

Rapid Bridge Replacement Techniques

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Abstract: The destruction of the World Trade Center building in September of 2001 exposed the vulnerability of domestic structures and facilities to terrorist attack. With transportation facilities on the list of potential targets, state DOTs initiated efforts to lessen the probability of an attack and to lessen the impact should such an attack occur. This project initially focused on the nation's bridges and sought to lessen the impact on an attack through rapid recovery operations by advanced planning and preparation, which includes the development of emergency response procedures and identification of rapid bridge replacement and repair techniques and materials. The scope of the project was later expanded to recovery operations following any extreme event; natural, accidental, or terrorist-planned. Chapter 2 identifies and summarizes rapid bridge replacement and repair materials and techniques for bridge superstructures, decks, substructures, and general elements or members as well as floating bridges and contractor and construction techniques and methods. Chapter 3 identifies and summarizes 26 real-world cases of rapid bridge replacements. A summary of lessons learned is also provided. Chapter 4 addresses the effectiveness of incentive clauses in shortening construction schedules. Chapter 5 addresses pre-event preparations and includes the evaluation of critical bridge assets and the development of Emergency Response Plans for those critical assets.					
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RESEARCH REPORT

by

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Prepared in cooperation with the Texas Department of Transportation and the U.S. Department of Transportation, Federal Highway Administration.

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Implementation Statement

This project report contains a large amount of material that is currently available for implementation. Chapter 2 contains information addressing rapid bridge replacement and repair materials and techniques. Topics addressed in Chapter 2 are bridge superstructures, decks, substructures, and general elements or members materials and techniques as well as floating bridges and construction or contractor techniques or methods. Chapter 3 summaries 26 real-world cases and provides lessons learned from those cases. Chapter 4 provides guidance for the use of construction incentives. Chapter 5 provides guidance for the development of a list of a state's critical bridge assets and the development of an Emergency Response Plan for those assets.

SI* (MODERN METRIC) CONVERSION FACTORS

APPROXIMATE CONVERSIONS TO SI UNITS

APPROXIMATE CONVERSIONS FROM SI UNITS

Symbol	When You Know	Multiply By	To Find	Symbol	When You Know	Multiply By	To Find	Symbol
LENGTH								
in	inches	25.4	millimeters	mm	millimeters	0.039	inches	in
ft	feet	0.305	meters	m	meters	3.28	feet	ft
yd	yards	0.914	meters	m	meters	1.09	yards	yd
mi	miles	1.61	kilometers	km	kilometers	0.621	miles	mi
AREA								
in ²	square inches	645.2	square millimeters	mm ²	square millimeters	0.0016	square inches	in ²
ft ²	square feet	0.093	square meters	m ²	square meters	10.764	square feet	ft ²
yd ²	square yards	0.836	square meters	m ²	square meters	1.195	square yards	yd ²
ac	acres	0.405	hectares	ha	hectares	2.47	acres	ac
mi ²	square miles	2.59	square kilometers	km ²	square kilometers	0.386	square miles	mi ²
VOLUME								
fl oz	fluid ounces	29.57	milliliters	mL	milliliters	0.034	fluid ounces	fl oz
gal	gallons	3.785	liters	L	liters	0.264	gallons	gal
ft ³	cubic feet	0.028	cubic meters	m ³	cubic meters	35.71	cubic feet	ft ³
yd ³	cubic yards	0.765	cubic meters	m ³	cubic meters	1.307	cubic yards	yd ³
NOTE: Volumes greater than 1000 l shall be shown in m ³ .								
MASS								
oz	ounces	28.35	grams	g	grams	0.035	ounces	oz
lb	pounds	0.454	kilograms	kg	kilograms	2.202	pounds	lb
T	short tons (2000 lb)	0.907	megagrams (or "metric ton")	Mg (or "t")	megagrams (or "metric ton")	1.103	short tons (2000 lb)	T
TEMPERATURE (exact)								
°F	Fahrenheit temperature	5(F-32)/9 or (F-32)/1.8	Celcius temperature	°C	Celcius temperature	1.8C + 32	Fahrenheit temperature	°F
ILLUMINATION								
fc	foot-candles	10.76	lux	lx	lux	0.0929	foot-candles	fc
fl	foot-Lamberts	3.426	candela/m ²	cd/m ²	candela/m ²	0.2919	foot-Lamberts	fl
FORCE and PRESSURE or STRESS								
lbf	poundforce	4.45	newtons	N	newtons	0.225	poundforce	lbf
lbf/in ²	poundforce per square inch	6.89	kilopascals	kPa	kilopascals	0.145	poundforce per square inch	lbf/in ²

* SI is the symbol for the International System of Units. Appropriate (Revised September 1993)

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CHAPTER 1. INTRODUCTION

BACKGROUND

The destruction of the World Trade Center buildings in the Fall of 2001 exposed the vulnerability of significant domestic structures and facilities to terrorist attack. Security advisors warn that favorite targets of terrorists include high-visibility targets of national significance such as those listed in Table 1.1 (Abernethy, 2002). Major transportation infrastructure critical to the economy is high on the list of terrorist targets.

Table 1.1 Terrorist Civilian Targets (Abernethy, 2002)

High profile government buildings
High profile national monuments, especially with large attendance
Major transportation infrastructure critical to the economy
Public utilities infrastructure of modern and large cities
Sports and recreational facilities with large attendance
Large educational institutions, especially those with high profile
Chemical manufacturing and aerospace facilities
Businesses critical to the economy

Transportation planners recognized the need to address the nation's vulnerability assessment requirements for highway transportation, and sponsored the development of a guide to highway vulnerability assessment for critical asset identification and protection (Smith, 2002). The guide was developed under the direction of the National Cooperative Highway Research Program (NCHRP) for the American Association of State Highway and Transportation Officials (AASHTO). The guideline authors divided vulnerabilities in highway transportation into the following three general categories:

1. The physical facilities themselves.
2. The vehicles (private and commercial motor carriers) operating on the system.

3. The information infrastructure that monitors and manages the flow of goods, vehicles, and people on the highway system.

The six steps for conducting a vulnerability assessment of highway transportation assets are described with the following objectives:

- Step 1. Critical Assets Identification. Identify those assets – infrastructure, facilities, equipment, and personnel – deemed “critical” for achieving the department’s primary mission.
- Step 2. Vulnerability Assessment. The vulnerability assessment is designed to systematically identify and evaluate critical assets in terms of their susceptibility to and the consequences of terrorist attacks. The process identifies exposures and weaknesses that can be exploited by terrorists.
- Step 3. Consequence Assessment. The consequence assessment helps identify assets which, if attacked, produce the greatest risks for circumstances and conditions. This assessment is based on an integrated analysis of the data collected on critical/key assets/activities, realistic and credible threats, and known or specifically identified vulnerabilities.
- Step 4. Countermeasures. Identify typical countermeasures to protect the critical assets from the threats and vulnerabilities assessed previously.
- Step 5. Cost Estimation. Provide general guidelines to calculate the range of costs for implementing the selected countermeasures.
- Step 6. Security Operational Planning. Improve the security of critical assets by guarding against potential consequences caused by acts of terrorism through security operational planning.

It should be noted that these 6 steps primarily focus on the prevention of a terrorist event. An additional step should be added to this list for each critical asset identified in Step 1. This additional step should be to develop an Emergency Response Plan to guide the actions of the responders should a terrorist or natural event occur that destroys the critical asset or disrupts its intended use. It is the pre-event preparations, including the identification of applicable rapid bridge repair and replacement techniques, that is the primary focus of this report

PURPOSE

Following the World Trade Center event, the Texas Department of Transportation (TxDOT) and other state transportation agencies initiated efforts to investigate and develop methods to lessen the impact of terrorist attack and other extreme events on the transportation infrastructure. Research efforts concentrated on bridges. TxDOT issued two research project statements for bridge security. One project was entitled “Design of

Bridges for Security” and was intended to determine how bridges may be economically designed for security. The other project was entitled “Rapid Bridge Replacement Techniques” and was intended to identify bridge replacement and repair techniques. Bridge replacement techniques were to include both temporary and permanent replacement. This report documents research and findings of the Rapid Bridge Replacement study.

The initial TxDOT Rapid Bridge Replacement project statement required an extensive literature search leading to a plan to identify, evaluate, and recommend rapid bridge replacement techniques. The literature search was to include international and military sources. Furthermore, researchers were to address how emergency response plans could be used to minimize traffic disruption and were to identify how incentives could be used to expedite construction during bridge replacement or repair. The research was to identify and document actual cases and describe bridge replacement and repair operations for several bridge types and damages.

In addition to terrorist attack, bridges are subject to damage from a variety of other sources such as vehicle impact, fire, and natural disaster. Because of the variety of possible bridge damage sources, the scope of the study was broadened to include damages that might result from any extreme event. Expanding the scope of the study increased the number of relevant bridge-damage events that could be investigated as case studies and helped ensure that the study produced broadly applicable bridge repair and replacement procedures and techniques. As the project scope was broadened, the project was transitioned during the summer of 2002 from a TxDOT funded project to a TxDOT-led Transportation Pooled-fund (TPF) project involving the following states:

Georgia	Illinois	Iowa
Minnesota	Mississippi	New Jersey
Ohio	South Carolina	Texas

Expanding the scope also allowed incorporating the U.S. Army Corps of Engineers, Engineering Research and Development Center (ERDC) as a consultant to the project. The ERDC experience in bomb-damaged bridge replacement and other rapid bridging techniques proved valuable to the project.

APPROACH

Project goals were accomplished in two phases following a systematic research approach. In Phase I, the research team employed the traditional transportation databases in search of information regarding rapid bridge replacement and repair techniques. Additionally, several defense related databases were investigated, and researchers met with TxDOT and military bridge engineers to specify previous experiences in rapidly replacing and repairing damaged bridges. TxDOT bridge engineers provided information on critical bridge assets in the state. The list of critical bridges was used to identify critical bridge types rather than specific bridges, and to determine applicable techniques for rapidly repairing or replacing bridge elements. During the literature review,

researchers established five categories of potentially useful rapid replacement/repair techniques addressing superstructures, substructures, decks, floating bridges, and contractor/construction related issues. Later in the project a general member/element repair section was added. Researchers presented a summary of the literature search findings to the Project Monitoring Committee (PMC) at the completion of Phase I of the project. The presentation also included a positive recommendation for project continuation, a strategic plan for the execution of Phase II, and descriptions of a number of bridge replacement events as candidates for the project case studies. The PMC approved the strategic plan which included a discussion of emergency response plans and incentives for rapid construction. In Phase II, researchers evaluated bridge replacement techniques identified in Phase I, prepared descriptions of the techniques, completed case studies on selected events, addressed emergency response procedures, and identified and summarized how monetary incentives have been used in real world applications. Originally, researchers were to complete five case studies on rapid bridge replacements of bridges following extreme events. However, due to changes in strategies and events during the project period, it was agreed to complete and publish 3 full case studies and incorporate 23 shorter case summaries. These case summaries allowed a broader reporting of rapid bridge replacement / repair events identified in the literature. Rapid bridge repair and replacement materials and techniques are addressed in Chapter 2. The case studies and summaries are provided in Chapter 3. Construction contract incentives are addressed in Chapter 4. Emergency response plans and preparations are addressed in Chapter 5.

LITERATURE SEARCH AND REVIEW

Researchers chose key words and key word combinations in search of available literature on the subjects of bridges, rapid repair, rapid replacement, reconstruction, rehabilitation, homeland security, and other subjects. A list of databases and sources searched is given in Table 1.2.

Table 1.2. List of Databases and Sources Used in Literature Search

AASHTO Security Task Force	Environments	NSF (National Science Foundation)
ASCE Publication	Equipment, Training and Support News	NTIS (National Technical Information Service)
Compendex	FAS – Military Analysis Network	Transportation System Security
Department of Defense	FHWA (Federal Highway Administration, Turner Fairbanks Research Center)	TRIS Online
Department of Energy	Google.com	Texas Tech University, Government Documents, Government Printing Office
DTIC (Defense Technical Information Center)	INSPEC	Texas Tech University, Government Documents, Military Library
Emerald	Jane’s Defense World	US DOT
Engineering Village 2	MIT Library	WES (Waterways Experiment Station)
Center for Transportation Research Library		

The initial literature search found nearly 300 documents potentially relevant to the research study. This number continued to grow as the research project progressed and the literature search continued. The research team reviewed abstracts from each document and organized the documents into categories for further review. A list of the initial categories selected is given in Table 1.3.

Table 1.3. Categories Used to Initially Organize Literature Search Documents

Case Studies
Homeland Security
Temporary Bridging
Transportation

Later in the literature review, additional categories were added pertaining to particular repair techniques. Categories also included specific case studies that were considered candidates for further investigation. A final list of sources and documents used in writing this report is provided in the References section of this report.

CRITICAL BRIDGE TYPES

Researchers used the list of critical bridges supplied by TxDOT to identify critical bridge types so that repair or replacement techniques could be selected for representative types of bridge elements. Although the review included only bridges in Texas, bridges for other states are similar in design. Originally, the team evaluated 80 critical bridges. Later this list was increased to 107 bridges. From this list of critical structures in Texas, the research team was able to identify the various types of superstructures and substructures of the main spans and the approach spans. The information determined by analyzing the Texas list of critical structures was then used to confirm that the various rapid repair techniques identified were applicable to the critical structure components.

The critical components of the superstructure on the Texas list of critical bridges are the span type, the roadway type, and the member type of the approach spans. After reviewing the list of critical bridges, it became apparent that main and approach spans have similar dominant features. The most dominant features of the spans, up to 200 feet in length, was that they used members of multiple pre-stressed concrete girders, rolled steel I-beams, or steel plate girders with cast in place concrete decks.

Critical components of the substructure include member type above ground, member type below ground, and bent caps of the main span and the major and minor approach spans. The list of critical bridges indicated that the main spans and the major approach spans have similar components. The most common components of the main spans and the major approach spans are multiple column bents above ground, drilled shafts below ground, and concrete bent caps. On the other hand, the most common components of the minor approach spans are concrete column bents with tie beams above ground, drilled shafts or pile cap on concrete piling below ground and concrete bent caps.

Using Texas' list of critical bridges as a representative sample of all U.S. bridges, the team was able to identify the most common types of bridges and the various repair techniques applicable to these various bridge components. The critical bridge components identified are typical of common or everyday bridge components. These critical components proved to be helpful in identifying rapid bridge repair techniques that are addressed in Chapter 2.

CHAPTER 2. REPAIR AND REPLACEMENT MATERIALS AND TECHNIQUES

INTRODUCTION

Six general categories of bridge repair and replacement materials and techniques were identified during the literature review portion of this project. These 6 categories are addressed in this chapter and include; superstructures, decks, substructures, member/element repairs, floating bridges, and construction/contractor related techniques. In addition, it was determined that the overall recovery process associated with the loss of or damage to a critical asset due to an extreme event can be broken into 3 phases. Phase 1, the development of an Emergency Response Plan (ERP) for any identified critical assets, is a pre-event activity that is necessary to minimize the impact of an extreme event. Issues and details associated with the development of an ERP are addressed in Chapter 5 of this report. Phase 2, temporary traffic, addresses issues associated with getting traffic flowing again as soon as possible in an effort to minimize the short-term impact on the driving public. These issues include the development of detours and alternate routes using existing traffic arteries to move traffic around and away from the effected asset and the use of temporary structures and repairs. The development of detours and alternate routes is beyond the scope of the research and is not addressed in this report. However, the use of temporary structures and repairs falls within the scope of this project and is addressed in this chapter. The effective use of temporary structures and repairs is dependent on short-term availability of materials and components which could require DOT's to pre-purchase, stockpile, and preposition materials and components in preparation for an extreme event. Issues associated with this concept are addressed in Chapter 5 of this report, Emergency Response Preparations. Phase 3, permanent repairs and replacements, is also within scope and is addressed in this chapter. Write-ups addressing the various temporary and permanent repair and replacement techniques for the 6 categories listed above are provided in this chapter. In addition, the information provided in this chapter is summarized in various tables included within this chapter.

Superstructure Techniques

AASHTO-TIG: Prefabricated Bridge Elements and Systems

Over the last 10 years, the development and use of prefabricated bridge elements and systems to reduce construction time and any impact on the driving public has been a major topic of interest. Even though the focus has not been for bridge repairs or replacements following extreme events, much of the developed technology is directly applicable to construction following many extreme events. However, due to the time required to prefabricate the elements and the preplanning requirements necessary for their effective use, changes in construction strategies will have to occur. One concept that could be effective is the utilization of a temporary bridge or repair to get the traffic moving while the permanent bridge elements or system is prefabricated and the preplanning is developed. Another strategy that could be utilized is the development,

prefabrication, and stockpiling of standard, generic, or adaptable elements that would be available for use on a very short notice.

The American Association of State and Highway Transportation Officials (AASHTO) Technical Implementation Group (TIG) on Prefabricated Bridge Elements and Systems has developed a very good resource for the use of prefabricated bridge elements and systems. At the time that this report was initially written, this resource was available on line at www.aashtotig.org/focus_technologies/prefab_elements and provided reference material on 23 available publications, 39 innovative projects, and 5 research projects; all addressing topics associated with either general issues of prefabricated bridges, prefabricated superstructures, prefabricated decks, or prefabricated substructures. The available publications portion of the web site identified 12 references addressing the general use of prefabricated bridge elements and systems and 1 reference addressing prefabricated superstructures, which are summarized in Table 2.1. The innovative projects portion of the web site identified 6 projects addressing prefabricated superstructures and 2 projects addressing prefabricated bridges that are applicable to rapid bridge replacement. These are summarized in Table 2.2. The research portion of the web site identified 1 project addressing the general use of prefabricated elements and systems and 1 project addressing prefabricated superstructures. These are summarized in Table 2.3. (AASHTO-TIG, 2001) Prior to final publication of this report, the above listed material from the AASHTO website was move to the FHWA website and can now be found at www.fhwa.dot.gov/bridge/prefab/.

Acrow Corporation

The Acrow Corporation of America produces several types of prefabricated bridges and shoring products. Two of their bridges, a panel bridge and a beam bridge, would be very applicable to rapid bridge replacement in either a temporary or permanent replacement scenario. Acrow bridges are available for purchase, rent, or lease depending on the needs of the customer. Information about these Acrow bridges is provided below. Contact information is provided in Table 2.4. Emergency assistance phone numbers are available at Acrow's web site listed in Table 2.4.

Acrow Panel Bridge - Acrow panel bridges are a modern version of the Bailey bridge, that was develop during World War II (WW II), and can be used to replace all or a part of the destroyed or damaged bridge. The main components of these bridges are the Acrow truss panel, orthotropic steel deck units, and transoms or floor beams. The truss panels can be placed in different configurations, laterally and vertically, to accommodate different load conditions and span lengths. The orthotropic deck panels distribute loads efficiently across the width of the bridge, which results in longer and stronger spans that are achieved with fewer pieces. The most recent version of the Acrow panel bridge is the 700XS, which is available "off-the-shelf" in three lane, two lane, or single lane widths, and can be customized to fulfill many specific requirements including pedestrian walkways or utility hangers. The Acrow panel bridge can span up to 250 feet and accommodate up to an AASHTO HS25-44 loading. These bridges can be easily transported and erected. They can be rolled into place in full cantilever (launched) from one side of the gap to be spanned, or they can be lifted into place with a crane. Over

water, they have also been floated into place. Once the bridge is no longer needed, it can be dismantled and returned (if rented) or stored for future use. The stockpiling of the components of this versatile type of bridge by a DOT has the potential to provide significant returns during the response activities associated with an extreme event. Also available is Acrow's older panel bridge, the 300 series. Contact information is provided in Table 2.4. (Acrow, 2000, Acrow, 2003a, Acrow, 2003b, and Bridge Builders Staff, 2000).

Acrow panel bridges were used as temporary bridges in two case summaries (CS) provided in Chapter 3 of this report, CS #14 and CS #16. The Blake Street Bridge in New Haven, Connecticut, (CS #14) lost its main piers due to scour. An Acrow panel bridge was used as a temporary bridge to carry detoured traffic while the damaged bridge was replaced. The I-80 bridge in Denville, New Jersey, (CS #16), was damaged by an explosion and subsequent fire. Again, an Acrow panel bridge was used to carry detoured traffic while the damaged bridge was replaced.

Some points that should be addressed when considering using this type of bridging are;

- (1) There must be a trained work crew available that has knowledge of the bridge and its components. The manufacturer will supply all the needed specifications and technicians but competent workers are needed to erect and launch the bridge.
- (2) If the temporary bridge is to be placed directly on the superstructure of a damaged permanent bridge, an analysis should be done to determine if the damaged structure can withstand the additional dead load that the temporary bridge will apply.
- (3) Care should also be given to the placement of the temporary bridge on the permanent bridge. The temporary bridge might need to be lengthened to transfer load to existing piers instead of the existing deck structure.

Acrow Swift Beam Bridge - Acrow Swift Beam Bridges are prefabricated, full span length, modular units that can span up to 70 feet, making them applicable for short span applications. Their lateral modularity allows adjacent units to be interconnected, providing flexibility in the number and widths of the required lanes. These bridges are capable of carrying single vehicle loads of up to 35 tons and have an optional guide rail that can easily be attached to the outside bridge beams. Typical deck options are timber or concrete but they can be supplied with other details that will allow other deck materials as best suited for a specific repair or use application. Acrow Swift Beam Bridges are made using adaptable modular components that can be used in permanent applications or disassembled and stored for future use. The bridges are constructed from steel and use either hot-dip galvanizing or weathering steel for corrosion protection. Contact information is provided in Table 2.4. (Acrow, 2003b and Bridge Builders Staff, 2000)

Bailey Bridges, Inc.

Bailey Panel Bridge - The Bailey bridge was the original panel bridge developed for military use during WW II and is the basis for all current models of panel bridging.

The standard model used by the U.S. Army is the U.S. M2 Bailey Bridge. Bailey bridges are comprised of approximately 13 different prefabricated, standardized components that can be assembled in various combinations to accommodate different span lengths and load conditions. They can accommodate spans from 50 to 190 feet with roadway width 14.25 feet and can carry up to an AASHTO HS15-44 loading. The primary load carrying components of the Bailey panel bridge is its modular, 10-foot-long, truss panel that can be interconnected “side-by-side” in combinations of 1, 2, or 3 panels, per side of bridge, to increase the capacity or the span length of the bridge. The panels can also be stacked “double-story” to further increase their capacity. Bailey bridges are all steel construction utilizing ASTM A242, Grade 50 steel, which is coated with an inorganic zinc-silicate for corrosion protection. The Bailey bridges require no welding and are assembled using combinations of bolts, pins, and clamps and can be quickly assembled and installed in a few days with only a small crew and light equipment. The bridges can also be disassembled and stored for reuse. The Bailey bridge can be crane lifted and set into place as a unit or incrementally launch as a cantilever from one abutment using a launching nose. Points similar to those identified above with the Acrow panel bridge should be addressed when considering the use of a Bailey panel bridge. Contact information is provided in Table 2.4. (Bailey, 2002)

A Bailey panel bridge was used as a permanent replacement for a damaged single lane bridge over the Seneca River in Port Byron, New York and was installed by a reserve army unit as a training exercise. See CS # 13 in Chapter 3 of this report for more information.

BIG R Manufacturing

BIG R Manufacturing provides prefabricated portable/modular steel bridges that can be used for either temporary or permanent applications. Span lengths range from 16 feet to 150 feet and are rated for AASHTO HS20-44 loading. The multiple steel I-beam units have modular widths of either 7 feet or 8 feet and can be placed side-by-side as necessary for multiple lane and various width requirements up to a maximum of 28 feet. The modular units typically come with 4.25-inch x 12-inch x 7 gauge formed steel decking which can be overlaid with a timber or asphalt ride surface. The bridges are available with square or skewed ends and come in weathering steel or can be painted to specification. The modular bridges are typically crane lifted into place and can be set on steel or concrete abutments. Bolt-on side guardrails and rental options are available. Contact information is provided in Table 2.4. (Big-R, 2004 and Bridge Builders Staff, 2002)

Hamilton Construction Co.

Hamilton Construction Company’s EZ Bridge is a family of pre-engineered, prefabricated steel girder bridges that can be used for temporary or permanent applications. The modular components of these bridges can be trucked to the job site, bolted together, set into place, and opened to traffic in as little as 3 hours after the components are delivered at the job site. The modular, bolted construction of these bridges allows the bridges to be disassembled and stored for reuse. Possible span lengths

range from 20 to 90 feet with modular lane widths of either 14 or 16 feet. EZ Bridges are designed to carry an AASHTO HS-25 loading and can be fitted with either a timber or concrete deck. The bridges are fabricated from either ASTM A588 weathering steel or ASTM A572 steel, which is galvanized or painted for corrosion protection. These bridges can be placed by a crane lift or launched from one abutment. Bolt on guardrails and rental options are available. Contact information is provided in Table 2.4. (Hamilton, 2004 and Bridge Builders Staff, 2004)

Fort Miller Co.

