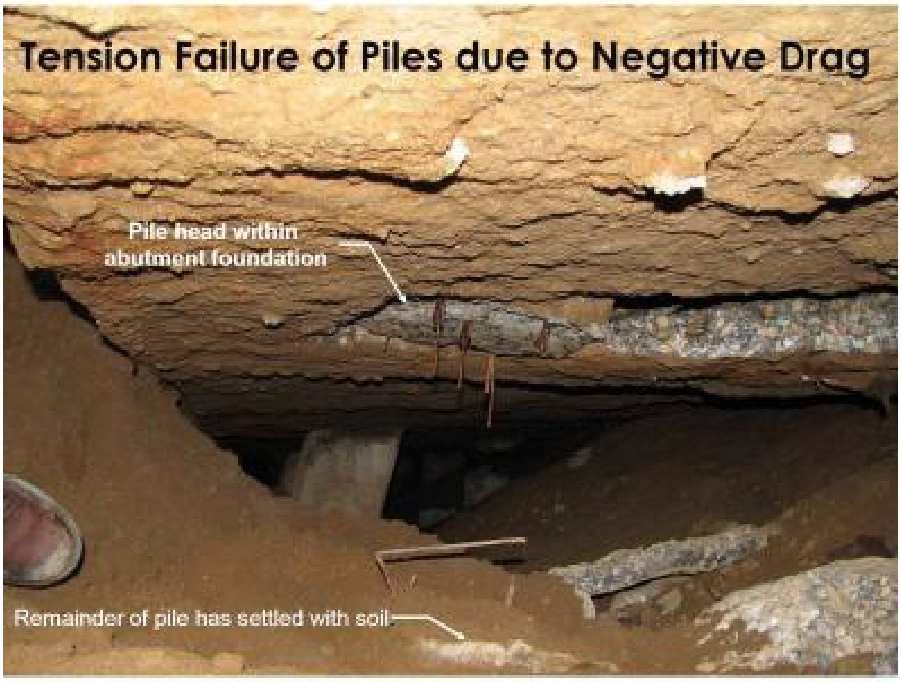


Figure A-17: Settlement Damage from Downdrag (DeStephen, 2015)

As of 2003, the center pier piles had settled up to 1.5 inches, the end pier piles had settled up to 3.5 inches, and the abutment piles settled from 4 to 12 inches. Repair alternatives considered included underpinning with micropiles, underpinning using jet grouting, or partial reconstruction of the bridge. No information on procurement of repairs was found in the reviewed literature. It was decided to reconstruct the bridge abutments while the piers and bridge spans were left in place. Sixteen-inch diameter steel pipe piles were installed as new foundations for the abutments. The piles were coated to reduce friction. Temporary shoring and steel H-piles were used to support the structure during abutment reconstruction. Square access holes were cut in the bridge deck to install the piles. Figure A-18 shows the temporary and permanent foundation elements replacing the original pre-stressed concrete piles. (DeStephen, 2015)

Figure A-18: Repairs and New Foundations (DeStephen, 2015)

Interstate 94 over Riverside Drive, Battle Creek, Michigan

The Interstate 94 bridges over Riverside Drive were originally completed in 1958 as three-span, simply supported structures with continuous partial-height abutment walls and isolated piers supported by shallow foundations (Thelen and Thome, 2011). The geologic section was characterized by a relatively thick glacial lake bed deposit, which formed a confining layer of clay over glacial spillway sands and gravels, which were under a “near artesian” piezometric head. Typical subsurface conditions are depicted by Figure A-19.