Fort Miller's Inverset patented prefabricated bridge system utilizes the benefit of composite action between its steel support beams and its concrete deck and the benefit of fabrication in a factory controlled environment. The modular components of this system are prefabricated up side down by casting the concrete deck slab in forms suspended from steel I-beams that will become its support members with the unit in its final inverted position. Vertical alignment is set so that one flange of each steel I-beam is encased in the concrete deck with adequate shear transfer provided to ensure composite action. Once the concrete is cast and allowed to cure, the entire unit is turned over to its normal load carrying position with the concrete deck on top and the steel I-beams below. This allows the full dead and live load to be carried by the composite section (concrete slab and steel I-beam), which is a significant advantage over the normal cast-in-place technique where the dead load is carried solely by the steel I-beam. Casting the units up side down also allows the densest concrete to end up as the top surface when the unit is in its load carrying position, which adds to concrete decks durability and resistance to chloride penetration. The modular units provide flexibility and can be designed for a wide range of widths, lengths, and load requirements. Spans have been designed using these units to span in excess of 100 feet. The units can be designed and fabricated as full bridge span length units that are modular in width so that multiple units can be placed side by side to complete the full bridge width. Alternately, they can be designed and fabricated as full bridge width units that are modular in length so that multiple units can be placed end to end, in the longitudinal direction, on top of the span support members to complete the full bridge span. These units are typically trucked to the job site and crane lifted into place. Contact information is provided in Table 2.4. (Fort, 2001)

Inverset bridge units were used by the New York Thruway Authority to replace a damaged bridge in Yonkers, New York, following a gasoline truck accident and fire. They were also used to replace the Sagtikos Parkway Bridge near Long Island, New York, following a similar incident that damaged the bridge. Additional information is provided in CS #3 and CS #20 for the two incidents, respectively, in Chapter 3 of this report.

Mabey Bridge and Shore, Inc.

Mabey Bridge and Shore, Inc. produces several types of prefabricated bridges and shoring products. Three of their bridges, 2 panel bridges and a beam type bridge, are very applicable to rapid bridge replacement in either a temporary or permanent

replacement scenario. Mabey bridges are available for purchase or rent depending on the needs of the customer. Information about these Mabey bridges is provided below.

Mabey Panel Bridges - Mabey panel bridges are similar in design and function to Acrow panel bridges, with minor differences. The main components of these bridges are the truss panels (either the Universal panel or the Compact 200 panel), steel deck units, and transoms or floor beams. The Universal Panel Bridge panels are 14.75-foot by 7.75-foot in dimension, and the bridge can accommodate up to four lanes of traffic, span up to 300 feet, and carry an AASHTO HS25-44 or a military MS250 loading. The Compact 200 panels are 10-foot by 7-foot, weigh 741 pounds and were designed to be able to be assembled by hand, if required. The Compact 200 Panel Bridge can handle up to three lanes of highway traffic, span up to 200 feet, and carry the same AASHTO and military loadings. Either bridge can be rolled into place in full cantilever (launched) from one side of the gap to be spanned, or they can be lifted into place with a crane. Deck materials can be timber, steel, concrete, or asphalt. Mabey offers full support for their bridges, with on-site representatives available to assist a work crew with the building of the bridge. Once the bridge is no longer needed, it can be dismantled and returned (if rented) or stored for future use. This bridge is commonly used by the United States military to replaced war damaged bridges around the world. Points similar to those identified above with the Acrow panel bridge should be addressed when considering the use of a Mabey panel bridge. Contact information is provided in Table 2.4. (Mabey, 2002, Mabey, 2003, and Bridge Builders Staff, 2004)

A Mabey panel bridge was used to carry temporary traffic during replacement operations after the permanent New York Thruway Bridge near Yonkers, New York, was damage by an intense fire following the crash of a gasoline tanker under the permanent bridge. A Bailey panel bridge was also used to bridge over four damage spans of the Sava River Bridge in Bosnia bomb damage during military operations make the permanent bridge unusable. Additional information is provided in CS #3 and CS #5 for these two incidents, respectively, in Chapter 3 of this report.

Mabey Quick Bridge - The Mabey Quick Bridge is a proprietary system that provides an “off-the-shelf” solution for both temporary and permanent short span applications. The fixed-length Quick Bridge comes in lengths of 20, 30, and 40 feet, comes in modular widths of 5.65 feet, and is designed to carry an AASHTO HS25-44 load. The basic bridge design consists of two beams connected to a deck surface, which can be quickly connected and installed in under an hour. In addition, its modular sections (5.65 feet wide) can be arranged side-by-side and interconnected, providing adaptability for a wide range of traffic lane widths and numbers. A detachable guardrail is available and simply bolts to the outermost modules. The deck is typically covered with an anti-skid material. Contact information is provided in Table 2.4. (Mabey, 2002, Mabey, 2003, and Bridge Builders Staff, 2004)

Steadfast Bridges

Steadfast Bridges offers a number of pre-engineered, prefabricated through-truss steel bridges for vehicular traffic that can be modified to meet the customer’s needs and

can be used as permanent or temporary bridges. Steadfast Vehicular Bridges are all steel construction, can be used with clear spans up to 150 feet, can accommodate roadway widths of up to 40 feet, and can be used with skewed alignments. These bridges are designed to meet AASHTO HS-20 and HS-25 load criteria. Corrosion protection can be specified as hot-dip galvanize, paint, or weathering steel. Deck surface options include concrete, asphalt over a corrugated steel base, wood, or fiber reinforced polymer. Bridge components are trucked to the job site and are connected using bolted field splices. The bridges can be crane lifted and set into place or launched from one side. Rental options are available. Contact information is provided in Table 2.4. (Steadfast, 2004 and Bridge Builders Staff, 2004)

U.S. Bridge

U.S. Bridge offers a number of prefabricated steel bridges for vehicular traffic that can be modified to meet the customer's needs and can be used as permanent or temporary bridges. They offer 2 general types of steel bridges; a through-truss bridge and rolled I-beam bridge. The truss bridge can accommodate clear spans over 140 feet while the beam bridge can accommodate clear spans up to 60 feet. Roadway widths options vary from 1 to 3 lanes. Both bridge types are designed to meet AASHTO HS-20 and HS-25 load criteria and can be adapted to skewed alignments. Deck surface options include concrete, asphalt over a corrugated steel base, or wood. The truss bridge can use either a raised floor or underslung floor option. Corrosion protection can be specified as hot-dip galvanize, paint, or weathering steel. Bridge components are trucked to the job site and are connected using bolted field splices. The rolled beam bridge can be fitted with bolt-on side rails. Both bridges can be crane lifted and set into place or launched from one side. Rental options are available. Contact information is provided in Table 2.4. (U.S. Bridge, 2003 and Bridge Builders Staff, 2004)

U. S. Military Bridges

Military Dry Support Bridge - The Dry Support Bridge (DSB) is a modular bridge that can span a 131-foot gap in 90 minutes with eight soldiers. One bridge set provides either one 131-foot bridge or two 65.5-foot bridges. The bridge will carry Military Load Classification (MLC) 96 wheeled (96 tons) or MLC 70 tracked vehicles and allows the crossing of a Heavy Equipment Transporter carrying an M1A1 tank. The DSB can be transported as a palletized load by a Common Bridge Transporter (CBT), Palletized Load System (PLS) trailer or by service support units equipped with PLS trucks. A bridge set consists of six M1077 flatrack container loaded with bridge components, one M1077 flatrack container loaded with launch beams, and a launcher vehicle.

The DSB program began with the contract award issued to Williams-Fairey Engineering Limited on June 10, 1999. The initial contract was a five-year, multi-year contract for 27 systems with the first system scheduled for delivery in March 2003. The Multi-Role Bridge Company (MRBC) will employ the DSB primarily for non-assault bridging applications. It will fill a limited assault role when either the Wolverine is unavailable or the gap is greater than 78 feet. Each Multi-Role Bridge Company will be issued four DSB systems. One DSB system will consist of one Launcher mounted on a

M1075 PLS chassis, one 131-foot bridge with four ramps, four PLS trailers, and seven M1077 flatrack containers. Contact information is provided in Table 2.4. (Project Manager, 2002a)

Military Rapidly Emplaced Bridge System - The Rapidly Emplaced Bridge System (REBS) provides MLC 30 dry gap bridging capacity across a 42.6-foot gap supporting the mobility of the military. The REBS is transported by the M1977 Common Bridge Transporter and has a 10-minute placement time during daytime hours. This bridge requires a crew of two soldiers to place the system and requires little or no site preparation. The launcher is mounted on a flatrack that is powered by a M1977 Common Bridge Transporter. The entire bridge is transportable by a C-130 aircraft. This system provides several improvements over the Medium Girder Bridge, including a reduction in the number of soldiers required for construction from 17 to two. The launch time was reduced from 45 minutes to 10 minutes, and the pallet loads were cut in half: from two to one. Contact information is provided in Table 2.4. (Project Manager, 2002b)

Table 2.1 AASHTO-TIG Prefabricated Bridges: Publications
(Superstructures & General Prefabrication)
(AASHTO-TIG, 2001)

Title	Author(s)	Topic	Publisher / Source / Contact
Innovative Prefabrication of Texas Bridges	R. Medlock, M. Hyzak, & L. Wolf	Use of prefabricated bridge elements in Texas.	Proceeding of Tx Section of ASCE, Spring Meeting, March 2002
Laying the Ground-work for Fast Bridge Construction	M. Ralls & B. Tang	Use of prefabricated bridge elements and systems to speed the construction process.	FWHA, Washington DC / Public Roads, Nov-Dec 2003, Vol 67, No. 3 / www.tfhr.gov/pubrds/03nov/02.htm
Main Attractions: Prefabricated Bridges	J. Johnson	Use of prefabricated bridges to meet a growing public demand.	Mercor Media, Chicago, IL / Bridge Builder, Vol. 5, No. 2, March/April 2002, pp. 10-14
Precast Posttensioned Abutment System and Precast Superstructure for Rapid On-site Construction	A. Scalon, A. Aswad, & J. Sellar	Use of prefabricated bridge elements to reduce on-site construction time. Double-cell box beam	TRB, Washington DC / Transportation Research Board Record 1814, Design of Structures 2002

		superstructure elements were used.	
Precast Technology and Bridge Design	J. Dick	Use of new precast technologies in bridges, including girder designs, concrete mixes, and strands.	Mercor Media, Chicago, IL / Structural Engineer: News, Views, and Industry Trends, Vol. 3, No.4, May 2002
Prefabricated Bridge Elements and Systems: A Winning Idea		Use of prefabricated technology to speed bridge construction, improve safety, and minimize traffic disruptions.	FHWA, Washington DC / Focus, May 2002 / www.tfhr.gov/focus/may02/prefab.htm
Prefabricated Bridge Elements and System Fact Sheet	AASHTO-TIG	Facts about the use of prefabricated bridge elements and systems.	AASHTO-TIG, 2004 / www.aashtotig.org/focus_technologies/prefab_elements/related_documents/prefab_facts.pdf
Prefabricated Bridge Technology: Get In, Get Out, and Stay Out		Use of prefabricated technology to speed bridge construction, improve safety, and minimize traffic disruptions.	FHWA, Washington DC / Focus, April 2003 / www.tfhr.gov/focus/apr03/04.htm
Prefabricated Bridges	AAHSTO-TIG	A brochure that addresses the growth of prefabricated bridge technology and summarizes 15 bridge projects with site-specific issues.	AASHTO, Washington DC / 2002 / www.aashtotig.org/focus_technologies/prefab_elements/related_documents/prefab_brochure.pdf
Prefabrication Minimizes Traffic Disruptions	K. Pruski, R. Medlock, & M. Ralls	Use of prefabrication with Texas Bridges.	FWHA, Washington DC & NCBC, Skokie, IL / HPC Bridge Views, No. 21, May/June 2002 / www.cement.org/pdf_files/hpc-21mayjun02.pdf

Short and Sweet	M. Issa & S. Islam	Use of precast elements to shorten construction closure times for short-span bridges.	Hemming Information Services, London, UK / Bridge Design and Engineering, Issue No. 27, 2 nd Quarter 2002 / www.bridgeweb.com
Soaring on the Feet of an Elephant	A. Zeyher	Use of prefabricated elements to construct a bridge in Bangkok, Thailand.	Scranton Gillette Communications, Des Plaines, IL / Road & Bridges, Vol. 41, No. 8, August 2003 / www.roadsbridges.com/rb/index.cfm
TxDOT/FHWA Workshop on Prefabricated Bridge Systems to Eliminate Traffic Disruptions	J. Cooper, P. Wells, T. Moon, K. Price, J. Muller, M. Kerley, W. Garbade, D. Tassin, M. Issa, J. Vogel, & G. Freeby	Workshop with 10 presentations addressing rapid bridge construction techniques and approaches used in the United States.	TxDOT, Austin, TX / PowerPoint Presentation available on CD-ROM / Contact: R. Medlock at rmedlock@dot.state.tx.us

Table 2.2 AASHTO-TIG Prefabricated Bridges: Innovative Projects
(Superstructure & Bridges)
(AASHTO-TIG, 2001)

Project Name & Location	Project Description	Contact Information
George P. Coleman Bridge, Yorktown, VA	Removal of 6 old spans and installation of 6 new spans were completed in 9 days. The truss superstructure spans were prefabricated and barged to site. Use of new lighter-weight materials allowed the reuse of the existing foundation while widening the structure. ADT: 27,000. Completed: 1995.	George Clendenin Virginia DOT 804-786-4575 George.Clendenin@VirginiaDOT.org
I-95/James River Bridge, Richmond, VA	VDOT chose night-only construction to minimize traffic disruptions during replacement of the bridges superstructure. Construction was limited to between 7 p.m. and 6 a.m., Sunday through Thursday, with one lane kept open during those hours. Old sections of the bridge	Dina Kukreja Virginia DOT 804-786-5172 Dina.Kukreja@VirginiaDOT.org

	were cut out and replace with prefabricated units each night. Replacement units utilized composite action between an 8.75-inch concrete deck and steel plate girders. ADT: 110,000. Completed: 2002.	
Lions' Gate Suspension Bridge, First Narrows, Vancouver, BC	The entire deck and superstructure truss elements were replace using 54 prefabricated elements with the bulk of the construction being accomplished during 10-hour shifts at night. Night construction was chosen to minimize traffic disruptions. Sections were either 10 or 20 meters long. ADT: 65,000. Completed: 2002.	Geoff Freer Ministry of Trans. 213-1011 4 th Ave. Prince George, Vancouver V2L 3H9 British Columbia Geoff.Freer@ gems3.gov.bc.ca
Main Street over Metro North Railroad, Tuckahoe, NY	NYS DOT's replacement of a through-girder bridge over a commuter railroad provided several unique challenges, including minimal disruption of the commuter line, maintaining 2 lane of vehicular traffic at all times, and increasing the vertical clearance of the railroad by 5 inches while not affecting the vertical profile of the bridge. NYS DOT limited work to between 2 and 4 a.m. on the weekends and used a commercially available modular precast prestressed concrete/steel composite system. Completed: 2000.	George A. Christian New York State DOT State Campus Bldg. 5 6 th Floor 1220 Washington Ave. Albany, NY 12232 518-457-6827 Gchristian@ gw.dot.state.ny.us
Norfolk Southern Railroad Bridge over I-76, Montgomery County, PA	PennDOT opted to prefabricate a steel truss railroad bridge and roll it to its final position over I-76. The bridge, that was 240 feet long, 42 feet high, and weighed 740 tons, was placed on 4 Hillman rollers and rolled into place during a single weekend. This technique was used to minimize the impact on vehicular traffic on I-76. ADT: 88,000. Completed: 2002.	Andrew Warren District 6 Pennsylvania DOT Montgomery County 610-205-6660 awarren@state.pa.us
SH 66 over Mitchell Gulch, between Franktown and Castle Rock, CO	The original design used 3 box culverts. The design was change via a value-engineering proposal. The alternate design utilized driven steel H piles, precast abutments and wings, and precast deck slab girders. Eight precast slab girders (each 5.25 feet wide, 1.5 feet thick,	Wes Goff 303-757-9116 wes.goff@ dot.state.co.us

	and 38.33 feet long) were placed into position and posttensioned in the transverse direction. The outside slab girders were prefabricated with guardrails. Construction detour time was reduced from 2 to 3 months to 48 hours. Completed: 2002.	
Baldorioty de Castro Avenue Overpasses, San Juan, Puerto Rico	This project used precast posttensioned technology to replace 4 overpasses totaling 3,200 feet to minimize traffic disruptions. The project used piles and cast-in-place footingw with precast box piers, pier caps, and 100-foot-long superstructure box beams. The erection of the precast portion of the overpasses took 36 to 21 hours to complete. ADT: 100,000.	Public Works Dept. San Juan, Puerto Rico, or John Dick, PCI, 312-786-0300 JDick@ PCI.org
Cross Westchester Expressway Viaducts, Westchester County, NY	This project incorporated a value-engineering contractor proposal using precast posttensioned technology to replace 2 major viaducts while working in a space restricted area. The project used precast segmental hollow pier sections and precast deck panels on steel tub girders. Deck panels, which were 10 feet long, 9 inches thick, and 42 to 50 feet wide, utilized longitudinal posttensioning. This technique reduced the original contract schedule by 8 months. Completed: 1999.	George A. Christian New York State DOT State Campus Bldg. 5 6 th Floor 1220 Washington Ave. Albany, NY 12232 518-457-6827 Gchristian@ gw.dot.state.ny.us

Table 2.3 AASHTO-TIG Prefabricated Bridges: Research Projects
(Superstructure & Bridges)
(AASHTO-TIG, 2001)

Project Title Project Number	Project Description	Sponsor
Precast Structural Elements for Bridge Construction, NCHRP Project 33-02	A synthesis study to summarize the current state-of- the-art practices of prefabricated technology to minimize traffic disruptions and maintain construction quality. Start date: 2001	National Cooperative Highway Research Program
Behavior of Cast-in-Place Slabs Connecting Precast Slab and Steel Girder Assemblies,	The project is developing, evaluating, and writing guidelines for a prefabricated full-depth concrete deck with composite steel girders system. The prefabricated modular units will be set into place and will utilize	Texas Department of Transportation

TxDOT 0-4122	narrow transverse (at interior bents) and longitudinal (between units) closure pours to connect the units. Start date: 2002	
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Table 2.4 Superstructure Techniques

Company (Model)	Description	Contact
Acrow Corp. (Panel 700XS)	Span: 250 ft. (max.) Width: 12 ft. modular (1 to 3 lanes) Loading: AASHTO HS25-44 (max.) Erection: Cantilever launch or crane lift	Acrow Corp. of America P.O. Box 812 Carlstadt, NJ 07072-0812 800-524-1363 www.acrowusa.com
Acrow Corp. (Swift Beam)	Span: 70 ft. (max.) Width: 11 ft. or 21 ft. modular Loading: single vehicle, 35 tons Erection: Crane lift	Acrow Corp. of America P.O. Box 812 Carlstadt, NJ 07072-0812 800-524-1363 www.acrowusa.com
Bailey Bridges, Inc. (M2 Panel)	Span: 190 ft. (max.) Width: 14.25 ft. (single lane) Loading: AASHTO HS15-44 Erection: Cantilever launch or crane lift	Bailey Bridge, Inc. 119 40 th Street N.E. Fort Payne, AL 35967 800-477-7320 www.baileybridge.com
Big R Manuf. (Modular)	Span: 90 ft. (max.) Width: 7 ft. - 8 ft. modular (28 ft. max.) Loading: AASHTO HS20-44 Erection: Crane lift	Big R Manufacturing, LLC P.O. Box 1290 Greeley, CO 80632-1290 800-234-0734 www.bigrmfg.com
Hamilton Construction Co. (EZ Bridge)	Span: 90 ft. (max.) Width: 14 ft. or 16 ft. modular Loading: AASHTO HS25 Erection: Cantilever launch or crane lift	Hamilton Construction Co. P.O. Box 659 Springfield, OR 97477 541-746-2426 www.hamil.com
Fort Miller Co. (Inverset)	Span: 100 ft. (plus) Width: Varies (modular) Loading: AASHTO (varies with design) Erection: Crane lift	The Fort Miller Co., Inc. P.O. Box 98 Schuylerville, NY 12871 800-821-1202 www.fortmiller.com
Mabey Bridge and Shoring, Inc. (Universal Panel)	Span: 300 ft. (max.) Width: 14 ft. modular (1 to 4 lanes) Loading: AASHTO HS 25-44 or MS 250 Erection: Cantilever launch or crane lift	Mabey Bridge & Shoring, Inc. 6770 Dorsey Road Baltimore, MD 21075 800-956-2239 www.mabey.com
Mabey Bridge and Shoring,	Span: 200 ft. (max.) Width: 14 ft. modular (1 to 3 lanes)	Mabey Bridge & Shoring, Inc.

Inc. (Compact 200)	Loading: AASHTO HS25-44 or MS 250 Erection: Cantilever launch or crane lift	6770 Dorsey Road Baltimore, MD 21075 800-956-2239 www.mabey.com
Mabey Bridge and Shoring, Inc. (Quick Bridge)	Span: 20 ft., 30 ft., or 40 ft. Width: 5.65 ft. modular Loading: AASHTO HS25-44 Erection: Crane lift	Mabey Bridge & Shoring, Inc 6770 Dorsey Road Baltimore, MD 21075 800-956-2239 www.mabey.com
Steadfast Bridge Co. (Vehicular Truss Bridge)	Span: 150 ft. (max.) Width: 12 ft. to 40 ft. Loading: AASHTO HS25 Erection: Cantilever launch or crane lift	Steadfast Bridge Co. 4021 Gault Ave. S. Fort Payne, AL 35967 800-749-7515 www.steadfastbridge.com
U.S. Bridge (Truss Bridge)	Span: 140 ft. (max.) Width: 1 to 3 lanes Loading: AASHTO HS25 Erection: Cantilever launch or crane lift	U.S. Bridge P.O. Box 757 Cambridge, OH 43725 740-432-6334 www.usbridge.com
U.S. Bridge (Beam Bridge)	Span: 60 ft. (max.) Width: 1 to 3 lanes Loading: AASHTO HS25 Erection: Crane lift	U.S. Bridge P.O. Box 757 Cambridge, OH 43725 740-432-6334 www.usbridge.com
U.S. Military (Dry Support Bridge)	Span: 130 ft. (max.) Width: 1 lane Loading: MLC 96-ton wheeled or 70-ton tracked Erection: Beam launch	Williams Fairey Engineering P.O. Box 41, Crossley Road Heaton Chapel, Sockport, Cheshire, SK4 5BD England +44 (0) 161-432-0281 email@williams-fairey- eng.co.uk
U.S. Military (Rapidly Emplaced Bridge System)	Span: 42.6 ft. Width: 1 lane Loading: MLC 30-ton wheeled or tracked Erection: Launch from flatrack powered M1977 CBT	US Army Program Executive Office Combat Support & Combat Service Support Att'n: SFAE-CSS-FP/401 Warren, MI 48379-5000 586-574-6915, peocscs.tacom.army.mil/p mFP

Deck Techniques

AASHTO-TIG: Prefabricated Bridge Elements and Systems

As discussed in the AASHTO-TIG section in the Superstructure Techniques section earlier in this chapter, the development and use of prefabricated bridge elements and systems has grown significantly over the last 10 years. There is high potential for their use or adaptation in some rapid bridge replacement scenarios as discussed in the earlier section.

The AASHTO-TIG web site on Prefabricated Bridge Elements and Systems (www.aashtotig.org/focus_technologies/prefab_elements) is a very good resource for the use of prefabricated bridge elements and systems. This resource provides reference material on 23 available publications, 39 innovative projects, and 5 research projects; all addressing topics associated with either general issues of prefabricated bridges, prefabricated superstructures, prefabricated decks, or prefabricated substructures. The available publications portion of the web site identifies 6 references addressing prefabricated bridge decks, which are summarized in Table 2.5. The innovative projects portion of the web site identifies 17 projects addressing prefabricated bridge decks, which are summarized in Table 2.6. The research portion of the web site identifies 2 projects addressing prefabricated bridge decks, which are summarized in Table 2.7. (AASHTO-TIG, 2001)

Alfab, Inc.

Alfab manufactures a portable runway system that is comprised of interlocking aluminum plates (AM2 Mats) that can be placed directly over existing subgrades with minimum preparation or can be placed over damaged runway surfaces to provide a rapid solution to airbase recovery operations following an enemy attack. This product has the potential to provide temporary repairs to damaged bridge decks that have substantial strength but very poor ride surfaces. These lightweight modular units are interchangeable, easily transported, and are easily assembled by hand for rapid recovery operations. Modular units are approximate 0.5-inch thick with lateral dimensions of 3 feet by 6 feet. Contact information is provided in Table 2.8. (ALFAB, 2004)

Creative Pultrusions, Inc.

Creative Pultrusions, Inc. uses a pultrusion process with fiber reinforced polymer (FRP) materials to manufacture a modular, prefabricated bridge deck product, Superdeck. These prefabricated deck sections can be used for permanent or temporary applications. Superdeck can be manufactured in various modular widths and lengths and shipped to the job site ready for installation on top of various types of structural support members and can be placed with a longitudinal or transverse orientation. Its cross-section is a repetitive, alternating sequence of full-depth hexagons and half-depth trapezoids and comes in an 8-inch depth. Superdeck can be used to meet AASHTO HS25, can be quickly installed in the field with minimal equipment and formwork, and is fabricated with a vinyl ester resin matrix with no metal reinforcing, which provides a corrosion

resistant product with reduced maintenance and extended life. Approximately 8,000 square feet of Superdeck was used by the Ohio Department of Transportation on a multi-span bridge along State Route 49, in Montgomery County, Ohio. Installation was completed in November 1999, with the deck product installed over W 36 steel girders and used with a polymer concrete overlay. The bridge was rated at AASHTO HS25-44. In addition, approximately 320 square feet of Superdeck was used by the West Virginia Department of Highways on a single span bridge along County Road 26/6, in Lewis County, West Virginia. Installation was completed in May 1997, with the deck product installed over FRP W-shape beams and used with a polyester polymer concrete overlay. This bridge was rated at AASHTO HS25-44. Contact information is provided in Table 2.8. (Creative, 2002)

CTS Cement Manufacturing Corp.

CTS manufactures a number of fast setting cement products applicable for DOT highway and bridge applications. These include Rapid Set Cement, Rapid Set DOT Cement, Rapid Set Repair Mix, and Rapid Set Cement All. Rapid Set Cement is a hydraulic cement capable of obtaining early high strengths with very little shrinkage and with good durability. Coordinated and well planned placement and finishing operations are a must due to rapid strength gain following initial set. Tests show compressive strengths in the order of 2,100 psi in 1 hour and up to 7,400 psi in 28 days. Rapid Set DOT Cement is similar in nature but is a calcium sulfoaluminate based hydraulic cement that has improved workability. Tests show compressive strengths in the order of 3,140 psi in 1 hour and up to 5,500 psi in 28 days. Rapid Set DOT Repair Mix is a pre-blended mix of Rapid Set Cement and sand that produces a quality mortar. Mix yields can be extended by mixing Rapid Set DOT Rapid Mix with additional aggregate of uniform size. Tests show compressive strengths of 3,000 psi in 1 hour and up to 9,500 psi in 28 days. Repairs are ready for traffic in 2 hours. Rapid Set Cement All is a high strength non-shrink grout that can be used for general concrete repair and anchoring applications. Tests show compressive strengths of 3,000 psi in one hour and up to 9,000 psi in 28 days. Repairs are ready for traffic in 1 hour but are limited to a maximum depth of 4 inches. Contact information is provided in Table 2.8. (CTS, 2003)

Exodermic Bridge Deck, Inc.

Precast and cast-in-place Exodermic bridge deck panels can be used for permanent deck replacement projects, and they provide the benefits of rapid construction and reduced dead load. The basis of an Exodermic deck panel is an interlocking lower steel grid that is cast compositely with a concrete deck and utilizes the tensile strength of the lower steel grid system and the compressive strength of the upper concrete deck. Two options are available with the Exodermic deck panels. First, deck panels consisting only of the lower steel grid system can be put into place with a single mat of reinforcing steel placed on top of and supported by the steel grid system. The steel grid system is a stay-in-place form and the concrete deck cast compositely with and over the steel deck system. Second, precast deck panels consisting of the lower steel grid system, the single mat of reinforcing bars, and the concrete deck are prefabricated as a single unit. Short

lengths of the upper steel reinforcing mat and lower steel grid system are left exposed around the perimeter of the panels to allow interlocking connections with adjacent panels using closure pours. The deck panels come in thicknesses from 6 to 10 inches and can span up to 18 feet between supports. The galvanized lower steel grid system provides significant corrosion protection. The Exodermic deck panels have been used successfully in multiple projects to shorten construction and deck replacement times. They also are effective in projects limited to overnight and weekend construction. They were used to replace a 250,000 square foot deck on the Tappen Zee Bridge in Tarrytown, NY, using only nighttime construction between 8 p.m. and 6 a.m. They were used to replace 3,200 feet of bridge deck on U.S. 421 between Milton, KY, and Madion, IN. Exodermic deck panels were used to replace 360-foot-long, single lane sections, one at a time. This left the other single lane in the work zone to accommodate opposing traffic on the bridge. They are also currently being used to replace deck sections of the Gowanus Expressway, a heavily traveled viaduct in Brooklyn, NY. Other project examples are available at Exoderic's web site listed in Table 2.5. Contact information is also provided in Table 2.8. (Brown, 2003)

Garon Products, Inc.

Garon's Industrial Products Group produces an easy to use product for the repair of concrete potholes over 3-inches deep, Hy-Speed 500. Hy-Speed comes in 5-gallon buckets and can be quickly mixed with water and poured into the pothole. No priming is required and its self-leveling characteristic eliminates the need for troweling. The material expands as it sets providing an interlocking action between it and the existing concrete to ensure a better bond. Hy-Speed is a rapid set material that is ready for traffic within one hour and obtains a final cure strength in the order of 10,000 psi. This product has the potential for rapid deck repairs in any area where the primary damage is surface spalls or potholes. Contact information is provided in Table 2.8 (Garon, 2004)

GeoCHEM, Inc.

The rapid repair line of products, PERCOL, for use with asphalt concrete overlays and Portland cement concrete decks is available through GeoCHEM, Inc. Asphalt concrete repair products include PERCOL Elastic Cement AC and PERCOL Alligator Glue, which are applicable for repair of cracks and potholes and do not require the removal of damaged asphalt. Portland cement concrete repair products include PERCOL Elastic cement, PERCOL Dopey Soup, and PERCOL Concrete Welder, which are applicable for repair of cracks, spalls, potholes, and overlays. Removal of damaged concrete is typically required. PERCOL is a polyurethane based product that was developed in the mid 1980's from US Air Force sponsored research seeking to develop Rapid Runway Repair (RRR) techniques. RRR techniques were developed by the military to expedite base recovery operations following an enemy attack. PERCOL products are safe A+B component mixes that provide durable load bearing repairs that can be traffic ready 10 minutes after placement. PERCOL products come in 55, 15, or 5-gallon containers and have a 12-month shelf life. PERCOL products can be applied in

below freezing temperatures but must be applied to dry surfaces. Contact information is provided in Table 2.8. (GeoCHEM, 2003)

Mabey Bridge and Shore, Inc.

Mabey Bridge and Shore, Inc. provides a composite mat system, Mabey Mats that can be used to provide temporary ride or work surfaces for extreme conditions. Its modular design allows for rapid installation and ease of transportation. The 4.5-inch-thick, high density poly-ethylene mats are strong and durable and come in 2 sizes; 8 feet by 14 feet and 7.5 feet by 8 feet. Adjacent mats are connected at over-lapping edges by an interlocking, removal pin system to provide flexibility in required surface area coverage and allow reuse. The larger mats weigh approximately 1,050 pounds. Their surface tread pattern provides good traction for a wide range of vehicles. Mabey Mats can be quickly installed in emergency circumstances and later disassembled and stored for future use. Its durability and “endless shelf-life” makes it a long-term economical solution. It has the potential to provide a temporary repair to damaged bridge decks with sufficient strength but poor ride quality. In addition, it can be used for temporary repairs for damaged bridge approach slabs. Mabey Mats are available for purchase or rent. Mabey Mats are very similar to Soloco’s Dura-Base mat system. Contact information is provided in Table 2.8. (Mabey, 2003)

Rapid Mat US LLC

Rapid Mat is a folding fiberglass mat system that can be used for emergency runway, roadway, or bridge deck repairs. A single mat is comprised of 9 interconnected fiberglass panels that unfold using elastomeric hinges into a 30-foot-long by 54-foot-wide panel that can cover damaged roadway or runway surfaces. The mats are approximately 3/8-inch thick, weigh approximately 3,000 pounds each and when folded have a 6-foot by 30-foot footprint and stand 8.83 feet tall. Individual mats can be interconnected to adjacent mats with joining panels of form larger areas to cover damaged ride surfaces. This product has the potential for temporary bridge deck repairs where the bridge deck has sufficient strength but a poor ride surface. Contact information is provided in Table 2.8. (Rapid, 2003)

REMR Technical Note CS-MR-7.3

Technical Note (TN) CS-MR-7.3 is titled *Rapid-Hardening Cements and Patching Material* and was published in the Repair, Evaluation, Maintenance, and Rehabilitation (REMR) Research Program under the control of the U.S. Army Corps of Engineers. This TN is available to the public and can be downloaded at the web site listed in the contact information in Table 2.8. TN CS-MR-7.3 summarizes information and material properties of 4 types of very early strength cements, which by definition typically require the material to reach a compressive strength of 3,000 psi within 4 hours. The very early strength cements included in the TN are magnesium-phosphate cement, high alumina cement, regulated-set Portland cement, gypsum cement, and special blended cement. The TN also identifies and summarizes 13 rapid-hardening, prepackaged products used for patching concrete. Products included in the TN are Bonsal Rapid

Patch, Gilco Highway Patch, Five Star Structural Concrete, Nitoflor Patchroc, Pyrament 505, Pyrament SAC PAC, RoadPatch II, Sikaset Roadway Patch, Euco-Speed, Quick-Set, Set Instant, Speed Crete, and Target Traffic Patch. Access information for TN CS-MR-7.3 is provided in Table 2.8 (REMR, 1992 and REMR 2002)

Soloco, LLC

Soloco manufactures the Dura-Base Composite Mat System that was developed to provide temporary ride or work surfaces for extreme conditions. Its modular design allows for rapid installation and ease of transportation. The 4.5-inch-thick, high density poly-ethylene mats are strong and durable and come in 2 sizes, 8 feet by 14 feet and 7.5 feet by 8 feet. Adjacent mats are connected at over-lapping edges by an interlocking, removal pin system to provided flexibility in required surface area coverage and allow reuse. The larger mats weigh approximately 1,050 pounds. Their surface tread pattern provides good traction for a wide range of vehicles. Dura-Base can be quickly installed in emergency circumstances and later disassembled and stored for future use. Its durability and “endless shelf-life” makes it a long-term economical solution. It has the potential to provide a temporary repair to damaged bridge decks with sufficient strength but poor ride quality. In addition, it can be used for temporary repairs for damaged bridge approach slabs. Contact information is provided in Table 2.8. (SOLOCO, 2002)

Strategic Highway Research Program (SHRP)

SHRP evaluated several techniques associated with the rapid repair of concrete bridge decks. Results of these evaluations are provided in a report titled *Concrete Bridge Protection and Rehabilitation: Chemical and Physical Techniques-Rapid Concrete Bridge Deck Protection, Repair, and Rehabilitation* (Publication No. SHRP-S-344), which is available through the Transportation Research Board bookstore. Included in this report are the use of very early strength (VES) and high early strength (HES) Portland cement concrete (PCC) overlays, polymer overlays, and asphalt overlays with membranes. Polymer overlays using an epoxy or a polyester styrene are used to seal the bridge deck, improve skid resistance, and extend the life of the deck. The asphalt overlay is used to seal the deck and improve its ride quality. The VES and HES PCC overlays are more applicable as rapid repair techniques for damaged bridge decks. VES PCC overlays can be placed and the bridge returned to service in 8 hours, which will allow its installation overnight. A typical overnight sequence would be to close the bridge by 9:00 p.m., prepare the deck surface by 11:00 p.m., complete the overlay installation by 2:00 a.m., and open the bridge to traffic by 5:00 a.m. The HES PCC overlay takes longer to place and to return the bridge to service, taking in the order of 18 to 36 hours. However, this will still allow a HES PCC overlay to be placed over a weekend, when traffic may be reduced. Material costs are typically greater for VES and HES PPC overlays but these can be offset by reduced costs associated with traffic control and work zone safety measures. Virginia Department of Transportation (VDOT) estimates the costs of VES, HES, and conventional PPC overlays as \$96, \$130, and \$92 per square yard, respectively. (Focus, 1998) Additional information about polymer overlays is available from the American Association of State and Highway Transportation Officials in *Task Force 34-*

Guide Specifications for Polymer Concrete Bridge Deck Overlays, Publication No. C97-TF-34.

In 1998, a VES latex-modified PPC overlay was selected for use by VDOT and was installed on the Braddock Road overpass over Interstate 495, which had an ADT of 64,000. The bridge deck needed replacing due to deterioration which resulted in a poor ride quality and permitted the flow of water and chloride ions into the deck. The VES PCC overlay was successfully completed in 8 hours using the typical schedule discussed above. More detailed information about this installation is provided in Case Summary No. 4 in Chapter 3 of this report. Contact information is provided in Table 2.8. (Sprinker, 1993, Jackson, 1998, and FHWA, 1998)

The Fort Miller Co.

Effideck - The Fort Miller Co. has developed a modular, lightweight, full-depth deck replacement system, Effideck, which is prefabricated and shipped to the job site ready for installation. These full-depth deck panels are fabricated using a lower steel grid support system cast compositely with a concrete deck. Materials include high strength, high performance concrete and ASTM A-500, Grade B steel tubes. The lower steel grid system is galvanized for increased corrosion protection and extended life of the panels. The panels can be used in a transverse or longitudinal orientation, depending on the configuration of the primary support members and can be fabricated in a wide range of lateral dimensions and thicknesses. The panels are secured to the support members by bolts, shimmed for vertical alignment, and use grout pockets and steel shear studs to insure composite action between the deck panels and the bridge support members. Panels have been tested at several universities for fatigue and composite action. Several notable projects that have used Effideck are listed on Fort Miller's web site and include Missiquoi Bay Bridge at Lake Champlain, VT, the New England Thruway at Larchmont, NY, and the Berkshire Outlet Village Bridge at Lee, MA. Contact information for The Fort Miller Co. is provided in Table 2.8. (Fort, 2001)

Super-Slab - The Fort Miller Co. has also developed a full-depth slab system, Super-Slab, which is a full depth, precast, modular reinforced concrete panel system that can be used to install or replace bridge approach slabs. Prior to installation, the sub-grade is fully compacted and graded to the proper elevation. A finely graded material is then added to the area, which is compacted and graded to the required elevation using a special laser screed process to a tolerance of +/- 1/16 inch. The panels are then placed into position and interlocked using a system of dowels, pockets, and non-shrink grout. Final bedding between the slab and the sub-grade is achieved by the installation of non-shrink grout through a series of "specially designed grout distribution channels" provided in the Super-Slab units. Contact information is provided in Table 2.8. (Fort, 2001)

Table 2.5 AASHTO-TIG Prefabricated Bridges: Publications
(Prefabricated Decks)
(AASHTO-TIG, 2001)

Title	Author(s)	Topic	Publisher / Source / Contact
The Bridges That Good Planning and Execution Built	G. Jakovich & J. Alvarez	A case study on the use of prefabricated bridge decks for 3 bridge deck replacements near Langley, VA.	FWHA, Washington DC / Public Roads, Vol.66, No. 2, Sept-Oct 2002 / www.tfhr.gov/pubrds/02sep/02.htm
Construction Procedures for Rapid Replacement of Bridge Decks	Mohsen Issa, A Yousif, & Mahmoud Issa	An overview of deck replacement procedures using full-depth precast deck panels or precast prestressed deck panels.	ACI, Farmington Hills, MI / Concrete International, Feb 1995 / www.concreteinternational.com/pages/index/asp
Field Performance of Full Depth Precast Concrete Panels in Bridge Deck Reconstruction	Mohsen Issa, Mahmoud Issa, S. Khayyat, A. Yousif, & I. Kaspar	Presents the findings of a field performance investigation on full depth precast deck panels and precast prestressed deck panel in the U.S.	PCI, Chicago, IL / PCI Journal, May-June 1995 / www.pci.org/publications/journal/
Full Depth Precast and Precast, Prestressed Concrete Bridge Deck Panels	M. Issa, A. Idriss, I. Kaspar, & S. Khayyat	A summary of survey results addressing the use of precast full depth and prestressed concrete deck panels in the U.S.	PCI, Chicago, IL / PCI Journal, Jan-Feb 1995 / www.pci.org/publications/journal/
Keep It Moving	A. Zeyher	A summary of the bridge deck replacement project on the Lions' Gate Bridge in Vancouver BC. The bridge carries 70,000 vehicles per day and remained open to traffic during the day.	Scranton Gillette Communications, Inc., Des Plaines, IL / Roads & Bridges, Vol. 40, No. 8, August 2002 / www.roadsbridges.com/rb/index.cfm

Rapid Bridge Deck Replacement: A Field Demonstration and Load Test	R. Osegueda & J. Noel	Reports on full-scale demonstration project and subsequent load test of rapid deck replacement technique using 8-inch thick precast concrete deck panels and rapid setting epoxy/sand mortar. Project was in Lubbock, TX.	Texas State Department of Highways and Public Transportation-Transportation Planning Division / Report FHWA/TX-88-324-5F/ http://tti.tamu.edu
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Table 2.6 AASHTO-TIG Prefabricated Bridges: Innovative Projects
(Prefabricated Decks)
(AASHTO-TIG, 2001)

Project Name & Location	Project Description	Contact Information
Dead Run & Turkey Run Bridges, George Washington Memorial Parkway, VA	The project required the removal and replacement of over 1,400 feet (14 spans) of 8-inch thick concrete bridge deck, 2 lanes wide. The bridges both used steel girders with non-composite deck action. Full-depth precast post-tensioned concrete panels were installed during weekends only due to high traffic demands. One span was replaced each weekend, starting on Friday night and being opened to traffic on Monday morning. ADT: 42,800. Completed: 1998.	Hala Elgaaly FHWA 21400 Ridgetop Circle Sterling, VA 20166 703-404-6233 hala.elgaaly@fhwa.dot.gov
The Governor Malcolm E. Wilson Tappan Zee Bridge, New York, NY	The project required replacement of the concrete deck for the 16,000-foot-long, 7-lane-wide bridge over the Hudson River. Due to high traffic demands, the project was required to have all 7 lanes of traffic open during morning and evening rush hour traffic. The project replaced the bridge deck at night using 7.5-inch-thick Exodermic deck panels, typically 24 feet x 12 feet or 18 feet x 12 feet. ADT: 130,000 Started: 1998	Thruway Authority NYSDOT 200 Southern Blvd. P.O. Box 189 Albany, NY 12201 518-436-2700

<p>I-5 / South 38th Street Interchange, Tacoma, WA</p>	<p>The project required a 2-span, 325-foot-long replacement bridge to be installed over I-5 at South 38th Street in Tacoma, WA. Due to the high volume of traffic on I-5, traffic disruptions below the new bridge needed to be minimized. The use of precast tub girder segments that were post-tensioned together along with 766, 3.5-inch-thick precast pretensioned partial-depth deck panels helped to minimize I-5 nighttime lane closures within a single week. Completed: 2001</p>	<p>Joseph Merth Washington State DOT 360-705-7166 merthjo@wsdot.wa.gov</p>
<p>I-45 / Pierce Elevated, Houston, TX</p>	<p>The project required the replacement of 226 spans carrying 3 lanes of traffic in a high volume area adjacent to downtown Houston. Conventional construction was estimated to take 1.5 years with an estimated user cost of \$100,000 per day. Existing columns were reused with new precast bent caps. Tops of the existing concrete column supports were sawcut to the proper elevation and the precast bent caps post-tensioned in place with bars. Standard precast pretensioned I-beams and partial depth deck panels were used to complete the structure along with a cast-in-place deck. The 226 spans were replaced in 190 days. Completed: 1997.</p>	<p>Kenneth Ozuna Texas DOT 713-802-5435 kozuna@dot.state.tx.us</p>
<p>Illinois Route 29 over Sugar Creek, Sangamon County, Springfield, IL</p>	<p>The project required the deck replacement of an existing 5-span, 253-foot-long steel girder bridge. Full-depth, full-width precast concrete panel were used and installed to develop composite action with the steel girders. The 5,000 psi concrete deck panels were 7.8 inches thick, 37.1 feet wide, and normally 8.2 feet long. A total of 29 panel were laid in the longitudinal direction and post-tensioned with high-strength steel bars. Completed: 2001.</p>	<p>Tom Domagalski Illinois DOT 217-785-2913 domagalskitj@nt.dot.state.il.us</p>
<p>Route 11 / Keaiwa Stream Bridge, Pahala, HI</p>	<p>The project required the replacement of an 80-foot-long bridge due to storm damage. Time of closure during replacement was important since the damaged bridge provided the only route for the southeast</p>	<p>Paul Santo Hawaii DOT 808-692-7611 paul_santo@exec.state.hi.us</p>

	side of the island. A 7-span, 230-foot-long bridge was chosen for the new bridge to prevent future flood problems. The new bridge used 4-foot-wide, 11-inch-thick precast prestressed concrete planks with a cast-in-place concrete topping to minimize traffic disruptions and limit lane closures. The project took 7 months to complete. Completed: 2000.	
SH 35 / Lavaca Bay Causeway, Port Lavaca, TX	The project was new construction of an 11,900-foot-long 63-foot-wide, 4-lane bridge across Lacava Bay. Precast deck slab units, each weighing 150 tons, were cast on shore, barged into position, and lower onto the supporting bents. Completed: 1961.	Bruce Bayless Texas DOT 361-293-4300 mbayless@dot.state.tx.us
Route 7 / Route 50, Fairfax County, VA	The project required the replacement of approximately 14,000 square feet deteriorated bridge deck. Lightweight precast deck panels were used along with nighttime construction to minimize traffic disruptions. Each night a section of the existing deck was removed and replaced with the precast deck panels with a rapid-set concrete overlay and reopened to traffic by morning. Completed: 1999.	Nicholas Roper Virginia DOT 703-383-2117 Nicholas.Roper@VirginiaDOT.org
Route 57 / Wolf River, Fayette County, VA	The project required the construction of a 1,408-foot-long, 46-foot-wide, 20-span replacement bridge across environmentally sensitive wetlands while maintaining traffic flow on the primary east-west route in the area. Staged construction and timed signals were used to maintain one lane of traffic during construction. Precast prestressed beams and precast prestressed concrete deck panels were used to complete the project in 11 months. Details were developed to precast 2-piece bent caps suitable for staged construction. Completed: 1999.	Edward Wasserman Tennessee DOT 615-741-3351 Ed.Wasserman@state.tn.us
SH 36 / Lake Belton, Waco, TX	This project used partial-depth precast prestressed deck panels along with precast prestressed U-beams and precast bent caps to construct two 3,840-foot-long twin structures that cross Lake Belton near Waco, Texas. Precast elements were used	Lloyd Wolf Bridge Division Texas DOT 125 E. 11 th Street Austin, TX 78701 512-416-2279

	to limit construction issues related to lake levels which can vary as much as 48 feet. Completed: 2004.	lwolf@dot.state.tx.us
SH 66 / Lake Ray Hubbard, Dallas, TX	This project used partial-depth precast prestressed deck panels along with precast prestressed I-beams and precast bent caps to replace 2 narrow inadequate bridges that were 10,280 and 4,360 feet long over Lake Ray Hubbard near Dallas, TX. Precast elements were used to improve work zone safety and speed up construction, therefore minimizing traffic disruptions. Completed: 2002.	Lloyd Wolf Bridge Division Texas DOT 125 E. 11 th Street Austin, TX 78701 512-416-2279 lwolf@dot.state.tx.us
SH 249 / Louetta Road Overpass, Houston, TX	This project used partial-depth precast prestressed deck panels along with precast prestressed U-beams and precast post-tensioned piers to construct 2 overpass bridges capable of carrying 6 lanes of traffic, 3 each direction. Three 130-foot-long spans were used for each structure. The prefabricated used were used to speed up construction and minimize traffic disruptions. Completed: 1994.	Mary Lou Ralls Bridge Division Texas DOT 125 E. 11 th Street Austin, TX 78701 512-416-2404 mralls@dot.state.tx.us
Spur Overpass / AT&SF Railroad, Lubbock, TX	This project required the deck replacement of the two 545-foot-long twin structures due to deck deterioration along with the need for widening. Deck replacement was completed using 8-inch-thick, full-depth, precast concrete deck panel that were epoxied into place. Panel dimensions were 6.25 feet and 45.75 feet. Construction was completed in a couple of days with minimum traffic disruptions. Completed: 1988.	Michael Hyzak Bridge Division Texas DOT 125 E. 11 th Street Austin, TX 78701 512-416-2184 mhyzak@dot.state.tx.us
Troy-Menands Bridge, City of Troy & Village of Menands, New York	This project used prefabricated Exodermic deck panels and nighttime construction to replace the existing deteriorated bridge deck of the 4 lane bridge in an effort to minimize traffic disruptions. During construction, lane closures were limit to nighttime hours between 10:00 p.m. and 6:00 a.m., with 1 lane required to remain open at all times. The contractor was typically able to install approximate 900 square feet of deck (6 panels) per night. Contract penalties of \$10,000 per hour for	Timothy Conway New York State DOT 518-473-0497 TConway@gw.dot.state.ny.us

	late lane openings never had to be assessed. ADT: 36,000. Completion: 1995.	
US 27 / Pitman Creek, Somerset, KY	This project used proprietary full-depth deck panels and partial lane closures to replace the deck on this 700-foot-long bridge that is a major north-south artery in the region. The contract required 1 lane of traffic to be open between 6:00 p.m. and 6:00 a.m. and required 2 lanes of traffic to be open between 6:00 a.m. and 6:00 p.m. High-early-strength concrete was used to make joint pours between panels and allowed traffic on the panels by 6:00 a.m. the following morning. Completion: 1993.	Steve Goodpaster Kentucky Transportation Cabinet 502-564-4560 Steve.Goodpaster@ mail.state.ky.us
US 59 under Dunlavy, Hazard, Mandel, and Woodhead Street, Houston, TX	Each bridge in this project used precast prestressed deck panels that were bolted to erection beams suspended from 2 tied arches 45 feet apart. The existing bridges were used as platforms for the erection of the tied arches for the new bridges. This technique allowed construction of the new bridges without falsework and minimized traffic disruptions on US 59, a high volume artery in Houston. Completion: 1995.	John Vogel Houston District Texas DOT 8100 Washington Ave. Houston, TX 77251 713-802-5235 jvogel@dot.state.tx.us
Wesley Street Bridge, Jacksonville, TX	This project used precast prestressed slab beams for accelerated construction of a replacement bridge in a populated housing area with limited access to minimize traffic disruption and reduce inconvenience to local residents. Construction took 4 months. Completion: 2002.	Steven Hall Texas DOT 903-586-9878 shall@dot.state.tx.us