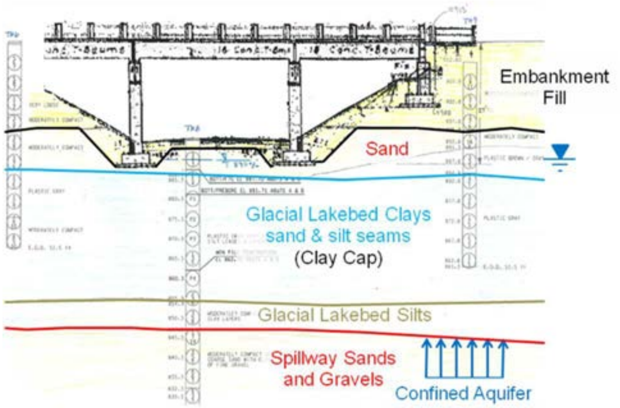


Figure A-19: General Soil and Groundwater Profile at Project Site (Thelen and Thome, 2011)

Plans for replacement bridges were based on single-span, simply supported structures with continuous full-height abutments supported by deep foundations consisting of HP12x53 piles. Construction of the replacement bridges was to be in partial-width stages so as to maintain traffic in both directions. However, during the initial construction stage, movements were significant enough to require temporary closures and emergency stabilization of the bridges.

Pile driving began on April 29, 2009 using a diesel impact hammer, but by May 13, settlement of Riverside Drive was visually estimated to be on the order of one foot. At that time, a vibratory pile hammer was in use, but it was not possible to determine over what time-frame the settlement had actually occurred relative to the initiation of pile installations.

The existing EB and WB I-94 bridges were closed to traffic on May 14, 2009 for emergency repairs. The bridge was reopened to traffic the next day after survey monitoring information indicated no significant continuing movements. A specialty foundation contractor was contracted directly through MDOT to provide an emergency micropile retrofit for two of the existing EB pier footings. In consultation with MDOT, the micropile designs were based on an allowable stress design load of 100 kips and were positioned as shown by Figure A-20 with the primary concentration of piles on the north end of both piers due to the observed settlement pattern. Duplex drilling with water proved successful in minimizing the potential impacts from the artesian conditions with the sands and gravels.

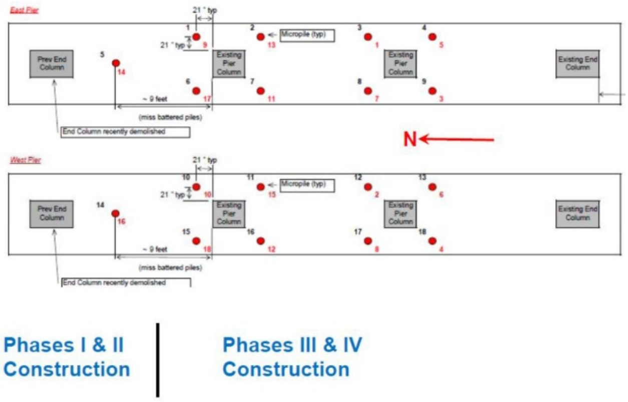


Figure A-20: Micropile Layout Plan (Thelen and Thome, 2011)

Overall, the emergency repairs included the following elements:

- Connecting the EB and WB bridge decks together at each pier;
- Placing hot-mix asphalt taper behind existing west abutment of WB I-94;
- Excavating behind existing Stage I abutments at a 1H:1V back slope;
- Removing existing Stage I abutments in sections after saw and wire cutting;
- Paving existing EB I-94 bridge and approach shoulders and traffic lanes;
- Connecting existing Abutment A to five of the six remaining EB I-94 T-beams;
- Underpinning existing EB I-94 Bridge Piers with micropiles; and
- Filling voids found behind EB Abutment A with flowable fill below the backwall.

Micropiles installed for the retrofit of the existing pier footings stopped the settlement until the stage construction could be completed. The travel lane of EB I-94 Bridge was reopened on May 26, 2009 after most of the underpinning of the EB I-94 Piers was complete. The passing lane of EB I-94 was reopened on May 27, 2009 after the underpinning of the EB I-94 Piers was complete.