Table 2.7 AASHTO-TIG Prefabricated Bridges: Research Projects
(Prefabricated Decks)
(AASHTO-TIG, 2001)

Project Title Project Number	Project Description	Sponsor
Behavior of Cast-in-Place Slabs Connecting Precast Slab and Steel Girder	The project is developing, evaluating, and writing guidelines for a prefabricated full-depth concrete deck with composite steel girders system. The prefabricated modular	Texas Department of Transportation

Assemblies, TxDOT 0-4122	units will be set into place and will utilize narrow transverse (at interior bents) and longitudinal (between units) closure pours to connect the units. Start date: 2002	
Rapid Bridge Deck Replacement: A Field Demonstration and Load Test, FHWA/TX-88-324-5F	This project used 2 adjacent and identical 50-foot simple spans to investigate the composite action of precast bridge deck elements. The 2 bridges were redecked, one using conventional cast-in-place methods and the other using full-depth precast panels. Load test data and 3D computer model results both yielded strong indications of composite action. Completed: 1988.	Texas Department of Transportation

Table 2.8 Deck Techniques

Product or Technique	Product Description and Use	Contact
AM2 Aluminum Landing Mats	AM2 aluminum landing mats were developed as a portable runway system that can be used for rapid runway repairs. The lightweight modular panels interlock providing a continuous ride surface. They have the potential for temporary rapid bridge deck repairs where the deck has adequate strength but a poor ride surface.	Alfab, Inc. 220 Boll Weevil Circle East Enterprise, AL 36331 334-347-9516 www.alfabinc.com
Superdeck	Superdeck is a modular, prefabricated, FRP bridge deck element manufactured by the pultrusion method. This lightweight, modular product can be shipped to the job site and quickly installed with minimal equipment and handling. The material is corrosion resistance which reduces maintenance cost and extends its life. Bridges can be designed to meet AASHTO HS25.	Creative Pultrusions, Inc. 214 Industrial Lane Alum Bank, PA 15521 888-274-7855 www.creativepultrusions.com
Rapid Set (Cement, DOT Cement, DOT Repair Mix, & Cement	Rapid Set is a line of hydraulic cement products that provide high early strengths, minimum shrinkage, and good durability and that are applicable for DOT applications. Compressive	CTS Cement Mfg. Corp. 11065 Knott Ave, Suite A Cypress, CA 90630 800-929-3030 www.rapidset.com

All)	strengths range from 2,100 to 3,000 psi within one hour and from 5,500 to 9,500 psi in 28 days.	
Exodermic	Exodermic deck panels are modular units fabricated with a lower steel grid system and an upper concrete composite deck. They are available as cast-in-place or precast panels. They are effective in shortening construction time, for staged construction, and for limited construction such as nighttime or weekends only. Larger sections are capable of meeting AASHTO HS25.	Exodermic Bridge Deck, Inc. 60 Long Pond Road Lakeville, CT 06039 860-435-0300 www.exodermic.com
Hy-Speed 500	Hy-Speed 500 is a single component material that is available to patch concrete potholes deeper than 3 inches. When mixed with water, it rapidly sets and is ready for traffic within the hour. No priming is required, and its self-leveling characteristic eliminates the need for troweling. At final cure, its compressive strength is in the order of 10,000 psi. It also expands as it sets providing interlock with the adjacent concrete to ensure better bond.	Garon Products, Inc. P.O. Box 1924 Wall, NY 07719 800-631-5380 www.garonproducts.com
PERCOL (asphalt & concrete repair)	PERCOL is a polyurethane based product used to repair cracks, potholes, spalls, and overlays in asphalt and concrete surfaces and decks. It is a two component mix that provides a durable load bearing repair that can be traffic ready in 10 minutes. The products can be applied in winter temperatures but must be applied to dry surfaces.	GeoCHEM, Inc. 3464 Newcomb Dr. Anchorage, AK 99508-4869 907-562-5755 www.geocheminc.com
Mabey Mats	Mabey Mats are a reusable product that can be rapidly installed, used to provide a temporary ride or work surface in extreme conditions, and then disassembled and stored for future use. The mats are made from a high density poly-ethylene, come in 8-foot by 14-foot dimensions, and can be interlocked to adjacent panels for dimensional flexibility. Panels weigh 1,050 pounds, and its tread pattern provides	Mabey Bridge & Shore, Inc. 6770 Dorsey Road Baltimore, MD 21075 410-379-2800 www.mabey.com

	good vehicle traction.	
Rapid Mat	Rapid Mat is a folded fiberglass mat (FFM) system that can be used for temporary bridge deck repairs where decks have sufficient strength but poor ride quality. Individual mats are 3/8-inch thick and consist of 9, 6-foot by 30-foot panels that unfold into a single mat able to cover an area 30 feet by 54 feet. Adjacent panels can be connected to cover larger damaged areas. Individual mats weigh 3,000 pounds.	Rapid Mat US LLC Washington, DC 20007 202-295-9097 www.rapidmat.com
REMR Technical Note (TN) CS-MR-7.3	This TN is published under the Repair, Evaluation, Maintenance, and Rehabilitation Research Program of the U.S. Army of Corps of Engineers and can be downloaded at the web site shown in the contact information. It summarizes information about 4 early high strength cements and 13 rapid-hardening patching materials.	REMR Research Program U.S. Army COE, WES www.wes.army.mil/REMR/tn.html#concrete
Dura-Base Composite Mat System	Dura-Base is a reusable product that can be rapidly installed, used to provide a temporary ride or work surface in extreme conditions, and then disassembled and stored for future use. The mats are made from a high density poly-ethylene, come in 8-feet by 14-foot dimensions, and can be interlocked to adjacent panels for dimensional flexibility. Panels weigh 1,050 pounds, and its tread pattern provides good vehicle traction.	Soloco, LLC 207 Town Center Parkway Lafayette, LA 70506 877-628-7623 www.soloco.com
Very Early Strength (VES) and High Early Strength (HES) Portland Cement Concrete (PCC) Overlays	VES and HES PPC overlays can be used as rapid bridge deck replacement techniques. A VES PPC overlay can be placed and opened to traffic in about 8 hours while a HES PPC overlay requires between 18 to 36 hours. This allows bridge decks to be replaced overnight or over a weekend, respectively, when traffic demands are reduced. General information is available in Publication No. SHRP-S-344 through TRB. A specific case	Strategic Highway Research Program (SHRP) Publication No. SHRP-S-344 www.TRB.org Braddock Road @ IH-495 Michael Sprinkel, VTRC Virginia DOT 804-293-1941

	using a VES PCC overlay is provided as Case Summary No. 4 in Chapter 3 of this report, which address Braddock Road Overpass at IH-495 in Virginia.	sprinkelmm@vdot.state.va.us
Effideck	Effideck is a lightweight, full-depth deck replacement system. The modular panels are prefabricated using a lower steel grid system and an upper concrete composite deck. They can be designed for a wide range of lateral dimensions and thicknesses. The panels are bolted to the support members, shimmed for vertical alignment, and grouted at pockets around shear studs to insure composite action between the panels and the support members.	The Fort Miller Co., Inc. P.O. Box 98 Schuylerville, NY 12871 800-821-1202 www.fortmiller.com
Super-Slab	Super-Slab is full-depth, modular, precast concrete unit used for rapid installation of bridge approach slabs. The sub-grade is fully compacted and graded using a finely graded material to the proper elevation +/- 1/16 inch. Panels are interconnected using dowels, pockets, and non-shrink grout. Final, full bedding between the panels and sub-grade is also achieved by grouting.	The Fort Miller Co., Inc. P.O. Box 98 Schuylerville, NY 12871 800-821-1202 www.fortmiller.com

Substructure Techniques

AASHTO Construction Handbook for Bridge Temporary Works

“This construction handbook has been developed for use by contractors and construction engineers involved in bridge construction on federal-aid highway projects. This document may also be of interest to falsework design engineers, and supplements information found in the Guide Design Specification for Bridge Temporary Works. The content is construction-oriented, focusing primarily on standards of material quality and means and methods of construction. The handbook contains chapters on falsework, formwork, and temporary retaining structures.” (AASHTO, 1995a) Related references are also identified within the construction handbook if additional or more in depth information is needed. Contact information is provided in Table 2.9. (AASHTO, 1995a)

AASHTO Guide Design Specifications for Bridge Temporary Works

“This guide design specification has been developed for use by state agencies to include in their existing standard specifications for falsework, formwork, and related temporary construction used to construct highway bridge structures. The specification should also be useful to bridge engineers, falsework designers, contractors, and inspectors. Sections within this specification address falsework, formwork, and temporary retaining structures.” (AASHTO, 1995b) Related references are also identified within the guide design specifications if additional or more in depth information is needed. Contact information is provided in Table 2.9. (AASHTO, 1995b)

AASHTO-TIG: Prefabricated Bridge Elements and Systems

As discussed in the AASHTO-TIG section in the Superstructure Techniques section earlier in this chapter, the development and use of prefabricated bridge elements and systems has grown significantly over the last 10 years. There is high potential for their use or adaptation in some rapid bridge replacement scenarios as discussed in the earlier section. The AASHTO-TIG web site on Prefabricated Bridge Elements and Systems (www.aashtotig.org/focus_technologies/prefab_elements) is a very good resource for the use of prefabricated bridge elements and systems. This resource provides reference material on 23 available publications, 39 innovative projects, and 5 research projects; all addressing topics associated with either general issues of prefabricated bridges, prefabricated superstructures, prefabricated decks, or prefabricated substructures. The available publications portion of the web site identifies 5 references addressing prefabricated substructures, which are summarized in Table 2.10. The innovative projects portion of the web site identifies 11 projects addressing prefabricated bent caps, columns, and piers, which are summarized in Table 2.11. The research portion of the web site identifies 2 projects addressing prefabricated substructures, which are summarized in Table 2.12. (AASHTO-TIG, 2001)

Acrow Corporation

Acrow Corporation has several bridge products available for purchase, rent, or lease that can be used to meet a wide range of shoring needs. As discussed in the superstructure section earlier in this chapter, Acrow produces 700 and 300 series panel bridges. Components of these panel bridges can be reconfigured and used for temporary shoring applications. Shoring configurations include Superprop or Panel Tower, both of which are described below. Contact information is provided in Table 2.9. Emergency assistance phone numbers are provided at Acrow’s web site listed in Table 2.9.

Superprop - An Acrow Superprop is configured as a “cruciform section” using four reinforcing chords from their standard panel bridges that are pinned together. The section is approximately 20-inches across and can carry 500 kips at an unbraced length up to 40 feet. Standard lengths for the reinforcing chord members are 2.5, 4.9, and 9.8 feet. Chord members of various lengths can be pinned together end-to-end to form a Superprop or required height. A Superprop can be used individually or interconnected by bridge truss panels into a shoring assemblage using pin connections. Head and base units

are also pinned to the Superprop to complete the shore. Contact information is provided in Table 2.9. (Acrow, 2003a and Acrow, 2003b)

Panel Tower - Acrow Panel Bridge truss panels (700 or 300 series) can also be assembled into tower configurations for use as shores. Even though either panel bridge series can be used, the primary information found in the literature addressed the newest 700XS Panel Bridge produced by Acrow. Towers can be configured using either four or two bridge truss panels. A 4-panel tower has a square footprint and uses four bridge truss panels oriented at 90 degrees to the adjacent panel. Special corner angle brackets are bolted to each truss panel chord every 30 feet to connect the panels and provide stability. Additional truss panels can be connected end-to-end to achieve various heights in increments of 5 feet. The 4-panel tower can be used for heights up to 60 feet without special bracing requirements and can carry loads in the order of 800 kips. “Crib beams” and “sole plates” are attached to the top and bottom of the tower, respectively, to complete the load transfer path. For smaller load capacity applications, a 2-panel tower can be used. The 2-panel tower uses two parallel truss panels that are separated and interconnected by bolting “brace frame” plates to the panel truss chords intermittently along the length of the panels. As with the 4-panel tower, height variations in 5-foot increments are available and similar top “crib beams” and bottom “sole plates” are used to complete the assembly. Acrow notes that the 2-panel tower may require special bracing and that they should be contacted. (Acrow, 2000). Contact information is provided in Table 2.9. (Acrow, 2000, Acrow, 2003a, and Acrow, 2003b)

California Falsework Manual

“The *California Falsework Manual* has been issued by the Department of Transportation's Division of Structures to fill a long-recognized need for a comprehensive design and construction manual devoted exclusively to bridge falsework. Its intended purpose is to provide administrative and technical direction to the Division's field engineers who are in charge of bridge construction on State highway projects. While emphasis is placed on contract administration, it is important to note that materials, design considerations, stress analysis, review criteria, construction, and construction inspection are covered as well. Proper use of the *California Falsework Manual* requires a thorough understanding of the principles of civil engineering design, and familiarity with the falsework specifications as well.” (Caltran, 1988) Some of the related topics addressed in the manual are design considerations, stress analysis (timber members, steel members, and cable bracing systems), falsework stability, steel shoring systems, and falsework foundations. Contact information is provided in Table 2.9. This manual is available on line at the web site listed in Table 2.9. (CalTran, 1988)

EFCO Corporation

EFCO Corporation has two systems available for use for temporary shoring of bridges; the Shore Tower system and the Super Stud system. These systems are available throughout the United States and may be purchased or leased. Contact information for EFCO's home office and web site address are provided in Table 2.9. Their web site

contains additional contact information for their 15 District Offices located across the U.S. as well as contact information for their Sales Offices located within each district.

EFCO Shore Tower - EFCO's Shore Tower system is capable of carrying heavy elevated construction loads. Six modular units are available for use, a 10-foot x 10-foot unit footprint with 10, 5, and 2.5-foot heights and an 8-foot x 8-foot unit footprint with 8, 4, and 2-foot heights. Each unit consists of four vertical legs interconnected by lateral elements and X-braces. Modular units with a similar footprint can be stacked vertically for height flexibility, using pinned connections for ease of installation. The 10-foot module is capable of carrying 100 kips per leg for a total of 400 kips per tower. The 8-foot module is capable of carrying 50 kips per leg for a total of 200 kips per tower. Up to four additional legs can be installed in each module to increase its capacity. Screw jack assemblies can be installed at the top and bottom of the tower on each leg for vertical adjustments. Product summary and contact information are provided in Table 2.9. (EFCO, 1998 and EFCO, 2004)

EFCO Super Stud - EFCO's Super Stud system is another product that can be used to carry heavy elevated construction loads and provides "erector set versatility." Super Stud is fabricated using two channel-shaped, formed metal sections welded together back-to-back via spacer along its entire length. Super Stud is available in two cross-sections, 9-inch x 9-inch or 6-inch x 6-inch. The 9-inch section is available in 12, 6, 3 or 1.5-foot lengths, and the 6-inch section is available in 12, 8, 4, and 2-foot lengths. Length flexibility is achieved by bolting elements of similar cross-section together, end-to-end. Screw jack assemblies can be installed at the top and bottom of each Super Stud shore for vertical adjustments. The 9-inch section can carry a concentric load of 30 kips at lengths up to 20 feet. Beyond 20 feet, the slenderness ratio controls and capacities must be calculated. The 6-inch section can carry a concentric load of 15 kips at lengths up to 10 feet. Beyond 10 feet, the slenderness ratio controls and capacities must be calculated. Bolt holes are provided in each face of the member along its entire length to provide configuration and connection flexibility. Super Stud elements can be used as individual shores or interconnected into tower configurations. Product summary and contact information is provided in Table 2.9. (EFCO, 1998 and EFCO, 2004)

Mabey Bridge and Shore, Inc.

Mabey Heavy Prop - The Mabey Heavy Prop is a modular system that provides flexibility for a wide range of temporary shoring needs. The Heavy Prop uses four standard chord members from Mabey's panel bridges that are connected into a square cross-section via "prop chord connectors." Length flexibility is provided by connecting standard chord lengths end-to-end as required and by using head and base units, which are capable of providing 15.7 inches of adjustment. Heavy Prop can be used as a stand-alone prop capable of carrying 490 kips or can be connected with other Heavy Props via standard Mabey bridge truss panels into a wide range of in-line or tower configurations. A range of accessories is available for use with the basic prop unit. Contact information is provided in Table 2.9. (Mabey, 2003)

Mabey Mass 50 and Mass 25 - The two Mabey Mass systems, 50 and 25, are similar in design and use, but are different in size and load capacity. Both systems are comprised of standard “off-the-shelf” modular units of various lengths that can be interconnected in the longitudinal and transverse directions to provide flexibility in height and configuration requirements. Modular units and accessories are connected via boltholes distributed in the members’ end plates and along its flanges. Adjustable head units and a range of other accessories provide the Mass systems additional flexibility. The Mass 50 and Mass 25 systems have 7-inch-wide and 4-inch-wide square cross-sections, respectively, and 112-kip and 56-kip axial load capacities, respectively. The size and weight of each modular Mass 25 unit allows it to be installed by hand. Contact information is provided in Table 2.9. (Mabey-Support, 2004)

Mabey Panel Tower - Mabey Panel Towers can be used to meet a wide range of temporary shoring needs. They can be constructed using standard “off-the-shelf” components of either the Mabey Universal or Compact Panel Bridges. Panel bridge truss units come in 5, 10 and 15-foot lengths for tower height flexibility. A range of accessories are also available for additional flexibility. The panel units “are connected together using corner brackets to form box units that are pinned end-to-end to produce a” tower that has a square cross-section. (Mabey-Support, 2004) A tower can be used individually or interconnected with other towers to meet a range of configuration and load requirements. A single Compact Panel Tower can carry up to 448 kips at heights up to 130 feet. Contact information is provided in Table 2.9. (Mabey, 2003 & Mabey-Support, 2004)

Salvaged / Stockpiled Materials

Salvaged materials from old bridges can be stockpiled and used during emergencies. If structural members, from a bridge that is being replaced, are still in good condition, and the owner has sufficient storage space, the members can be stockpiled for possible future use when quick repairs or shoring are needed. Texas DOT’s San Antonio District was able to use stockpiled steel beams as temporary shoring when significant cracking of several cantilevered piers was discovered. The cracked piers supported the upper level of Eastbound I-10 near downtown San Antonio, Texas, a high traffic volume area. Under the emergency conditions, several W36 x 230 beams were selected from a stockpile of used beams and cut into 10-foot-long sections. The beam webs were stiffened with 6-inch by 6-inch angles and then stacked into a tower to provide shoring. Large timbers were used on top of the tower for final height adjustment along with solid steel plates. These stockpiled beams were only approved for use after they were carefully measured so that capacities could be verified. Additional information about the San Antonio “Y” incident is provided in CS #18 in Chapter 3 of this report.

If structural members are stockpiled for future use, their sizes should be clearly marked when they go into the stockpile to eliminate the need for measurement during an emergency. Any materials that have been stockpiled for several years will need to be carefully examined before use to verify their soundness. Contact information is provided in Table 2.9. (Kelly, 1995 and Heaves, 1995)

Scaffolding & Shoring Services

Scaffolding & Shoring Services provides a versatile lightweight system (XPS-60) that can be utilized for a wide range of temporary shoring needs. The system is available for purchase or rent and comes with the support of a 24-hour emergency response team. The system is comprised of individual lightweight components that can be interconnected with pins and bolts to provide single shores or shore towers for various heights and configurations. The main load bearing component is a circular cross-section vertical “post” that is available in heights between 4 and 10 feet, comes in 2-foot increments, and has a maximum weight of 147 pounds. A truss type “frame” is used to provide lateral connections between the vertical “posts” to create shoring towers in lieu of a single individual shore. The “frame” is available in lengths between 4 and 10 feet, comes in 2-foot increments, and has a maximum weight of 140 pounds. Bottom “base plate” and top “U-head” elements are available along with screw jack assemblies for vertical adjustments at the bottom and top of the shores. Other components that are required to complete the assembly include “coupling pin,” “corner brace,” and “connecting bar” elements. Shore towers can be assembled up to 31-feet in height by stacking three 10-foot-tall sections with a capacity is 240 kips (4 legs at 60 kips per leg).

This system was recently utilized twice by TxDOT in emergency situations. In January 2004, a truck lost control and impacted the Pyka Road Bridge over IH-10 in Austin County, Texas. A single bridge column was fractured and the XPS-60 system was used as temporary shoring while the column was replaced by Gibson Associates, Inc. of Balch Spring, Texas, under an emergency contract. Emergency shoring cost for this incident was \$23,470. In May 2004, a truck lost control and impacted the Tanchua Street Bridge over IH-37 in Corpus Christi, Texas. One column was severely damaged and required the replacement of the column, its footing, and one-half of its bent cap. Again, the XPS-60 system was used as temporary shoring. The construction work was completed by SCR Construction Inc. of Richmond, Texas, under an emergency contract with an emergency shoring cost of \$80,540.

Table 2.9 Substructure Techniques

Product or Technique	Product Description and Use	Contact
AASHTO Construction Handbook for Bridge Temporary Works	“This construction handbook has been developed for use by contractors and construction engineers involved in bridge construction.” (AASHTO, 1995) It contains chapters that address falsework, formwork, and temporary retaining structures.	American Association of State Highway and Transportation Officials 444 North Capitol Street N.W., Suite 249 Washington, DC 20001 202-624-5800 www.transportation.org/aashto/home.nsf/FrontPage
AASHTO Guide Design	“This guide design specification has been developed for use by State	American Association of State Highway and Transportation

Specifications for Bridge Temporary Works	agencies to include in their existing standard specifications.” (AASHTO, 1995) It contains sections on falsework, formwork, and temporary retaining structures.	Officials 444 North Capitol Street N.W., Suite 249 Washington, DC 20001 202-624-5800 www.transportation.org/aashto/home.nsf/FrontPage
Acrow Superprop Shore	Superprop is formed using 4 standard “reinforcing chords” from Acrow’s standard panel bridges. The chords are pinned together to form a “cruciform” section 20-inches across and can carry 500 kips at unbraced lengths up to 40 feet. Standard chord lengths are 2.0, 4.9, and 9.8 feet and can be connected end-to-end to meet height requirements.	Acrow Corporation 396 Washington Ave. Carlstadt, NJ 07072 201-933-0450 www.acrowusa.com
Acrow Panel Tower Shore	Panel towers are formed using either 4 or 2 standard bridge truss panels that are connected to each other by corner “angle brackets” or “brace frame” plates, respectively, that are bolted to their truss chords. Panels can be connected end-to-end for height variability, in increments of 5 feet. Special top “crib beams” and bottom “sole plates” are used to complete the towers. The 4-panel tower can carry loads up to 800 kips and used for heights up to 60 feet without special bracing. The 2-panel tower may require special bracing and Acrow should be contacted.	Acrow Corporation 396 Washington Ave. Carlstadt, NJ 07072 201-933-0450 www.acrowusa.com
<i>California Falsework Manual</i>	“The <i>California Falsework Manual</i> has been issued by the Department of Transportation’s Division of Structures to fill a long-recognized need for a comprehensive design and construction manual devoted exclusively to bridge falsework.” (Caltran, 1988) Some of the related topics addressed in the manual are design considerations, stress analysis (timber members,	California DOT Offices of Structure Constr’n. Att’n: Manual Coordinator 1801 30 th Street Sacramento, CA 95816 916-227-7777 www.dot.ca.gov

	steel members, and cable bracing systems), falsework stability, steel shoring systems, and falsework foundations. The manual is available on line.	
EFCO Shore Tower	Six standard modular unit sizes are 10-ft x 10-ft footprint in heights of 10, 5 and 2.5-ft and 8-ft x 8-ft footprint in heights of 8, 4, and 2-ft. Tower capacities are 100 kips per leg for the 10-ft units and 50 kips per leg for the 8-ft units. Modules may be stacked vertically for required heights and screw jack assemblies used for vertical adjustments.	EFCO Corporation 1800 NE Broadway Blvd. Des Moines, IA 50313 515-266-1141 www.efco-usa.com
EFCO Super Stud	The two available standard cross-sections are 9-inch x 9-inch in lengths of 12, 6, 3, and 1.5 feet and 6-inch x 6-inch in lengths of 12, 8, 4, and 2 feet. Elements of common cross-section can be bolted together end-to-end for required heights and screw jack assemblies can be used for vertical adjustments. The 9-inch and 6-inch sections have maximum capacities of 30 kips and 15 kips, respectively, for length up to 20 feet and 10 feet, respectively. Super Stud elements can be used as a stand alone shore or be interconnected in a tower configuration.	EFCO Corporation 1800 NE Broadway Blvd. Des Moines, IA 50313 515-266-1141 www.efco-usa.com
Mabey Heavy Prop	Heavy Prop is a modular system that uses four standard chord members from Mabey's standard panel bridges connected into a square cross-section as the basic prop module. These modules can also be connected end-to-end or laterally to provide flexibility in length and in configuration. Individual Heavy Prop units can carry up to 490 kips.	Mabey Bridge & Shore, Inc. 6770 Dorsey Road Baltimore, MD 21075 410-379-2800 www.mabey.com
Mabey Mass 50 and Mass 25	The Mass 50 and Mass 25 systems are comprised of standard "off-the-	Mabey Bridge & Shore, Inc. 6770 Dorsey Road

Systems	shelf” modular units that can be interconnected in the longitudinal and transverse directions for flexibility in height and configuration requirements. The Mass 50 system has a 7-inch-wide square cross-section and a 112-kip capacity. The Mass 25 system has a 4-inch-wide square cross-section and a 56-kip capacity. Bolted connections and accessories add to the flexibility of the Mass systems. The weight of the Mass 25 system components allows hand installation.	Baltimore, MD 21075 410-379-2800 www.mabey.com
Mabey Panel Tower	Mabey Panel Towers can be constructed using standard “off-the-shelf” components of either the Mabey Universal or Compact Panel Bridges. Panel truss units come in 5, 10, and 15-foot lengths that can be used for height flexibility. Individual towers are constructed by connecting four truss panels at the corners to form a box section that is pinned end-to-end with other box section to form a tower with a square cross-section. Panel towers can be used separately connected to other panel towers to meet load and configuration requirements. A single Compact Panel Tower can carry up to 448 kips at heights up to 130 feet.	Mabey Bridge & Shore, Inc. 6770 Dorsey Road Baltimore, MD 21075 410-379-2800 www.mabey.com
Salvaged / Stockpiled Materials	Salvaged or excess material can be stockpiled for future use during emergencies. TxDOT’s San Antonio District used salvaged / stockpiled W36 x 230 beams as temporary shoring when significant cracking was discovered in cantilevered piers supporting a high traffic volume of I-10 in San Antonio. The W36 beams were cut into 10-foot lengths and their webs stiffened with 6-inch x 6-inch	Texas DOT San Antonio District Office P.O. Box 29928 San Antonio, TX 78229 210-615-1110

	angles. The beam sections were then stacked into a tower to provide shoring for the cantilevered portion of the cracked pier.	
Scaffolding & Shoring Services	The XPS-60 system can be used as temporary shoring for a wide range of needs from single shores to shore towers. The system contains a number of lightweight components that are interconnected with pins and bolts to create variable dimension shores. Vertical “post” members come in heights between 4 and 10 feet in 2-foot increments while horizontal “frame” members come in identical lengths and are used to provide lateral connections between “posts” to create towers. Three 10-foot sections can be stacked for a maximum tower height of 31 feet with a total load capacity of 240 kips. Top and bottom load bearing plate elements are available along with screw assemblies for vertical adjustments, top and bottom.	Scaffolding & Shoring Services 3640 W. 12 th Street Houston, TX 77008 713-869-1935 www.scaffoldingandshoring.com

Table 2.10 AASHTO-TIG Prefabricated Bridges: Publications
(Prefabricated Substructures)
(AASHTO-TIG, 2001)

Title	Author(s)	Topic	Publisher / Source / Contact
Development of a Precast Bent Cap System	E. Matsumoto, M. Waggoner, G. Sumen, M. Kreger, S. Wood, & J. Breen	This report addresses the use of precast bent caps in non-seismic areas. Example connection details (grout pockets, grouted vertical ducts, and bolted connections) are included for	Center for Transportation Research at the University of Texas at Austin, U.S. DOT, & Texas DOT / Report No. 1748-2 (2001) / www.aashtotig.org/focus_technologies/prefab_elements/related_documents/report1748-2.pdf

		attaching the precast bent caps to cast-in-place columns and precast concrete trestle piles.	
FHWA/AASHTO/ TxDOT Precast Concrete Bent Cap Demonstration Workshop	B. Tang, L. Wolf, M. Hyzak, T. Friggle, W. Duguay, & Traylor Brothers, Inc.	The workshop CD includes a series of presentations addressing the use of prefabricated bridges and rapid bridge construction in the U.S. and in Texas. Also addressed is the use of prefabricated bent caps on Texas' SH 66 bridge over Lake Ray Hubbard.	Texas DOT / Workshop CD-ROM / Ronnie Medlock at rmedloc@dot.state.tx.us
Grouted Connection Tests in Development of Precast Bent Cap System	E. Matsumoto, M. Kreger, M. Waggoner, & G. Sumen	This article presents test data results used to develop an anchorage design methodology and provisions used to connect precast bent caps to cast-in-place columns and precast trestle piles in non-seismic areas.	TRB, Washington DC / Transportation Research Board Record No. 1814, Design of Structures 2002
Precast Posttensioned Abutment System and Precast Superstructure for Rapid On-site Construction	A. Scanlon, A. Aswad, & J. Stellar	This paper reports on the use of precast posttensioned abutment units installed on cast-in-place footings to reduce on-site construction time. A demonstration	TRB, Washington DC / Transportation Research Board Record No. 1814, Design of Structures 2002

		project in Pennsylvania established its feasibility.	
A Precast Substructure Design for Standard Bridge Systems	S. Billington, R. Barnes, & J. Breen	This report describes a proposed substructure system that was determined to be cost effective and that can be used to shorten on-site construction time.	The Center for Transportation Research at the University of Texas at Austin / Report No. CTR 1410-2F / www.utexas.edu/research/CTR/index.html

Table 2.11 AASHTO-TIG Prefabricated Bridges: Innovative Projects
(Prefabricated Substructures)
(AASHTO-TIG, 2001)

Project Name & Location	Project Description	Contact Information
Beaufort & Morehead Railroad Trestle Bridge over Newport River, Morehead City / Radio Island, NC	This project used precast reinforced concrete pile caps supported by composite piles constructed using steel pie piles protected by concrete cylinder sleeves. The project also used precast prestressed T-beams to replace 2,298 feet of trestle approach spans during 4-day periods when the track was not in use. Completed: 1999.	John Frye North Carolina DOT 919-250-4049 jfrye@dot.state.nc.us
I-45/Pierce Elevated, Houston, TX	This project replaced 226 spans of I-45 near downtown Houston in 190 days in lieu of the estimated 1.5 years. Precast bent caps were anchored by post-tensioning bars to existing columns which had been saw cut to the proper elevation. The project also used precast prestressed concrete I-beams and partial-depth deck panels to expedite construction in this high traffic area which had an estimated user cost of \$100,000 per day. Completed: 1997.	Kenneth Ozona Texas DOT 713-802-5435 kozona@dot.state.tx.us
Route 57 / Wolf River, Fayette County, TN	This project constructed a 20-span, 1,408-foot-long, 46-foot-wide replacement bridge in eleven months while maintaining traffic on the only east-west route in the region. One lane of traffic was maintained at all times by staged construction. Two piece bent cap details were developed and used that were compatible with the staged construction technique used during bridge replacement. The project also used precast prestressed concrete I-beams and deck panels to expedite construction. Completed: 1999.	Edward Wasserman Tennessee DOT 615-741-3351 Ed.Wasserman@state.tn.us
SH 36 / Lake Belton, Waco, TX	This project constructed 3,840-foot-long twin structures supported by cast-in-place columns with 62 identical precast bent caps. Each bent cap is supported by a single column creating “some of the highest moment-demand cap-to-column	Lloyd Wolf Texas DOT 125 E. 11 th Street Austin, TX 78701 512-416-2279 lwolf@dot.state.tx.us

	connections used yet with precast caps in Texas.” The project also used precast prestressed concrete U-beams and partial-depth deck panels. Completion: 2004.	
SH 66 / Lake Ray Hubbard, Dallas, TX	This project constructed 14,640 feet of bridge to replace the existing narrow two-lane bridge. The project used 43 precast concrete bent caps to minimize construction time near overhead power lines. The cap-to-column connections utilized grouting of rebar dowels extending from the columns and threaded through plastic ducts cast in the caps. The project also used precast prestressed concrete I-beams and deck panels. Construction procedures were used to allow early placement of bent caps and I-beams to expedite construction. Completed: 2002.	Lloyd Wolf Texas DOT 125 E. 11 th Street Austin, TX 78701 512-416-2279 lwolf@dot.state.tx.us
SH 66 / Mitchell Gulch, Franktown / Castle Rock, CO	This project used precast concrete abutments and wings to minimize traffic disruptions. Individual elements were precast and welded to steel H-piles that had been driven outside the limits of the existing bridge prior to demolition. The project also used precast concrete slab girders to expedite construction. The estimated construction detour time of 2.5 months was reduced to 48 hours by the value-engineering proposal. Completed: 2002.	Wes Goff 30-757-9116 wes.goff@dot.state.co.us
SH 361 / Redfish Bay and Morris-Cummings Cut, Aransas County, TX	This project used precast concrete piles and bent caps to minimize over-water construction time of the 2 bridges having a total length of 2,435 feet and using 44 identical bent caps. Epoxy-coated steel rebar hairpins were installed in the ends of the piles and concrete was placed from above in bent cap pockets to complete the connection. Precast concrete double-tees were also used. Completed: 1994.	Lloyd Wolf Texas DOT 125 E. 11 th Street Austin, TX 78701 512-416-2279 lwolf@dot.state.tx.us
US 290 Ramp E-3, Austin, TX	This project used a contractor proposed precast concrete straddle bent cap to reduce the estimate ramp closure time from 7 days to 4 hours. The cap was	Gregg Freeby Texas DOT 125 E. 11 th Street Austin, TX 78701

	<p>precast on-site then placed. Post-tension bars and grout were used to complete the cap-to-column connection. Completed: 1996.</p>	<p>512-416-2192 gfreeby@dot.state.tx.us</p>
<p>Dallas/Fort Worth International Airport People Mover, Dallas, TX</p>	<p>This project used precast post-tensioned segmental columns to improve constructability, minimize aircraft traffic disruptions on the ground, and allow night-time only construction of the columns necessary to support the People Mover System. Completion: 2004.</p>	<p>STOA/Carlos+ Law AE 850-432-1912</p>
<p>NASA Road 1 / I-45, Houston, TX</p>	<p>This project used 24-inch precast concrete driven pile/columns during the replacement of the 4-span 2-lane structure over the heavily traveled I-45. Cast-in-place concrete bent caps were used but the reinforcing steel cages and formwork were prefabricated and set into place as a unit when the pile/columns were ready. Shallow precast prestressed box beams were used to increase clearance and eliminate the need for deck formwork. Demolition and construction were completed in 10 days. Completed: 2002.</p>	<p>John Vogel Texas DOT 8100 Washington Ave. Houston, TX 77251 713-802-5235 jvogel@dot.state.tx.us</p>
<p>SH 249 / Louetta Road Overpass, Houston, TX</p>	<p>This project used single precast post-tensioned concrete piers as interior bents to support the 54-inch precast prestressed concrete superstructure U-beams. Each of the 2 overpass structures consisted of 3 spans approximately 130 feet in length. The structures also used precast prestressed partial-depth deck panels. "All piers and beams were designed and fabricated using high-performance/high-strength concrete." Completed: 1994.</p>	<p>Mary Lou Ralls Texas DOT 125 E. 11th Street Austin, TX 78701 512-416-2183 mralls@dot.state.tx.us</p>

**Table 2.12 AASHTO-TIG Prefabricated Bridges: Research Projects
(Prefabricated Substructures)
(AASHTO-TIG, 2001)**

Project Title Project Number	Project Description	Sponsor
Development of Precast Bridge Construction Systems, TxDOT 0-4176	This project will seek to extent the technology developed in TxDOT Project 0-1748, "Design and Detailing of Precast Bent Cap System," to other substructure elements; such as abutment caps, wingwalls, and backwalls. The project is expected to produce a set of draft specifications. Completion: 2003	Texas Department of Transportation
Development of a Precast Bent Cap System, TxDOT 0-1748	This report addresses the use of precast bent caps in non-seismic areas. Example connection details (grout pockets, grouted vertical ducts, and bolted connections) are included for attaching the precast bent caps to cast-in-place columns and precast concrete trestle piles. The project also provided a design methodology and construction guidelines.	Texas Department of Transportation

Member / Element Repair Techniques

Epoxy Injection

Regions of structural concrete damaged by cracking can be repaired by the injection of an epoxy resin. The cracks can be the only damage to the member, or they can be adjacent to an area of more severe damage, such as actual loss of concrete or damage to reinforcing steel, that will require an additional form of repair. The epoxy reestablishes the structural quality of the concrete and most importantly, reseals the cracks to prevent moisture egress into the member and corrosion of the reinforcing steel. Concrete cracks as small as 0.002-inch in width can be sealed using epoxy injection. Epoxies for structural application should conform to ASTM 881, have viscosities in the 300-600 CPS range, and have tensile and bond strengths in the 7,000 psi range. A typical sequence used for epoxy injection repair of cracks is as follows. First, clean the cracks by vacuuming or flushing. Second, seal the surface of the cracks to prevent surface leaking and force the epoxy to penetrate into the cracks. Third, install injection ports along the length of the cracks, typically every 4 to 8 inches. Mix and pressure inject the epoxy into the cracks. Inject pressures should be in the 40 psi range. Higher pressures do not ensure better penetration of the epoxy in the cracks and can even cause the cracks

to propagate further into the member. Epoxy injection should proceed from bottom to top for vertical cracks and from one end to the other for horizontal cracks. Fourth, the surface seal and ports should be removed once the epoxy is hardened. The basic information provided above was taken from three primary sources. (Lambert, 1994, ACI Committee 224, 1998, REMR, 1985) Epoxy injection repair information is summarized in Table 2.13. Contact information for several companies involved with the epoxy injection repair of concrete in the U.S. is provided in Table 2.14.

In addition, ACI Committee 503, Adhesives for Concrete, has a new publication, in committee, titled, "Specification for Crack Repair by Epoxy Injection." Also, the epoxy injection technique was used to repair damaged concrete bridge members on Bridge 8750/M20 in England, on the Century Road Overpass at Highway 16X in Canada, and on FM 1927 Overpass at I-20 in Texas. Additional information about these three incidents is provided as CS #6, CS #7, and CS #25, respectively, in Chapter 3 of this report.

FRP Strengthening / Repair

The use of externally bonded fiber reinforced polymers (FRP) applied to concrete bridges has grown significantly over the last 20 years and has seen significant use in Japan and Europe. (MDA, 2004) NCHRP Report 503 summarizes the results of a study designed to, "develop a strategic plan for guiding the application of fiber reinforced polymer composites in the highway infrastructure," and contains the strategic plan. The report also indicates that FRP, "composite materials show great potential for integration into the highway infrastructure." (Mertz, 2003) Research Project 0-1776 conducted by the Center for Transportation Research (CTR) at the University of Texas at Austin investigated the use of externally bonded woven carbon fiber reinforced polymers (CFRP) fabric and pultruded CFRP plates to strengthen reinforced concrete members subjected to static and cyclic transverse loadings. Strengthening efforts were most successful when transverse strips or sheets of CFRP were wrapped and bonded to the web of the members, thereby delaying debonding of the CFRP material from the bottom flange and increasing the flexural capacities. An analytical model was developed and verified by the project, and design guidelines are presented. (Brena/Wood, 2001 & Brena/Bramblett, 2001) Currently available codes, specification, and design guides include the following:

- ACI 440.2R-02, *Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures*, American Concrete Institute, 2002.
- Europe fib Bulletin 14, *Externally Bonded FRP Reinforcement for RC Structures*, Federation Internationale du Beton, 2001.
- CSA S806-02, *Design and Construction of Building Components with Fiber-Reinforced Polymers*, Canadian Standards Association, May 2002.
- *Strengthening Reinforced Concrete Structures with Externally Bonded Fibre-Reinforced Polymers*, ISIS Canada, www.isiscanada.com.

In addition to the documents listed and discussed above, NCHRP Report 514, which is the product of NCHRP Project No.10-59, was recently published. Report 514 provides recommendations for construction specifications and quality control processes associated with the repair and retrofit of concrete structures using bonded FRP composite materials and was written in a effort of ensure “performance as designed.” (Mirmiran, 2004)

“The proposed specifications include eight main sections: General; Submittals; Storage, Handling, and Disposal; Substrate Repair and Surface Preparation; Installation of FRP System; Inspection and Quality Assurance; Repair of Defective Work; and Measurement and Payment. The proposed process control manual covers quality control (QC) and quality assurance (QA) prior to, during, and after completion of the repair project. It consists of planning, record keeping, inspection, and QC tests. The manual includes the following main sections: QA Policy and Program Overview; QA Guidelines for Construction Activities; and Implementing and Monitoring of the QA Program. The manual also consists of a number of QA checklists for the FRP repair project.” (Mirmiran, 2004)

Characteristics of externally bonded FRP that make it attractive for member strengthening (flexure and shear) due to change in function or loading, seismic retrofit of columns to increase ductility, and repair of damaged members include its light weight, high strength, corrosion inertness, shape adaptability, and ease of application. Common materials used in FRP applications are carbon, glass, or aramid fibers. Fiber materials are commonly available with unidirectional or multidirectional orientations and are available as fabric sheets or strips for “wet lay-up” applications or as pre-cured sheets, strips, or shapes for “pre-cured” applications. Fabric rolls typically come in 12 to 24-inch wide rolls that are 150 to 200-feet long. A typical application sequence for a wet lay-up application has several steps. First, substrate preparation is required to provide a surface that is rough but uniform and free of substances that would prevent bonding such as dust, oil, or standing water. Second, saturate the fabric with the adhesive resin prior to installation of the fabric. Third, apply the saturate fabric to the member surface one layer at a time and work out air bubbles, typically by rolling with a hard rubber roller. Fourth, apply a surface coat of resin to the installed material to complete the saturation and seal the surface. Similar steps are used for the pre-cured application except that the adhesive resin is typically applied to the substrate instead to the fiber material. Attention to adhesive thickness requirements and set time as provided by the manufacturer are important during application. FRP strengthening information is summarized in Table 2.13. Contact information for companies associate with FRP strengthening or repair of concrete structures is provided in Table 2.14.

It should be noted that ACI currently sponsors a one day seminar titled, “FRP Composites for Reinforced Concrete Construction.” It should also be noted that the FRP repair technique was used to repair damaged prestressed concrete bridge beams on FM 1927 Overpass at I-20 in Texas. Additional information is provided in CS #25 in Chapter 3 of this report.

Prestressed Concrete Beams: Evaluation and Repair

This project identified two groups of reports that address the evaluation and repair of damaged prestressed concrete bridge beams. The first 2 reports (the first group) are NCHRP Reports 226 and 280, which are from the early to mid 1980's and were written by Shanafelt and Horn. Report 226 addresses assessment and repair of prestressed concrete girders damaged by impact, fire, manufacturing defects, and other causes. Damage assessment and repair selection criteria include, "service load capacity, ultimate load capacity, overload capacity, fatigue life, durability, cost, user inconvenience and speed of repairs, esthetics, and range of applicability." (Shanafelt, 1980) Report 280, as its title indicates, provides "Guidelines for Evaluation and Repair of Damage Prestressed Concrete Bridge Members." (Shanafelt, 1985)

The second 3 reports (the second group) are CTR Reports 1370-1, 1370-2, and 1370-3F, which are from the mid 1990's and were written by Jirsa, Carasquillo, and others. CTR Report 1370-1 addresses, then current, U.S. and Canadian repair techniques and practices for damaged prestressed concrete beams. (Feldman, 1996) CTR Report 1370-2 developed and evaluated a device for use to estimate stress levels in exposed strands. The device uses measured lateral strand displacements due to lateral loads applied to the strand. "The special features of the device developed in the project are its simplicity, portability, and versatility." (Civjan, 1995) CTR Report 1370-3F suggests a procedure for "rapid initial assessment of damage" to prestressed concrete bridge girders and "should allow field personnel to distinguish between various types and locations of impact damage and to determine the course of action to be taken regarding the evaluation, repair, or replacement of an impact-damaged girder." (Zobel, 1997) The project used full-scale laboratory tests to evaluate repair materials and techniques including various concrete patch materials and 4 different types of strand splice hardwares. Pre-manufactured concrete patch materials included magnesium-phosphate or Portland cement based materials for cast-in-place patch applications and latex-modified or fiber-reinforced silica fume modified mortars for hand-applied patch applications. Summary information for this technique is provided in Table 2.13.

This technique was used to repair damaged prestressed concrete bridge beams on the Century Road Overpass at Highway 16X in Canada and on the FM 1927 Overpass at I-20 in Texas. Additional information about these incidents is provided in CS #7 and CS #25, respectively, in Chapter 3 of this report.

Steel Girders: Evaluation and Repair

This project identified two primary reports and one ongoing research project addressing the evaluation or repair of damaged steel bridge members. The first report, NCHRP Report 271, *Guidelines for Evaluation and Repair of Damage Steel Bridge Members*, had an objective to, "provide guidance for the assessment of accidental damage to steel bridge members and to identify, develop, and evaluate the effectiveness of repair techniques." The report contains details and information necessary to evaluate and repair damaged steel members. "Guidelines are presented for the following methods of repair: flame straightening, hot mechanical straightening, cold mechanical straightening, welding, bolting, partial replacement, and complete replacement." (Shanafelt, 1984) The

second report, FHWA-IF-99-004, *Heat-straightening Repairs of Damaged Steel Bridges: A Manual of Practice and Technical Guide*, was written with the purpose, “to provide comprehensive guidelines on heat straightening repairs techniques for damaged steel bridge members.” The report is divided into three parts all addressing the heat-straightening technique: a background review and overview, a technical guide for engineers, and guidelines, specifications, and references. (Avent, 1998) Four other articles were identified that address the heat-straightening process written by Avent, et al. (Avent, 1993, Avent, 1996, Avent, 1999a, and Avent, 1999b)

In addition, FHWA has developed an interactive multimedia guide that can be used as a training aid. The guide, “Heat-Straightening Repair for Damaged Steel Bridges: An Interactive Guide,” is available as two-volume CD-ROM. “Volume 1 covers the management, design, and techniques of heat-straightening and includes video demonstrations. Volume 2 includes a complete case study of a Lake Charles, Louisiana, bridge repair project.” (FHWA, 2000) Contact information is provided in Table 2.13. The heat straightening technique was used to repair a portion of the I-40 Webbers Falls Bridge in Oklahoma after several spans collapsed following a barge impact. Additional information about the incident is provided as CS #2 in Chapter 3 of this report.