APPENDIX B: FOUNDATION REPAIR CHECKLIST

Advance Preparation and Planning Check List

The following information should collected and maintained in a central state or regional location for ready reference, when needed, in response to a foundation failure event. It is assumed that each point of contact noted in this checklist will have established an organization beneath them and that the response from an organization will be initiated by the point of contact for that organization.

Response Organization Points of Contact:

	Yes	N/A
State DOT	○	○
Regional DOT	○	○
County Government Office	○	○
City/Town Government Office	○	○
FHWA Regional Office	○	○
Police Department	○	○
Fire Department	○	○
Governor's Office	○	○
Design Consultant(s) Currently Under Contract	○	○
Contractor(s) Currently Under Contract	○	○
Public Outreach Coordinator	○	○
US Army Corps of Engineers	○	○
US Coast Guard	○	○
Railroad	○	○
Transit Agency	○	○

Notification Contacts:

Ownership of Feature under the Bridge	○	○
Under-bridge Easement Holders	○	○
Utility Owners (On and Under Bridge)	○	○
Adjacent Property Owners	○	○

The following check list can be used as guidance for acquiring pre-event information such as bridge records, right-of-way records including under bridge easements, utilities carried on or under the bridge and information regarding the use of the feature crossed by the affected bridge.

Bridge Records:

Design Drawings	○	○
As-built Plans	○	○
Geotechnical Data	○	○
As-Built Plans	○	○
Maintenance Records	○	○
Easement Records	○	○
Utility Records	○	○
Right-of-Way Records	○	○

Post Event Activities:

Once an event has occurred, the following check list can be used as a starting point to generate a project specific check list and action plan for use during the response to the event.

Bridge Closure Procedures:

	Yes	N/A
Health and Safety Plan Developed	○	○
Health and Safety Plan Distributed	○	○
State of Emergency Declared	○	○
Initial Closure Methodology:		
Engage Maintenance Forces	○	○
Notify Police	○	○
Notify Fire Department	○	○
Feature Crossed Initial Closure Methodology		
Engage Maintenance Forces	○	○
Notify Police	○	○
Notify Fire Department	○	○
Contact US Army Corps of Engineers	○	○
Contact US Coast Guard	○	○
Closure Notifications:		
Organize Response Team	○	○
Contact Governor's Office	○	○
Contact Count Executive's Office	○	○
Contact Mayor's Office	○	○
Contact News Media	○	○
Contact First Responders	○	○
Contact Local Hospitals	○	○

Site Assessment:

	Yes	N/A
Bridge Stability Evaluated	○	○
Bridge Emergency Stabilization Measures Identified	○	○
Bridge Emergency Stabilization Measures Installed	○	○
Recordation of Initial Existing Conditions	○	○
Determine Timeline of Events	○	○
Instrumentation Plan Developed	○	○
Instrumentation Plan Implemented	○	○
Testing Program Developed	○	○
Testing Program Implemented	○	○
Right-of-Way Cleared	○	○
Utilities Cleared	○	○
Permits Acquired	○	○
Update Stake Holders	○	○

Remediation Design:

	Yes	N/A
Design by DOT Departments	○	○
Engage Consultants	○	○
Existing Footing/Pile Cap Suitable for Re-use	○	○
Existing Footing/Pile Cap not Suitable for Re-use	○	○
Micro-pile Design	○	○
Drilled Shaft Design	○	○
Driven Steel Pile Design	○	○
Substructure and Superstructure Repair Design	○	○
Utility Repair Design	○	○
Updates to Stake Holders	○	○

Construction Activities:

Procurement Methodology Defined	○	○
Contractor(s) Engaged	○	○
Bids Received	○	○
Contract Awarded	○	○
Notice to Proceed Issued	○	○
Inspection Staff in Place	○	○
Instrumentation Program Active	○	○
Construction Close-out	○	○
Bridge Re-Opened	○	○
Updates to Stake Holders	○	○
As-Built Records Prepared	○	○

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