An ongoing research project, NCHRP Project 10-63, *Heat-Straightening Repair of Damaged Steel Bridge Girders: Fatigue and Fracture Performance*, that is currently be conducted by Lehigh University, was also identified. The objectives of NCHRP Project 10-63 are to: “(1) determine the relative effects of damage and subsequent heat-straightening on the fatigue and fracture performance of steel girders; (2) identify and quantify the material and process parameters that may affect the fatigue and fracture performance of heat-straightened steel girder; and (3) establish guidelines, including limits on initial damage and critical process parameters, to minimize the potential for fracture and fatigue problems in heat-straightened steel girders.” (TRB, 2004) The project was started as a 3-year project scheduled for completion in March 2006. Summary information is provided in Table 2.13.

Table 2.13 Member / Element Repair Techniques

Product or Technique	Product Description and Use	Contact
Epoxy Injection	Epoxy injection can be used to repair concrete cracks as small as 0.002-inch. The technique can be used to repair cracks only or in conjunction with other techniques that repair spalled concrete or damaged reinforcing steel. Typical repairs steps are provided in the section on epoxy injection in this chapter. Epoxies for this use should conform to ASTM	See Table 2.14 for multiple contacts.

	881. See ACI Committee 503 and Committee 224 publications for additional guidance.	
FRP Strengthening / Repair	The use effective use of FRP materials in bridge applications to strengthen or repair member has seen significant growth. Common materials include carbon, glass, and aramid fibers. A number of available reports codes, specifications, or design guidelines are listed in the FRP section of this chapter. FRP materials can be used with either a “wet lay-up” or “pre-cured” application. Typical application steps are provided in the FRP section of this chapter. FRP fabric typically comes in 12 to 24-inch-wide rolls that are 150 to 200-feet long.	See Table 2.14 for multiple contacts.
Prestressed Concrete Beams: Evaluation and Repair	Two groups of reports were identified that provide guidelines and procedures for the evaluation and repair of damaged prestressed concrete bridge beams. The first group, NCHRP Reports 226 and 280, was from the early to mid 1980’s and was written by Shanafelt and Horn. The second group, CTR Reports 1370-1, 1370-2, and 1370-3F, was from the mid 1990’s and was written by Jirsa, et al.	<p><u>NCHRP Reports</u> Transportation Research Board 500 Fifth Street, NW Washington, DC 20001 202-334-2934 www.trb.org</p> <p><u>CTR Reports</u> Center for Transportation Research The University of Texas at Austin 3208 Red River, Suite 200 Austin, TX 78705 512-232-3100 www.utexas.edu/research/ctr/</p>
Steel Girders: Evaluation and Repair	Two research reports, an interactive multimedia guide, and one ongoing research project were identified that provide guidelines and procedures for the evaluation and repair of damaged steel bridge girders. The first report, NCHRP Report 271, was written by Shanafelt and Horn in 1984. The second report,	<p><u>NCHRP Report 271</u> Transportation Research Board 500 Fifth Street, NW Washington, DC 20001 202-334-2934 www.trb.org</p> <p><u>Report FHWA-IF-99-004</u> National Technical Information Service</p>

	<p>FHWA-IF-99-004, was written by Avent and Mukai in 1998. The interactive multimedia guide is a two-volume CD-ROM that is available from FHWA. An ongoing research project, NCHRP Project 10-63, is being conducted by Robert Conner at Lehigh University and is scheduled for completion in early 2006.</p>	<p>5285 Port Royal Road Springfield, VA 22161 703-605-6000 www.ntis.gov</p> <p><u>FHWA Interactive Guide (CD)</u> Krishna Verma FHWA 202-366-4601 krishna.verma@fhwa.dot.gov</p> <p><u>NCHRP Project 10-63</u> Robert J. Connor (PI) Lehigh University 117 ATLSS Drive Bethlehem, PA 18015 610-758-6103 www.atlss.lehigh.edu</p>
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Table 2.14 Member / Element Repair Techniques Contact Information

Technique	Company / Contact Information
Epoxy Injection	Balvac Inc. 470 Buffalo Road East Aurora, NY 14052 800-553-2302 716-655-5981 www.balvac.com
Epoxy Injection	Epoxy Design Systems, Inc. P.O. Box 19485 Houston, TX 77224 713-461-8733 www.epoxydesign.com
Epoxy Injection	Epoxy Systems, Inc. 352-489-1666 www.epoxy.com
Epoxy Injection	Mobile Enterprises, Inc. 832 Southway Circle Ft. Worth, TX 76115 817-921-1444 www.mobileenterprises.com
FRP Strengthening / Repair	Market Development Alliance of the FRP Composite Industry 600 Mamaroneck Avenue, Suite 429 Harrison, NY 10528 914-381-3572 www.mdacomposites.org
FRP Strengthening / Repair	Delta Structural Technologies, Inc. 18109 Ammi Trail Houston, TX 77060 800-728-5444 www.fiberwrap.com
FRP Strengthening / Repair	Edge Structural Composites, Inc. 145 Park Place Richmond, CA 94804 510-233-8654 www.edgefrp.com
FRP Strengthening / Repair	Epoxy Design Systems, Inc. P.O. Box 19485 Houston, TX 77224 713-461-8733 www.epoxydesign.com
FRP Strengthening / Repair	Fyfe Co. LLC Nancy Ridge Technology Center 6310 Nancy Ridge Drive, Suite 103

	San Diego, CA 92121 858-642-0694 www.fyfeco.com
FRP Strengthening / Repair	Gordon Composites, Inc. 2350 Air Park Way Montrose, CO 81401 800-399-0757 www.gordoncomposites.com
FRP Strengthening / Repair	Hexcel Schwebel Civil Engineering & Construction Systems, Inc. 2200 South Murray Avenue Anderson, SC 29622 864-260-6593 www.hexel.com
FRP Strengthening / Repair	Hughes Brothers, Inc. 210 N. 13 th Street Seward, NE 68434 800-869-0359 www.hughesbros.com
FRP Strengthening / Repair	QuakeWrap Inc. 5630 E. Via Arbolada Tucson, AZ 85750 818-723-3990 www.QuakeWrap.com
FRP Strengthening / Repair	Saint-Gobain Technical Fabrics 345 Third Street, Suite 615 Niagara Falls, NY 14303 716-285-0731 www.sgtf.com
FRP Strengthening / Repair	Sika Corporation Construction Products Division 201 Polito Avenue Lyndhurst, NJ 07071 800-933-7452 www.sikaconstruction.com
FRP Strengthening / Repair	TechFab, LLC 2200 South Murray Avenue Anderson, SC 29624 864-260-3268 www.techfabllc.com
FRP Strengthening / Repair	VSL Corporation 7455 New Ridge Road, Suite T Hanover, MD 21076 410-850-7000 www.vsl.net
FRP Strengthening / Repair	Watson Bowman Acme 95 Pineview Drive

	Amherst, NY 14228 716-691-7566 www.wbacorp.com
Heat Straightening	Civil Construction Company 10310 State Route 161 Plain City, OH 43064 614-873-8196 www.plain.lib.oh.us/CivilConstruction/index.html
Heat Straightening	Flame On, Inc. 4415 Tom Marks Road Snohomish, WA 98290 425-397-7039 www.flameoninc.com
Heat Straightening	High Steel Structures, Inc. 1770 Hempstead Road Lancaster, PA 17605 717-390-4270 www.highsteel.com
Heat Straightening	International Straightening Inc. 6514 Island Drive Bismarck, ND 58504 701-223-5972 www.steelstraightening.com
Heat Straightening	Sargent Engineers, Inc. 55 South Main Driggs, ID 83452 208-354-4400 www.sargentengineers.com

Floating Bridges / Supports

Military Upgraded Standard Ribbon Bridge

A ribbon bridge is made up of two types of modular floatation units that individually unfold in the water and are joined together to form a single lane floating roadway. The two unit types are “ramp units” and “interior bay units.” Each ribbon bridge has a ramp unit on each end connected by a varying number of interior bay units that depends on the required length of the bridge. These bridges have some potential as use for temporary bridges where navigation of the waterway is not required or can be temporarily interrupted in an emergency. Their use in a given geographic region would require the pre-purchase and storage of the units or cooperation and coordination with a U. S. military bridge unit that has these units in their inventory. The modular units of the ribbon bridge are transportable by commercial vehicles. Approximate unit launch and retrieval times are 5 and 10 minutes, respectively.

“The Upgraded Standard Ribbon Bridge (USBR) provides bridging and ferry capabilities as part of the US Army’s Multi-Role Bridging Company. The Upgraded Standard Ribbon Bridge is fully interoperable with the Standard Ribbon Bridge (SRB) and retains the same operational requirements. The Upgraded Standard Ribbon Bridge provides significant enhancements to the SRB; its ramp and interior bays feature numerous improvements, such as positive flotation and rapid deployment. In the water, the Upgraded SRB includes special non-skid surfaces, high bow dams to keep water from swamping the roadways, and improved folding and unfolding mechanisms to reduce cable breakage. Its sealed hydraulic system uses an environmentally friendly, biodegradable hydraulic fluid. The Upgraded SRB has an 80-ton load capacity for tracked vehicles and a 100-ton capacity for wheeled loads in water velocity of 10 feet per second.” (United Defense, 2003) This product is summarized and contact information is provided in Table 2.15.

Mabey Uniflote

Mabey Uniflote units are modular units that can be interconnected together to provide a temporary floating bridge or bridge piers to support a panel bridge. As with the ribbon bridge, these units have some potential as use for temporary bridges where navigation of the waterway is not required or can be temporarily interrupted in an emergency. If the Uniflote units are used as bridge piers to support a panel bridge, some clearance is available under the bridge.

Each Uniflote unit is a steel plate and frame structure utilizing all welded construction. Couplers are provided and positioned at the sides and ends of the units so that Uniflote units can be easily connected in the water from deck level in either a side-to-side, end-to-end, or end-to-side configuration. These couplers allow transmission of loads both in shear and bending throughout a Uniflote raft. Concentrated loads are applied from above through saddles that distribute the loads into the structural frame. Two internal bulkheads are incorporated inside each unit to provide three watertight compartments, each of which is served by a watertight hatch for access. Runners are attached to the bottom to assist with skidding operations on shore.

The Uniflote body is 17.3 feet long and 8.0 feet wide, providing a work surface area of 138 square feet. Scow ends are available that decrease water resistance by deflecting water and make possible the use of Uniflote units as floating piers for panel bridges. A standard floating pier is comprised of three Uniflote units coupled with scow ends, “Triflote Pier”, but can be replaced by a “Quadriplote Pier” or a “Biflote Pier” depending on load conditions. Each internal span of the bridge will have a Triflote or Quadriplote pier at each end, making each section self supported. A floating bay can be built at any convenient site and then floated into position for the bridge. At each end of a bridge, a landing bay must provide a span of sufficient length to cross to deep water and to accommodate tidal or seasonal variations of the water level. Some optional features available for use with the Uniflote units are steel or timber deck sets that enable wheeled or tracked vehicles to drive directly on top of the Uniflote units as soon as they have been assembled into a causeway configuration. Uniflote units can also be connected and used as floating work platform with a wide range of configurations and capacities. A product

summary and contact information are provided in Table 2.15. (Mabey, 2002 & Mabey-Support, 2004)

Robishaw Flexifloat

Robishaw Flexifloat units are modular pontoon units that can be interconnected together to provide a temporary floating bridge or bridge piers to support a temporary bridge structure. As with the other floating bridge units, these units have some potential as use for temporary bridges where navigation of the waterway is not required or can be temporarily interrupted in an emergency. These units can also be used as floating work platforms or barges to float bridge structures into position in a marine environment. If the Flexifloat units are used as bridge piers to support a temporary bridge, some clearance is available under the bridge.

Flexifloat pontoon units are fabricated using all steel and welded construction and are heavily reinforced to permit extended and multiple uses. The pontoon units can be interconnected side-by-side, end-to-end, or end-to-side to provide a wide range of configurations and load capacities. The units are connected together by a self-contained, high-strength locking system with no loose parts that can be lost. The simple connections can be made on-deck with typical hand tools. Flexifloat units are available in 3 series; H-50, S-50 and S-70. All 3 series are also available in “Quadrafloat,” “Duofloat,” “End Rake,” and “Loading Ramp” modules that can be interconnected with other modules within their own series. Modules from all 3 series are within highway transportation size and weight limitations. (Robishaw, 2003)

Series H-50 unit assemblies can be used for operational loads in the 5 to 100-ton range. The largest module, Quadrafloat, within the H-50 series is 30 feet long, 7.5 feet wide, and 3.8 feet deep and has a 10.5-ton buoyant capacity at 65% draft. Series S-50 unit assemblies can be used with intermediate operational loads between the H-50 and S-70 series capacities. The Quadrafloat unit of the S-50 series is 40 feet long, 10 feet wide, 5 feet deep and has a 27-ton buoyant capacity at 65% draft. Series S-70 unit assemblies can be used for operational in the 150 to 300-ton range. The Quadrafloat unit in the S-70 series is 40 feet long, 10 feet wide, and 7 feet deep and has a 40-ton buoyant capacity at 65% draft. (Robishaw, 2003) General product and contact information is provided in Table 2.15.

Table 2.15 Floating Bridges / Supports

Product or Technique	Product Description and Use	Contact
Upgraded Standard Ribbon Bridge (USRB)	A ribbon bridge made up of 2 basic modular floatation unit types (ramp or interior bay) that are connected together to form a floating roadway. Units can be transported by commercial trucks and require approximately 5 minutes per unit to launch. Any number of interior bay units can be used to adapt to site length	United Defense Corp. HQ 1525 Wilson Blvd., Suite 700 Arlington, VA 22209 703-312-6100 www.udlp.com

	conditions. The USBR is a single lane bridge that has a 100-ton capacity for wheeled vehicles and can be used in water velocities up to 10 feet per second.	
Mabey Uniflote	Mabey Uniflote units are modular units that can be interconnected to provide a temporary floating bridge or bridge piers to support a panel bridge. They are fabricated as all steel welded units that are 17.3 feet long and 8 feet wide. Side and end connectors around the perimeter of each unit allows for side-by-side, end-to-end, or end-to-side configurations of the units using top-side connections. As bridge piers, they can be used in “triflote,” “quadriflote,” or “biflote” configurations as controlled by load conditions. Uniflote units can also be used as floating work platforms.	Mabey Bridge & Shore, Inc. 6770 Dorsey Road Baltimore, MD 21075 410-379-2800 www.mabey-support.com
Robishaw Flexifloat	Robishaw Flexifloat modular pontoon units can be interconnected and used as a temporary floating bridge, used as bridge piers to support a temporary bridge, used as a floating work platform, or used as a barge to float in materials or components. The Flexifloat pontoons are available in 3 series; H-50, S-50 and S-70 that have assembly operational capacities that range from 5 to 300-tons from the H-50 to the S-70 series, respectively. Each series has “Quadrafloat,” “Duofloat,” “End Rake,” and “Loading Ramp” modules available for use. Units within a given series can be connected side-to-side, end-to-end, or end-to-side to provide a wide range of geometric configurations and load capacities. Units are connected together from on-deck via self-contained high-strength locking system points located around the perimeter of each module. Module dimensions vary between series and module types but all modules fall within dimensional and weight limits required for highway transportation. Specific unit sizes and buoyant	Robishaw Engineering, Inc. 10106 Mathewson Lane Houston, TX 77043 713-468-1706 www.flexifloat.com

	capacities are available on line at Robishaw Engineering's web site.	
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Contractor / Construction Techniques

Construction Work Schedules

The use of various construction work schedules can have a significant impact in the rapid replacement or repair of bridges. Beyond the standard 8 to 5 work schedule, there are 3 that warrant discussion; 24-hour construction, 12-hour construction, and nighttime only construction. The choice of the appropriate work schedule can be written into the contract or left to the discretion of the contractor as he develops his cost estimate and work plan to execute the project within the restraints of the contract (time, cost, and incentives/disincentives). Issues that should be considered when selecting the appropriate construction work schedule include:

1. Increases in construction costs typically associated with accelerated construction schedules.
2. Decreases in user costs and public inconveniences associated with shorter out-of-service periods or with off-peak traffic demand closures.
3. Availability of state DOT personnel for inspection and problem solving during typical off-duty hours.
4. Availability of materials and material deliveries during non-standard hours.
5. Loss of worker productivity, loss of quality control, and increased worker safety issues typically associated with accelerated or nighttime construction or extended work shifts.

Nighttime only construction is not an accelerated construction schedule technique but is a technique that can be used with repair or replacement projects that require normal daytime use of the bridge due to high traffic demands.

Construction projects that were identified during the course of this research project show that accelerated work schedules can be use to complete projects in shorter periods of time but that they typically increase the overall cost of the projects. However, increases in construction cost will typically be offset by corresponding decreases in user costs or actual state DOT costs associated with temporary traffic. A case in point is the Queen Isabella Causeway (QIC) incident that occurred during September 2001 in Texas. A barge impact brought down five bridge spans, totally severing the only traffic artery between South Padre Island and the Texas mainland. Temporary transportation for traffic and pedestrians was provided for approximately 2 months by ferries at a cost of over \$3.5 million.

Utilization of a 24-hour construction schedule is warranted when circumstances are severe enough to justify the increase in cost typically associated with its use. Special attention addressing quality control, inspection, change order approval, engineering or construction problem resolution, lighting, safety, worker fatigue, and material deliveries must be addressed as work continues 24-hours a day utilizing either three 8-hour shifts or two 12-hour shifts a day. In addition to the issues directly related to the construction process, other issues like noise, vibrations, and light that can be a nuisance to nearby property owners also have to be addressed when evening and nighttime construction is

being utilized. Guidance for these issues is provided in a NCHRP report, *Mitigation of Nighttime Construction Noise, Vibrations, and Other Nuisances*. (Schexnayder, 1999) In addition, special requirements for nighttime lighting must be addressed. Guidance for issues related to nighttime lighting is provided by another NCHRP report, *Illumination Guidelines for Nighttime Highway Work*. (Ellis, 2003) In addition to the QIC incident in Texas mentioned above, seven other projects that utilized 24-hour construction during all or a part of their respective projects are identified and used in this report. Following the I-95 Chester Creek Bridge incident in Pennsylvania, a combination of 24 and 12-hour construction schedules were used during its replacement; 12-hours during demolition and 24-hours during reconstruction. These seven projects are identified in Table 2.16 along with a summary of the 24-hour construction work schedule.

Utilization of a 12-hour construction schedule is warranted when circumstances are not severe enough to justify a 24-hour schedule, along with its significant cost increase, but critical enough that a standard 8-hour day will not provide an acceptable estimated project completion schedule. Even though many of the costs increases associated with a 24-hour schedule are not incurred with 12-hour schedule, they must be weighed against increased construction time, user cost, and traffic congestion that will be have to be endured. In addition, many of the issues discussed above that require special attention during 24-hour construction are eliminated or reduced during 12-hour construction. Some portions of any given project may require accelerated or relaxed work schedules that vary within the project. As noted above, during the demolition phase of the I-95 Chester Creek Bridge replacement project, time sequencing was not critical enough to warrant the increased cost associated with 24-hour construction and so 12-hour construction was used. Two other bridge replacement projects identified during this research project that used 12-hour construction are identified in Table 2.16 and summarized in Chapter 3.

Utilization of nighttime construction is warranted when circumstances are severe enough to justify the increases in cost and coordination that are associated with its use. In addition to its incorporation into a 24-hour work schedule, there are circumstances that require the use of a nighttime only construction schedule. Nighttime only construction is commonly used for bridge deck replacement projects of bridges with high volume traffic where daytime construction would cause unacceptable traffic disruptions. During these projects, portions of the bridge deck are replaced each night during reduced traffic flow and are opened to traffic the next morning prior to rush hour traffic. This type of project typically has a heavy monetary penalty associated with any late reopening of the bridge in the morning. Key issues associated with nighttime construction that need to be addressed are discussed in the 24-hour construction section above and are not repeated here. Three projects that used nighttime only construction were identified during this research project and are discussed in Chapter 3. These projects are identified in Table 2.16.

Innovative Contracting: A + B Bidding

This innovative contracting method, also known as cost plus time bidding, incorporates the impact of construction on the general driving public during the award process. New York State DOT first started using A + B bidding in 1994 “under the

provisions of FHWA Special Experimental Project Number 14, Innovative Contracting Practices.” (Kent, 2003) It is not intended for general routine construction projects but for projects that have the potential for high driving public impact and disruption of highway traffic. The following are some characteristics of projects considered appropriate for A + B bidding as listed by David Kent (Kent, 2003):

- High traffic volume facilities in urban areas
- Major reconstruction or rehabilitation that will severely disrupt traffic
- Major bridges that are out of service
- Projects with length detours of high volumes of traffic
- Project with high accident locations that may be magnified by construction

One of the primary purposes of A + B bidding is “to encourage Contractors to more actively manage their work schedule and, when necessary, to adopt innovative and aggressive scheduling and construction management processes that will shorten the construction duration and reduce inconvenience to the public.” (Kent, 2003)

A + B bidding, as its name implies, uses two criteria during the bid evaluation process, cost and time. The “A” portion of the bid contains the cost to complete the project and includes all work items, as in any standard project bid. The “A” portion becomes the contract award amount. The “B” portion of the bid contains the time required to complete the contract work, which is multiplied by a DOT defined daily user cost to complete the total cost of the project, A + B. This total cost is then used to evaluate the bids and determine the award. Incentives / disincentives are also typically incorporated into the contract as well to ensure timely completion and encourage early completion.

The successful outcome of a large percentage of the 120 New York State DOT A + B bidding contracts demonstrates the effectiveness of this technique to increase construction speed and shorten construction durations. During the 120 contracts, 103 contractors earned incentive totaling approximately \$50 million, roughly 2.5 percent of the original contract values. Even though this seems like a high cost to pay to complete the projects early, New York State DOT estimated a saving of \$246 million in user cost and 20,000 construction days. Additional guidance can be found online in a New York State DOT Engineering Instruction titled “Guidelines for the Use of Time-Related Contract Provision.” (NYSDOT, 1999) Contract information is provided Table 2.16. The A + B bidding technique was used by the Oklahoma DOT in the I-40 Webbers Fall Bridge incident in the summer of 2002. A summary of this incident is provided in CS #2 in Chapter 3 of this report.

Mammoet Heavy Lifting Equipment

Developments in heavy hauling and lifting equipment have opened up the possibility of prefabricating and erecting entire bridge superstructures, which can reduce roadway and river-crossing closures to a minimum. Mammoet has equipment that has been developed and can be used for rapid bridge replacement applications. Their equipment is available for use on land (highway and rail) and in a marine environment. The equipment includes heavy lift devices (cranes, towers, and gantries), trailer and rail transports, skidding, and jacking. Their Titan Bridge Lift System can be used in conjunction with their

computerized self-propelled modular transporters (SPMT) to lift and move extremely large loads. Each pair of wheels on the SPMT turns independent of the other pairs, giving the transporter maximum mobility. A single SPMT can carry as much as 180 tons. Multiple STMPs can be placed in varied configurations to carry much higher loads. The Titan Bridge Lifting System has been used to jack loads of 500 tons to heights of 80 feet and SPMTs have been used to move entire bridge sections weighting 3,300 tons. (Mammoet, 2003) Mammoet products are available for purchase or rent. Product summary and contact information is provided in Table 2.16. Mammoet is available across the U.S. and additional contacts are available at Mammoet's web site listed in Table 2.16.

Maturity Method for Estimating Concrete Strength

Even though the concrete maturity concept was first suggested around 1950, significant developments and use of the method by industry and governmental agencies did not occur until the mid to late 1990's. "A survey conducted by the Pennsylvania Transportation Institute in 2000 found that 32 of the 44 States responding had conducted or were currently conducting research on implementation of the maturity concept. Thirteen of the States had a protocol for the use of maturity testing, with the most common use being to predict the concrete strength so as to open the pavement earlier to traffic." (FHWA, 2002b) The primary national document that was found that guides the use of the maturity method for the determination of concrete strength was ASTM C-1074-98, *Standard Practice for Estimating Concrete Strength by the Maturity Method*. Texas DOT has developed it own standard to guide the use of this method, Tex-426-A, which is based on ASTM C-1074 and TxDOT funded research. In addition, a 16-page PowerPoint presentation that was developed by K. M. Nemati that summarize the maturity method concept was found online. (Nemati, 2002)

The maturity method correlates concrete maturity (a temperature-time value of the concrete) to the concrete's strength. Once this relationship is established for a specific concrete mix, measuring the concrete's maturity allows the engineer to predict the concrete's strength so that decisions about form removal and loading can be made. By embedding temperature sensors in the fresh concrete, the temperature-time value (maturity) of the concrete can be determined and used for strength evaluation. This method uses measurements from in-situ concrete to determine its strength in lieu of the standard concrete cylinders, which uses non-in-situ concrete. This method allows the continuous monitoring of the in-situ concrete's maturity and strength and typically allows for earlier form removal and loading than does the older more conventional concrete cylinder method, thereby accelerating the construction process.

The maturity method of concrete strength evaluation has become more commonplace in the last few years and has the potential to significantly accelerate construction times. FHWA sponsors a Mobile Concrete Laboratory (MCL) that "has played a major role in sharing success stories and working with State highway agencies to implement the maturity method. The MCL has promoted the use of the maturity concept and other nondestructive testing techniques for over 15 years to more than 30 State highway agencies." (FHWA, 2002b) Two case studies completed in this project

used the maturity method to accelerate bridge re-construction following extreme events. The two case studies are Case Study I: I-95 at Chester Creek, Pennsylvania, and Case Study II: I-40 at Webbers Falls, Oklahoma. The actual case studies are provided in this report as Appendix A and B, respectively, and summaries of the studies are provided as Case Summary No. 1 and 2, respectively, in Chapter 3 of this report. In both cases, the use of the maturity method partially contributed to the early completion of the bridge replacement projects. Summary information about the method is provided in Table 2.16 along with contact information for several key individuals identified in FHWA article “Maturity Meters: A Concrete Success.” (FHWA, 2002b)

Roll-in Construction

The use of roll-in construction has evolved over the last several years. Historically, its use seems to be more focused on the replacement of railroad bridges where detours are difficult, if not impossible, and long delays of rail traffic are unacceptable. This technique requires the use of temporary falsework to support the new structure as it is built immediately adjacent to its final alignment. When the new structure is ready for installation, the old structure is quickly demolished or rolled laterally out of the way, allowing the new structure to be rolled into its final alignment where it is jacked up, allowing the rollers to be removed, and then lowered onto its permanent supports. Once the structure is in place, any final ballast or rails can quickly be installed making the bridge ready for rail traffic.

A similar technique can be and has been utilized to install highway bridges that can only be closed for short periods of time. Special high capacity equipment is required for the execution of this technique for any type of bridge. One manufacturer of specialty high capacity equipment used to move entire bridge structures is Mammoet USA, Inc., who provides computerized self-propelled modular transporters described earlier in this section. (Mammoet, 2002) Another manufacturer of high capacity rollers used with this technique is Hilman Rollers who produces several standard series of rollers capable of carrying loads in the order of 2 kips up to 2,000 kips. They have also produced special order rollers capable of carrying 10,000 kips. (Hilman, 2004) Eight 200 kip Hilman rollers were used to laterally roll into place New York Route 8 Bridge over the Hudson River, a single span through-truss 2-lane bridge. (Hilman, 2004) Contact information for Hilman Rollers is provided in Table 2.16.

Another example of roll-in construction is the replacement of the Norfolk & Southern Railroad bridge over the Wabash River near Logansport, Indiana. During this project, temporary falsework was required across the river to support the new 4-span through-girder bridge during construction adjacent to its final alignment position and during roll-in installation as well as to support the old bridge during roll-out removal. Once the new bridge was in place, the old bridge was demolished by controlled explosives. The bridge change out was scheduled to be completed in a 16-hour window, which required rail traffic to be suspended. The construction phase of this project was completed by Halverson Construction Co. Inc. (Halverson, 2004) Contact information for Halverson Construction Co. is provided in Table 2.16.

Another example of roll-in construction is the 24-hour installation of the Union Pacific Railroad Bridge over SH 21 in the Bryan District of the Texas DOT in December

of 2003. Replacement of the bridge was required as SH 21 was converted from 2 to 4 lanes. This required a significant lengthening of the bridge span. The new bridge, a single span through steel plate girder, was prefabricated off-site, disassembled, shipped to the job site, and reassembled on temporary falsework adjacent to its final alignment. The new bridge was placed on four sets of rollers (two sets at each end) that were set on channel tracks allowing the bridge to be rolled laterally into place. (TxDOT, 2003) The construction phase of this project was completed by CONCHO Construction Company, Inc. Contact information for CONCHO Construction Co. and Texas DOT is provided in Table 2.16.

Staged Construction

Several cases and variations of staged construction were identified and determined to be effective in the repair and replacement of bridges during this project. Staged construction, just as its name implies, is where repair or replacement is done in planned sequential stages, maintaining portions of the bridge in an operating condition for traffic while other portions are closed for repair or replacement. Traffic can be maintained via an undamaged portion of the existing structure or of an adjacent parallel structure or via a temporary bridge on the original or an adjacent alignment.

The New York Thruway Bridge incident at Yonkers, NY (Case Study No. 2 in this report) used a staged construction approach to replace the fire damaged bridge. Once the initial damaged bridge was removed, two temporary Acrow Panel Bridges were installed on a portion of the original site to carry a reduced traffic flow while a portion of the bridge was reconstructed. Once the initial portion of the bridge was ready for traffic, traffic was rerouted onto it and one of the two temporary bridges was removed and replaced by another portion of permanent bridge. Once the second portion of permanent bridge was ready for traffic, traffic was rerouted on to it and the last temporary bridge was removed and replaced by a permanent bridge, thus completing the bridge replacement.

The I-95 Bridge incident at Chester Creek, PA (Case Study No. 1 in this report) also used a staged construction technique to replace the fired damaged bridge needed to carry 3 lanes of southbound I-95 traffic. The 3-lane parallel structure for northbound I-95 traffic was re-stripped to carry 2 lanes of traffic each way and southbound traffic was rerouted to the northbound traffic structure while repairs on the damage structure were completed.

Substructure problems were discovered on the Wantagh Parkway Bridge near New York, NY (Case Summary No. 21 in this report), and the decision was made to replace the entire bridge. To maintain high traffic volume across the existing bridge, two temporary bridges were installed adjacent to and parallel to the existing bridge while demolition and replacement of the existing bridge was completed. Each temporary bridge was a 2-lane Acrow Panel Bridge approximately 1,000 feet long.

The Tennessee DOT chose a staged construction technique to replace the Wolf River Bridge in Fayette County, TN. (AASHTO-TIG, 2001) Since the Wolf River Bridge is the primary east-west traffic artery in its region, traffic needed to be maintained across the bridge during replacement to avoid a long and unacceptable detour. The entire bridge was replaced while maintaining one lane of traffic with alternating traffic flow

controlled by timed signals. Several other similar examples of staged construction that were identified during this project are identified in Table 2.16.

Waive Standard Construction Specification

Standard construction specifications are commonly used throughout the United States and serve a very important purpose; to insure quality control as well as structural strength and integrity in common construction scenarios. However, in some cases, these standards are overly conservative and unnecessary and can add significant time to the bridge repair or replacement process following an extreme event. Several examples, where one or more standard specifications were determined to be unnecessary and therefore waived, were identified during this project. It should be noted that the standard specifications serve an important function and should only be waived after careful consideration of the local conditions using good engineering judgment. The decision to waive any standard specification should be the exception and not the norm. Two issues were identified in this project where standard specifications were waived: cast-in-place concrete and pile driving.

Several different examples where standard concrete specifications were waived to expedite construction were identified during this project. During reconstruction of a portion of the Queen Isabella Causeway at South Padre Island in 2001 following a barge impact that caused the collapse of five spans, the TxDOT standard 4-day minimum cure specification for ready mix concrete was waived with all members membrane cured. Forms were stripped when concrete strength reached 3,000 psi, which typically occurred in 16 to 20 hours. During reconstruction of the I-95 Chester Creek Bridge in Pennsylvania in 1998 following a gasoline truck crash and fire, all time-based specification for concrete maturity were waived. In addition, 50% of the ties for the bottom reinforcing bars in the bridge deck were waived. During the planned rapid replacement of the NASA Road 1 overpass over I-45 in Houston in 2002, time related concrete provisions were relaxed as much as possible. This included allowing membrane curing of concrete and subsequent load at the lowest possible concrete strength of 2,000 psi. In addition, some construction tolerances were relaxed to speed construction. Contact information for these cases is provided in Table 2.16.

Several different examples where standard pile driving specifications were waived to expedite construction were identified during this project. During reconstruction of a portion of the Queen Isabella Causeway following the 2001 barge impact incident, piles were initially driven 3-feet short per specification but were redriven after one day versus the specified 7 days. Based on pile driving records of the initial piles, later piles were either driven to elevation with no redriving or left 2 feet short and redriven after only a few hours, saving significant time. Standard TxDOT pile driving specifications were waived during the planned rapid replacement of NASA Road 1 overpass over I-45 in Houston. Prior to bridge closure and the start of the replacement process, test piles were driven adjacent to the site in an effort to eliminate the need to redrive piles, which could take significant time and was in the critical path of construction. Contact information for these cases is provided in Table 2.16.

Table 2.16 Contractor / Construction Techniques

Product or Technique	Product or Technique Description and Use	Project Example or Contact
Construction Work Schedule (24-hour)	The 24-hour a day work schedule is warranted when circumstances are severe enough to justify its use in spite of the increased costs and other problems that are typically involved with its use. Special attention considering quality control, inspection, change order approval, construction or engineering problem resolution, lighting, safety, worker fatigue, and material delivery issues must be addressed. Seven projects utilizing 24-hour construction that are included in Chapter 3 of this report are identified in the adjacent cell of this table.	<p>I-95, Chester Creek Bridge Pennsylvania (CS #1) *</p> <p>I-40, Webber Falls Bridge Oklahoma (CS #2)</p> <p>I-93 Bridge Boston, Massachusetts (CS #15)</p> <p>I-80 Bridge Denville, New Jersey (CS #16)</p> <p>I-45 (Pierce Elevated) Houston, Texas (CS #17)</p> <p>Nasa Road 1 at I-45 Houston, Texas (CS #19)</p> <p>I-65 at I-59 Bridge Birmingham, Alabama (CS #22)</p>
Construction Work Schedule (12-hour)	The 12-hour a day work schedule is warranted when circumstances are only moderately severe and acceptable estimated project completion time can be achieved with its use. Many of the extreme cost increases and special issues that have to be addressed as associated with 24-hour construction are significantly reduced or eliminated with 12-hour construction. Three projects utilizing 12-hour construction during all or a part of the projects and that are included in Chapter 3 of this report are identified in the adjacent cell of this table.	<p>I-95, Chester Creek Bridge Pennsylvania (CS #1) (demolition phase only)</p> <p>John Ross Bridge South Africa (CS #9)</p> <p>Wantagh Parkway Bridge New York (CS #21)</p>
Construction Work Schedule (Nighttime only)	Nighttime only construction is commonly used with bridge deck replacement projects with high traffic volume bridges where typical daytime	<p>Braddock Road Overpass Virginia (CS #4)</p> <p>Brooklyn Bridge</p>

	<p>construction would cause severe traffic congestion and delays. During these projects, portions of the bridge deck are replaced each night during reduced traffic and are opened to traffic the next morning prior to rush hour traffic. Heavy monetary penalties for late morning openings are common. Three projects utilizing nighttime only construction are included in Chapter 3 of this report are identified in the adjacent cell of this table.</p>	<p>New York City, New York (CS #10)</p> <p>Lion's Gate Suspension Bridge, British Columbia, Canada (CS #12)</p>
<p>Innovative Contracting: A + B Bidding</p>	<p>This innovative contracting method, also known as cost plus time, incorporates the impact of construction on the general driving public during bid evaluation and contract award. The "A" portion contains the cost of the contract work items. The "B" portion contains the number of construction days to complete the project and is multiplied by a DOT determined daily user cost. The total cost (A+B) is used to determine the award company and the "A" portion is used as the award amount. The use of this technique is typically limited to projects with sever impacts on the driving public.</p>	<p><u>A + B Bidding</u> David L. Kent New York State DOT 518-457-0520 dkent@dot.state.ny.us</p> <p>I-40 Webbers Falls Bridge Oklahoma, (CS #2)</p>
<p>Mammoet Heavy Lifting</p>	<p>Mammoet has developed equipment capable of jacking and moving extremely heavy loads. Their equipment and expertise allows the placement of complete prefabricated bridge segments at one time in support of rapid bridge replacement restraints, thus minimizing bridge closure and public impact. Their Titan Bridge Lift System can be used in conjunction with their computerized self-propelled modular transporters to lift and move entire bridge segments into place in a short period of time.</p>	<p>Mammoet USA, Inc. 20525 FM 521 Rosharon, TX 77583 281-369-2200 www.mammoet.com</p>
<p>Maturity Method for Estimating</p>	<p>The maturity method uses a temperature-time (maturity) value of in-situ concrete to predict the strength</p>	<p>Gary Crawford FHWA 202-366-1286</p>

<p>Concrete Strength</p>	<p>of the concrete for form removal and load application decisions. This method has been shown effective in reducing overall construction times by allowing earlier form removal or concrete loading. The development and use of this method has seen significant growth since the mid to late 1990's. The primary national document that guides the use of this method is ASTM C-1074-98. FHWA also sponsor a Mobile Construction Laboratory that has played a key role in the increased national use of this method. Contact information of key individual identified in a FWHA article about the maturity method is provide in the adjacent cell of this table.</p>	<p>gary.crawford@fhwa.dot.gov</p> <p>Leif Wathne FHWA 202-366-1335 leif.wathne@fhwa.dot.gov</p> <p>Jim Grove Iowa DOT 515-239-1848 jim.grove@dot.state.ia.us</p> <p>Jim Cable Iowa State University 515-294-2862 jkcable@iastate.edu</p> <p>James Hill Texas DOT 469-371-0649 jhill@dot.state.tx.us+</p>
<p>Roll-in Construction</p>	<p>This technique utilizes high capacity rollers to roll preassembled bridges into place and is utilized where only very short durations of traffic closure are acceptable. A typical construction sequence assembles the new structure on temporary supports adjacent to the existing structure. When the new structure is ready, the old structure is quickly demolished or rolled out of the way allowing the new structure to be rolled laterally into place. When lateral alignment is set, the bridge is jacked up, the rollers are removed, and the bridge is lowered onto its permanent supports. Three examples of the use of this technique are listed in the Roll-in Construction write-up section in this chapter.</p>	<p>Hilman Rollers 12 Timber Lane Marlboro, NJ 07746 732-462-6277 www.hilmanrollers.com</p> <p>Halverson Construction Company Inc. 620 N 19th Street Springfield, IL 62702 217-753-0027 www.halversonconstruction.com</p> <p>CONCHO Construction Company Inc. 196 International Road Garland, TX 75042 972-276-8589</p> <p>Lloyd Wolf Bridge Division Texas DOT 125 E. 11th Street Austin, TX 78701</p>

		512-416-2279 lwolf@dot.state.x.us
Staged Construction (Using existing parallel bridge)	One type of staged construction uses an existing undamaged, parallel structure to carry temporary traffic during repair or replacement of the damage structure.	I-95 Chester Creek Bridge Pennsylvania (CS #1) Route 78 Bridge New Jersey (CS #8) Sagtikos Parkway Bridge Long Island, New York (CS #20)
Staged Construction (Using temporary bridge)	One type of staged construction uses a temporary bridge installed specifically to maintain traffic flow during repair or replacement operations. The temporary bridge can use a portion of the original bridge alignment or can be installed adjacent to the existing bridge.	New York Thruway Bridge Yonkers, New York (CS #3) Blake Street Bridge New Haven, Connecticut (CS #14) Wantagh Parkway Bridge New York (CS #21)
Waive Standard Construction Specification	Several examples were identified where standard construction specifications were waived to expedite construction. Standard specifications should only be waived after using good engineering judgment to evaluate local conditions and circumstances. Several standard specifications associated with concrete construction were waived during reconstruction of a portion of the Queen Isabella Causeway in Texas in 2001, the reconstruction of the I-95 Chester Creek Bridge in Pennsylvania in 1998, and the planned rapid replacement of NASA Road 1 Overpass at I-45 in Texas in 2002. In addition, standard specifications associated with pile driving were also waived with the Queen Isabella Causeway reconstruction and the NASA Road 1 Overpass replacement.	<u>Queen Isabella Causeway</u> Jody Ellington Texas DOT P.O. Box 1717 Pharr, Tx 78577 956-702-6100 jellingt@dot.state.tx.us <u>I-95 Chester Creek Bridge</u> Rex Mackey Pennsylvania DOT 7000 Geerdes Blvd. Montgomery County, PA 19604 610-205-6675 rmackey@state.pa.us <u>NASA Road 1 Overpass</u> John Vogel Texas DOT 8100 Washington Avenue Houston, TX 77251 713-802-5235 jvogel@dot.state.tx.us

* Case Summary No. in Chapter 3 of this report.

CHAPTER 3. CASE STUDIES AND CASE SUMMARIES

INTRODUCTION

The terrorist attack on September 11, 2001, and subsequent potential threats to United States transportation systems have presented an urgent need for the State Departments of Transportation (State DOTs) to elevate the security of the transportation infrastructure and develop emergency response plans to quickly react to the possible consequences of an extreme event. Highway bridges, as the critical component of the nation's transportation network, have received closer attention from many State DOTs. A pooled-fund research project, led by the Texas Department of Transportation titled "Rapid Bridge Replacement Techniques," was conducted from March 2002 through August 2003. The objective of the research was to identify strategies and technologies to restore the use of a bridge quickly in the event it is damaged or destroyed. Results of the research provide valuable information and knowledge for State DOTs to develop and/or update their rapid bridge replacement techniques and emergency response plans. Other State DOTs, which participated in the project, include Georgia, Illinois, Iowa, Minnesota, Mississippi, New Jersey, Ohio, and South Carolina.

One of the tasks associated with the research project was to conduct several case studies of previous bridge replacements following extreme events. Extreme events include explosion and fire caused by vehicle impact, water vessel collision with a bridge or part of a bridge, and flood or earthquake damage. The research team reviewed 26 cases including incidents in the United States and abroad. Originally, five case studies were required. However, only a few of the incidents found provided enough information for a detailed study. The researchers suggested that only three of the incidents be included in the detailed studies termed "case studies," and other incidents be summarized in less detailed descriptions. These less detailed descriptions were termed "case summaries." Three incidents were selected for case studies, and 26 incidents were selected for case summaries. The selected case studies describe repairs of the I-95 Chester Creek Bridge in Pennsylvania, the I-87 New York State Thruway (Governor Thomas E. Dewey Thruway Bridge) in Yonkers, New York, and the I-40 Webbers Falls Bridge in Oklahoma. The objective of the case studies was to identify and expand on lessons learned from bridge replacement incidents. The gained knowledge can be applied in designing bridge repair techniques and incorporated into State DOTs' emergency response plans. Brief descriptions of each case study were also included in the case summaries.

Case Study and Case Summary Methodology

Case studies and case summaries were conducted using a three-step approach. First, the research team reviewed the literature to identify incidents of bridges damaged by extreme events. Criteria for selecting an incident for further study included the bridge description and the availability of details describing the repair technique. Literature searched included newspaper articles, conference and journal papers, technical reports, and web sites. Additionally, researchers contacted the U.S. Army Corps of Engineers and manufacturers of temporary bridges in search of possible incidents for further study.

During the selection process, 26 incidents were identified. Second, three of the 26 incidents were selected to conduct detail case studies. Incidents selected for case studies are presented in the appendices. The three case studies were chosen because they each are critical components on major interstate highways and their incidents had significant impacts on the surrounding community. All three bridges had steel girders with concrete deck structures. Webbers Falls Bridge is over Arkansas River in a rural area. Both the Chester Creek Bridge and New York State Thruway Bridge are over land in urban areas. Finally, researchers compiled information from each of the 26 incidents into case summaries. The first three case summaries are brief descriptions of the case studies.

During the detailed case study stage, the research team interviewed people who were involved in the incident via the telephone. These people came from State DOTs, design firms, contractors, and material suppliers. In the telephone interviews, people were asked a series of questions regarding their role in the incident and their knowledge about it. From the telephone interviews, the research team developed a better understanding of the incident and were able to document details of the incident not found in published information.

Following the telephone interviews, survey questions were developed and sent to the people with first-hand knowledge of the incidents. There were several reasons for choosing the survey method to acquire information. First, a survey is a relatively easy way to solicit answers to the same questions from several people. Second, a survey questionnaire provides, in general, a very clear statement of information needs. Third, a survey gives people more time to respond to the questions as compared to personal interviews. Fourth, survey results are easy to compare and analyze. Responses to each returned survey questionnaire are given in the appendices along with the corresponding case study.

Case Summaries

A listing of the case summaries is given in the Table 3.1. The table provides the case summary identification number, the case summary title and any important points within the case summary. Case summaries for each incident are given in the subsequent text. Each case summary identifies the references used for that particular summary. In addition, Table 3.2 is provided as a quick reference for key words and issues contained in the case summaries and can be used to identify cases of immediate interest.

Table 3.1 Case Summaries

Summary Number	Title	Important Points
1	I-95 Chester Creek Bridge Chester, Pennsylvania	Three-span steel girder over traffic Concrete deck Concrete piers Gasoline tanker impact / fire on deck Replaced steel girders
2	I-40 Webbers Falls Bridge Oklahoma	Four-span steel girder over water Concrete deck Concrete piers Barge impacted substructure Replaced steel girders with precast concrete Replaced piers Contract incentives used
3	New York Thruway Bridge, Yonkers, New York.	One-span steel girder over traffic Concrete deck Gasoline tanker impact / fire under deck Temporary bridge used to detour traffic Total replacement
4	Braddock Road Overpass Virginia	Concrete deck Concrete deterioration Deck replacement
5	Sava River Bridge Bosnia	29-span steel-truss over water and land Bomb damage from military operations Replaced four spans with panel bridges Repaired two piers
6	Bridge 8750 on the M20 England	Four-span pre-stressed concrete beams Cast-in-place concrete slab Abutments and concrete portals Vehicle impacted portal Spalling / cracking of portal Resin injection repair of concrete damage
7	Century Road Overpass over Highway 16X Canada	Pre-stressed bulb tee girders Impact from over-height load Damaged 15 of 18 girders Repairs included patching with epoxy resin, splicing tendons, recasting girders Contract incentives used
8	Route 78 Bridge New Jersey	Steel stringers Concrete pavement Garbage fire under bridge Catastrophic damage to structural elements beneath the deck Temporary bypass used to detour traffic Total replacement
9	John Ross Bridge South Africa	Two-section pre-stressed concrete Extreme flood causing total collapse Total replacement using incremental launching Contract incentives used

10	Brooklyn Bridge New York City, New York	Steel superstructure (cable suspension) Cast-in-place concrete deck Concrete and steel deterioration of deck Deck replacement using modular panels Contract incentives used
11	Judge Seeber Bridge New Orleans, Louisiana	Barge impacted substructure Collapse of one pier and two spans Reconstructed bent, superstructure and deck sections
12	Lions' Gate Suspension Bridge British Columbia, Canada	Steel superstructure Concrete deck Deterioration of deck Replaced deck and widened lanes
13	Seneca River Bridge Port Byron, New York	Single-lane bridge over water Snowplow blade impacted vertical member Collapse of 40-ft section Installed panel bridge sections as permanent repair
14	Blake Street Bridge New Haven, Connecticut	Three-span reinforced concrete beams over water Scouring of piers Failure of main pier supports Temporary bridge used to detour traffic Total replacement
15	I-93 Bridge Boston, Massachusetts	Steel beams with double deck over traffic Corrosion of steel beams Buckling of one beam Erected new support beams
16	I-80 Bridge Denville, New Jersey	Simple-span concrete I-beams over water Explosion and fuel fire Cracking in 5 of 6 beams Temporary bridge used to detour traffic Steel I-beams used as replacement
17	I-45/Pierce Elevated Houston, Texas	Existing bridge reached end of useful life and was demolished Total replacement using prefabricated members Contract incentives used
18	I-10 San Antonio "Y" San Antonio, Texas	Post-tensioned wing segmental design over traffic Cracking of two cantilever piers Temporary scaffolding used during repair
19	NASA Road 1 Houston, Texas	Five-span non-composite steel box beams Replaced to increase clearance High strength concrete and rapid construction techniques used Contract incentives used
20	Sagtikos Parkway Bridge Long Island, New York	Four-span, rolled steel beams over traffic Concrete deck Concrete piers Car/petroleum tanker collision and subsequent fire under bridge deck Severe fire damage to beams, deck and a pier Replaced span and pier Inverset™ composite steel beam units used in repair

21	Wantagh Parkway Bridge New York	Original structure over water was closed and demolished Tidal scour damage created separation of piers from roadbed Installed panel bridge sections as temporary repair
22	I-65/I-59 Bridge Replacement Birmingham, Alabama	Three-span steel girders over traffic Gasoline tanker impact / fire beneath deck Extreme sagging of steel girders Total replacement Contract incentives used
23	I-610 Houston Ship Channel Bridge Houston, Texas	Pin and hanger supported steel girders over water Concrete deck Cargo boom impacted superstructure and deck Damaged two girders and deck slab Damaged girder portions were removed and replaced using welding techniques Rebar replaced and new concrete placed
24	Hoan Bridge Milwaukee, Wisconsin	Steel beams and girders over land Cold temperature, heavy loads and construction flaws leading to beam failure Two of three beams suffered cracking Total span replacement Contract incentives used
25	FM 1927 Over I-20 Ward County, Texas	Four-span pre-stressed concrete beams over traffic Concrete deck Impact from over-height load Localized damage to external beam Repairs used epoxy injection, rapid set grout and concrete
26	Ohio Bridge GUE-513-1.80 Quaker City, Ohio	Cast-in-place concrete deck Scheduled deck replacement Replaced existing deck with post-tension, pre-cast, modular deck slabs Contract incentives used

Table 3.2 Case Summaries Quick Reference

Sum. No.	Date	Contact	Event	Structure	Spans / Length	Crossing	Detour	Repair	Temp. Bridge	Shoring	Contract	Time	Cost
1	May 1998	Rex Mackey PennDOT 610-688-1700	Gas Fire	Steel Plate Girder	3 360-foot	Water	Yes	Replace	Existing north bound	No	Time & material + markups	42 days	\$4 million
2	May 2002	George Raymond Oklahoma DOT 405-521-2561	Barge Impact	Steel Plate Girder	13 1988-ft.	Water	Yes	Replace w/ P/C Beams	No	No	A + B w/ I/D	64 days	
3	Oct. 1997	Paul Provost NY Thruway 518-436-3041	Gas Fire	Steel Plate Girder	1 79-ft.	Route 100	Yes	Staged Replace w/ Inverset	Mabey	No	I/D	155 days	\$2.5 million
4	May 1998	Michael Sprinkel Virginia DOT 804-293-1941	Deck Deterioration	R/C Deck		IH-495	No	VES Overlay Night-time only	No	No		8 hours / night	\$96 / S.Y.
5	1996	Paul Mlkar US Army-WES Vicksburg, MS	War Damage	Steel Truss	26 800-m	Water	No	Mabey panel truss bridge	No	No		20 days	
6	Dec. 1992	S. R. Rigden Univ. London London, England	Truck Impact	R/C Pier	4 spans	Hwy. M20		Epoxy injection	No			6 days	£ 5,000 Engl.
7	Nov. 1996	Ed Kowal Albert Trans. Ed.Kowal@gov.ab.ca	Truck Impact	P/C Girder		Overpass Hwy. 16X		Splice tendons & epoxy injection			I/D	21 days	
8	Aug. 1988	Alfred R. Pagan Contributing Ed. <i>Better Roads</i> 847-391-9070	Fire	Steel Plate Girder			Yes	Temp. bypass (parallel Struct.)	No	No		9 days for temp. bypass	
9	Sep. 1987		Flood	P/C Girder	7 413-m	Water	Yes	Replace w/ P/C Box	No	No	Dsn./Bld. w/ I/D	182 days	R 6.7 million (Rand)

								(Incr. launch)					
10	June 1999	Foster Fabricated Products Pittsburgh, PA 412-928-7854	Deck & Steel Deteri- oration	Supsen- sion w/ steel supports	3 3,500- ft.	Water	No	Incre- mental replace, night only	No	No	Dsn./Bld. w/ I/D	130 nights	\$33.5 million
11	May 1993	Boh Brothers Construction New Orleans, LA 504-821-2400	Barge Impact	Steel Truss	3 spans	Water	Yes	Replace & Repair	No	No	Part- nering	60 days	25% under budget
12	Sep. 2000	M. Abrahams w/ Parsons, Brinckerhoff, Quade & Douglass New York, NY	Deteri- oration	Suspen- sion w/ steel support	3 1,518- m	Water	No	Incre- mental replace, night only	No	No	Dsn./Bld.	180 days	\$58 million
13	Nov. 1990	John Ozolins Cayuga County New York State 315-253-1366	Snow- plow Impact	Steel Truss	1 133-ft.	Water	No	M1 Bailey Bridge	No	No	Military Training	18 days plan. & 15 hrs. replace	
14	Apr. 1996	Public Works City of New Haven, CN 203-946-7700	Flood	R/C T-beam	3 95-ft.	Water	Yes	Replace	Acrow (adj. parallel)	No		4 years	\$2.0 million (est.)
15	May 1999	Tom Broderick Massachusetts Hwy. Dept. 617-973-7800	Deteri- oration	Steel Beam			Yes	Repair: 24-hour constr.	No	No		3 days	
16	June 2001	Bill Killeen Acrow Corp. Carlstadt, NJ 201-933-0450	Gas Fire	R/C Beam	1 50-ft.	Water	No	Replace R/C w/ Steel Beam	Acrow 700-XS	No		60 days	
17	1997	Delvin Dennis Houston Dist. Texas DOT	Deteri- oration	P/C Beam	Multi. 1.64- miles	City streets (elevated)	Yes	Replace: 24-hour constr.	No	No	I/D	302 days	\$26 million

		713-802-5000				fwy.)							
18	Mar. 1995	Brian Merrill Texas DOT Austin, TX 512-416-2232	Service Load Cracks	R/C Support		City streets (elevated fwy.)		Temp. shoring	No	Yes		2 days	
19	Apr. 2002	John Vogel Houston Dist. Texas DOT 713-802-5235	Insufficient Clear.	Steel Beam	4 300-ft.	IH-45	Yes	Replace: 24-hour constr. P/C Box	No	No	I/D	10 days	
20	Oct. 1994	NY State DOT Structures Div. 518-457-6827	Petroleum Fire	Steel Beam	4 spans	Long Island Express.		Replace: stock-piled beams & staged constr.	No	Yes		57 days	
21	Apr. 1998	Eugene Sobecki Acrow Corp. Carlstadt, NJ 201-933-0450	Tidal Scour		Multi. 600-ft. (est.)	Water	Yes	Replace: temp. bypass (1000 ft)	Acrow 700-XS	No	Fast-track	90 days (less than)	
22	Jan. 2002	Mike Mahaffey Dist. Engineer Alabama DOT 205-581-5702	Gas Fire	Steel Beam	3 120-ft. (main)	IH-59	Yes	Replace: P/C Beam & 24-hour constr.	No	No	I/D	37 days	\$2.1 million
23	Dec. 2000	John Vogel Houston Dist. Texas DOT 713-802-5235	Ship Cargo Boom Impact	Steel Plate Girder	Multi. 430-ft. (main)	Water	Yes	Repair: weld in sections & tears	No	No		46 days	
24	Dec. 2000	Wisconsin DOT Bureau of Structures 608-266-8489	Service Load Cracks & Failure	Steel Plate Girder	Multi. 270-ft. replace	Water	Yes	Repair cracks & replace failed beams	No	No	I/D	240 days	\$16 million

25	Jan. 2003	Dingyi Yang Texas DOT Austin, TX 512-416-2457	Truck Impact	P/C Beam	4 210-ft.	IH-20	No: lane reduct.	Repair P/C beam w/ CFRP	No	No	Negotiated C/O w/ mainten. contract	5 days (repair)	\$47 k
26	June 2003	Ohio DOT Office of Structural Engr. Columbus, Ohio 614-466-2463	Sched- uled Replace- ment	CIP R/C Slab	2 60-ft.	Water	No	Replace: pre-fab. modular P/T concrete slabs	No	No	A + B w/ I/D	17 days	\$379 k

Summary No. 1: I-95 Chester Creek Bridge, Chester, Pennsylvania

A gasoline tanker-truck hauling 8,700 gallons of fuel and traveling northbound on Interstate 95, crashed through the concrete median barrier and exploded after striking a pickup truck traveling southbound on I-95 on the bridge over Chester Creek in Delaware County, Pennsylvania, at 7:00 am on Saturday, May 23, 1998. The 360-foot long, 3-span continuous bridge was built in 1965. The superstructure of the bridge included steel girders and frames with a concrete deck. Concrete piers supported the steel girders. PennDOT bridge engineers evaluated the bridge and declared that the southbound structure was unsafe due to severe damage caused by the fire and that the northbound structure was undamaged. The flames scorched most of the 360-foot long concrete deck and caused the steel superstructure to sag, but not collapse. Approximately two-thirds of the superstructure needed to be replaced. The foundation of the bridge was not damaged. The substructure had one pier, which required some minor concrete repairs with Gunitite.

The replacement was identical to the original bridge. Since the repair work used the original shop drawings, there was no need for PennDOT to approve the drawings; this saved considerable time during the replacement process. Some requirements in the standard specifications were waived based on engineering judgments in order to expedite the replacement process. The Secretary of PennDOT immediately awarded the repair contract to Buckley and Company, Inc., who built the original bridge and had previously successfully repaired a similar project. The entire replacement was conducted in three stages, including demolition, material preparation, and reconstruction. After High Steel Structures, Inc. received the repair contract it was determined that the company could fabricate the replacement girder segments with cross frames under very tight schedule. The fabrication of nine, 65 to 80 foot long girders segments, each standing 6'-8" high, weighing 15 to 20 tons, was completed in ten days. Buckley installed the nine steel girder segments in two days, then construction crews set 14-foot wide steel deck pans between the four rows of girders. Next, reinforcing bars were installed in place for the concrete deck which exceeded the required 4,000-psi less than a week after the deck pour. Working seven days a week, 24 hours a day, all repair work was completed on Friday, July 3 (40 days from incident date). Buckley received \$500,000 overtime pay.

References

Burns (1999), Carey (1998a), Carey (1998b), and Jennings (1998)

Summary No. 2: I-40 Webbers Falls Bridge, Oklahoma

On Sunday morning, May 26, 2002, the towboat Robert Y. Love pushing two empty barges upstream on the Arkansas River hit the I-40 Webbers Falls Bridge around 7:47 am. The incident caused part of the bridge to fall into the river. ODOT closed the bridge and the Navigation System. The 64-foot wide, 1988-foot long, four-lane bridge was built in 1967, the original structure was a continuous haunched steel girder bridge with a 200-ft-330 ft-200 ft main span combined with steel girder approach spans and a reinforced concrete deck. The steel girders were supported by 12 concrete piers. The barge knocked down two piers, damaged one pier, and four spans of approximately 500 feet were also damaged. ODOT awarded a cost plus emergency contract to the Jensen

Construction Company, who was working on a bridge project nearby, to remove wreckage and stabilize damaged portions of the bridge so victims and vehicles could be recovered. ODOT then awarded a lump sum contract to the Jensen for demolition work necessary to remove the damaged sections of the bridge. The duration of the contract was 16 days with an incentive/disincentive of \$50,000/day.

ODOT awarded the design contract to the Poe & Associates Inc. on the day of incident. The designers made several changes on the original plans and specification in order to expedite the repair process. After the incident, three 130-foot pre-cast, pre-stressed concrete girders were utilized in lieu of the original steel plate girders. Using concrete girders reduced the material delivery time, but increased the bridge dead load. New specifications allowed using high early strength concrete, steel stay-in-place forms, steel diaphragms for pre-stressed concrete beams, and concrete maturity method. The contract of the bridge reconstruction was awarded using A plus B competitive bid method; the owner evaluated the bid proposals based on not only the cost, but also the schedule. In the bid document, ODOT specified 72 days as the maximum time allowed to complete the reconstruction. The contract was issued to Gilbert Central Corporation for \$10.9 million, with \$6,000 per hour bonus/penalty clause without cap either way. The major scope of repair work involved constructing a 524-foot-long combination concrete and steel girders that would tie into the undamaged four-lane bridge structure, three piers, four spans, an abutment, a 30-foot-long concrete approach slab and a 40-foot-long roadway section. On average, there were 70 to 80 workers on site with two 12-hour shifts per day, 7 days a week. The project was finished in 46 days and 16 hours. Gilbert received \$1.5 million in bonuses.

Reference

Greiner (2002), Melnick (2002), and Stidger (2002), FHWA (2002), Cherokee Nation (2002), and ODOT (2002)

Summary No. 3: New York Thruway Bridge, Yonkers, New York.

A gasoline tanker, making a U-turn under the New York State Thruway (I-87) that passes over Central Park Avenue Route 100, was struck by an oncoming car. After the collision, the gasoline truck exploded underneath the Thruway in the City of Yonkers. Structural engineers assessed the damages and closed the bridge to traffic, which normally carries 65,000 vehicles per day.

Detours were established until temporary bridges were placed. These bridges, manufactured by Mabey Bridge & Shoring, Inc., were panel bridges consisting of prefabricated steel truss structures and spanned over the damaged abutments. A ten-man crew assembled the temporary bridges and they were launched by using stationary launch rollers and a crane, and were ready for use in 11 days.

The reconstruction contract was awarded by competitive bid to Felix Equities Inc. on October 31, 1997. Stage construction techniques were implemented in order to minimize the disruption and/or inconvenience. First the abutments were rehabilitated by removing

damaged material to a depth of 6 inches and replaced with an 11-inch high performance concrete overlay. The second stage involved rebuilding of the southbound bridge deck. The Fort Miller Company utilized the Inverset™ Bridge System to produce 12 modular pre-stressed bridge deck panels. This method involves the upside-down placement of a reinforced concrete bridge deck panel on a prefabricated steel frame. After curing in a controlled inside environment, the assembled panels are turned right side up and transported to the site for placement, where they are set by cranes.

When the southbound span was completed and could accommodate four lanes of traffic, the southbound and northbound temporary bridges were taken down while work was completed on the permanent northbound structure. Construction was completed within three months and 4 days of the accident.

Reference:

Kulewicz (1998), Vero (2000), NYSTWA (1997), Gross (1997), Revkin (1997), Newman (1997), and New York (1998).

Summary No. 4: Braddock Road Overpass, Virginia

Replacement of a concrete bridge deck wearing surface is a common event due to deterioration of the surface concrete caused by weathering leading to spalling of the surface concrete caused by corrosion of the steel reinforcing bars. This replacement/repair process is usually a very time consuming process that can have major impacts on the driving public.

To minimize these impacts, in May of 1998, the Virginia Department of Transportation (VDOT) employed a rapid deck repair technique, which had been evaluated during the Strategic Highway Research Program (SHRP), on a bridge in northern Virginia (Braddock Road Overpass at I-495) that carried an average of 64,000 vehicles per day. VDOT selected the use of a very early strength (VES) latex-modified Portland cement concrete (PCC) overlay. Using this material, portions of the bridge deck were replaced each night on successive nights until the entire bridge deck was replaced. The typical nightly schedule used during this deck replacement was as follows: close the bridge at 9 p.m., complete deck surface preparations by 11 p.m., place the overlay by 2 a.m., and reopen the bridge by 5 a.m. Properties of this system include: durability equal to conventional overlays, a very early strength that allowed the bridge deck to be opened to traffic only 3 hours after placement, and a permeability lower than that of conventional latex-modified concrete overlays.

According to Donald Jackson of FHWA, material costs for VES overlays are higher but are offset by savings associated with traffic control and work-zone safety. VDOT estimated the cost of labor and materials for the VES overlay at \$96 per square yard compared to \$130 per square yard for conventional PCC overlays.

Reference:

Jackson (1998), and FHWA (1998)

Summary No. 5: Sava River Bridge, Bosnia

During hostile fighting between factions in Bosnia, intentional demolition and bombings destroyed sections of the Sava River Bridge at Brcko. U.S. peacekeeping forces needing a link to central Europe during the annual spring flood, choose the Sava River Bridge as their best course of action, because much of the bridge remained intact. Damaged areas included a 35-meter gap in one span over the navigable waterway and three 20-meter sections collapsed on the flood plain where the piers were damaged as well. The design to repair the structure was to retrofit the gaps with Mabey 200 Compact Panel Bridges where sections of the original bridge were missing and to repair the 2 damaged masonry piers.

After it was determined that the remaining existing piers and trusses were either intact or could be repaired and could withstand the point loading of the panel sections, a combination of civilian and military crews began work. Steel cutting charges were used to remove mangled sections of trusses. Civilian contractors then began repairs on the 2 damaged masonry piers by removing the damaged masonry with jackhammers and replacing it with mass concrete and used embedded, grouted reinforcing bars to provide continuity between the existing masonry piers and concrete repairs. U.S. and Hungarian military units then installed the panel bridging in 10 days. The panel bridge sections were assembled on the existing roadway and launched into their final position. The 35-meter span was installed as a simple span, while the 3, 20-meter spans were installed as a 3-span continuous structure. Once the panel bridge sections were in position, they were lowered by jacking onto their supports and prefabricated deck panels were installed. The existing bridge and its repairs were load rated at MLC 60 (60 tons). The bridge was then tested with a tracked vehicle representing planned loads and the structure was found to be satisfactory. The process, from planning and inspection to panel installation, took only 20 days total to complete. No incentives / disincentives or contract type information was found for this incident and it is felt to be non-critical give the military and war-time scenario associated with this incident.

Reference:

Mlakar (1997)

Summary No. 6: Bridge 8750 on the M20, England

At an intersection between two of England's important highways, A28 and M20, a head on impact between a heavily loaded truck carrying construction materials with one of the bridges main outside supports occurred and caused significant damage to the impacted bridge support. Bridge 8750 is a four-span structure with a cast-in-place concrete slab acting compositely with prestressed concrete beams. The structure is supported by 2 abutments and 3, 2-bay concrete portals. It was the north leg of the east portal that was impacted and severely damaged. Some spalling occurred at the point of impact but the major damage was represented by 3 diagonal cracks that were visible on all 4 faces of the pier with a maximum crack width of 0.7 mm. Only one leg of the impacted portal was

damaged. Several options were considered for repair including demolition and replacement of only the damaged leg (estimated cost of £150,000), demolition and replacement of the entire damage portal (estimated cost of £250,000), and replacement of the entire structure (estimate cost of £10M). Time and cost factors led to the selection of a fairly recently developed resin injection repair technique.

A negotiated contract was signed with Reptek Ltd. to complete the work. They were associated with Structoplast Contractors Ltd. who had just recently successfully completed a similar laboratory project (referenced below) using the selected resin injection technique. Concessive 1380 resin was proposed for use by Reptek and was control tested for shrinkage, slant shear strength, and compressive strength. The resin was injected into the cracks on all 4 faces using injection ports spaced at 300 mm and at pressures up to 10 bars with 5 bars being more common. Cores were also drilled after injection to assure proper penetration of the resin. The work was completed in 6 days with a direct cost of £5000, significantly less than any of the other considered repair/replacement options. This technique allowed the repair to be done quickly and cost effectively, returning the bridge to its normal operating use. No incentives / disincentives were discussed with respect to this project.

Reference:

Abu-Tair (1991) and Rigden (1995)

Summary No. 7: Century Road Overpass over Highway 16X, Canada

A truck carrying an over-height load of industrial forestry logging equipment was traveling on Highway 16X West in Alberta, Canada, and struck the Century Road Overpass during the evening of November 6, 1996. Damage was done to 15 of the 18 bulb tee pre-stressed girders that make-up the structure. Two girders received minor damage consisting of isolated concrete cracks, nicks, shallow spalls, and/or scrapes. Eight girders received moderate damage consisting of large cracks and spalls large enough to expose undamaged prestressing tendons and distorted reinforcing bars. Five girders received severe damage consisting of cracking, crushed concrete in the bottom flanges and webs of the girders, broken stirrups, and some severed prestressing tendons. Due to the onset of winter conditions, repairs were delayed until the spring due to increases in cost and quality control issues associated with winter construction. While waiting for good weather to start the repairs, loose and shattered concrete fragments were removed and netting installed below the damaged girders to prevent any additional fragments from falling onto the roadway below. In addition, traffic was diverted off of the 4 most severely damaged girders using barricades and lighting.

Repairs of the damaged girders were started in June 1997. A preloading of 44 tons was applied to 13 of the 15 damaged girders prior to execution of the repairs. Severed prestressing tendons were spliced, pretensioned, and repositioned prior to recasting of the concrete sections. The concrete girders were recast to their original lines using 5,100 psi concrete. Cracks less than 0.02-inch in width were externally sealed at the surface of the concrete. Cracks 0.02-inch in width or wider were sealed using a full-depth injection

technique with an epoxy resin. All recast concrete was externally sealed after recasting. The contract included an incentive/disincentive of \$500/day. The construction contract was completed in three weeks which was proposed; therefore, no incentive or disincentive was awarded.

Reference:

Feldman (1998)

Summary No. 8: Route 78 Bridge, New Jersey

A garbage fire under a portion of Route 78, a 17-year-old, 10-lane highway bridge caused major damages and costly repair problems for the congested highway. The heat from the fire caused catastrophic damage to the steel stringers supporting the pavement, the concrete pavement, the diaphragms, the concrete pedestals, and the rocker bearings. A 3500 ft.-long bypass was constructed within nine days to allow the remaining portion of the bridge to be used. One of the four parallel spans of Route 78 was stable enough to support traffic flow; therefore two lanes in each direction were usable for the bypass.

The Governor of New Jersey declared the disaster to be a state emergency and asked for federal funds. The six million dollar temporary bypass and unknown cost to repair the bridge would be covered by mostly by federal agencies and additional money may be collected from a local trash carrier after an insurance settlement. At the time of the article no contract had been awarded for repair and no indication of when repair might get under way.

Reference:

Pagan (1989)

Summary No.9: John Ross Bridge, South Africa

The John Ross Bridge crossing the Tugela River in Natal, South Africa suffered total collapse during an extreme flood event in September 1987. This prestressed concrete bridge was constructed in 1959, was 412.5-meters long, and took 3 years to construct. It was constructed using 2 continuous sections (one section 5 spans long and the other section 2 spans long), which were separated by an expansion joint at one of the supporting piers. The high loads from the flood waters caused the pier supporting the expansion joint to move laterally, allowing the ends of the 2 supported sections to fall. This caused a chain reaction that led to the total collapse of the bridge that was a main traffic artery.

During the bridge replacement process, traffic was rerouted to 2 low standard bridges that were located 4.5 kilometers upstream, which required an additional 30 minutes travel time and resulted "in an estimated increase in road user cost of R40,000 per day, where R represents the South African currency, the Rand. The fast reconstruction of the bridge was therefore regarded as a high national priority." A prestressed concrete segmental box girder and deck section was selected for the replacement bridge, which was placed using

an incremental launching technique from the south abutment. The original bridge alignment was maintained but new foundations were constructed due the time and cost associated with retrofitting the existing foundations to meet the higher load conditions of the re-design. The new bridge piers were constructed using cast in place, reinforced concrete and were configured as 2 circular columns supported by a rigid pile cap on top of 4 or 6 "permanently cased bored piles." The new structure was composed of six 55-meter main spans with end spans of 44 meters or 38.5 meters, one on each end.

A 2-phase design/construct bidding process was used with 34 firms submitting prequalifications and technical proposals, which included construction times and costs. These firms were narrowed down to 5 firms, which then submitted preliminary designs. From these 5 firms, Grinaker Construction Natal, who had submitted a proposal costing R6.7 million with a construction time of 8 months, was selected for construction with Van Niekerk, Kleyn, and Edwards as their designer. The bridge was constructed and launched into position in just under 13 weeks and was reopened to traffic after 26 weeks of construction, 10 weeks ahead of schedule. The final contract included a bonus/penalty clause of R5,000 per day that increased by R1,000 per day for each additional day up to a maximum of R30,000 per day.

Reference:

Feature (1989)

Summary No. 10: Brooklyn Bridge, New York City, New York

The New York City Department of Transportation issued a notice to proceed for the night time replacement of over 207,000 square feet of bridge deck on the Brooklyn Bridge in October, 1998. Actual construction began in June, 1999 and was completed in December, 1999 and took only 130 construction nights to complete. The Brooklyn Bridge, having an ADT of over 130,000, is composed of 2 parallel structures, with each structure having 3 lanes of traffic and being approximately 3,500 feet long and having a 30-foot-wide deck. The bridge utilizes a steel superstructure with either suspension cables or cable stays in different regions of the bridge. The original deck was fabricated using a grid of 3-inch deep I-beams, inverted U-shaped tub forms, and cast in place concrete. The bridge deck was scheduled for resurfacing when significant deck concrete and steel deterioration was discovered and necessitated the complete replacement of the deck.

The deck replacement project was implemented using a design-build contract and was awarded to the design firm of Weidlinger Associates and the general construction company of Yonkers Contracting Company, Inc., with a bid price was \$33.5 million. The deck was replaced using 7.5-foot by 30-foot prefabricated modular panels which bolted together and were made using 3-inch inverted steel T-sections and light weight concrete. A "microsurface" overlay was specified to insure a smooth ride quality for the finished deck. Each construction night, traffic was routed off of one of the twin structures to allow 2 crews to each replace a 30-foot by 30-foot section of the deck; with the 30-foot wide bridge deck being formed by 4 7.5-foot wide panels bolted together

forming longitudinal joints. Work was conducted from above using the existing or previously replaced deck surface as well as from below utilizing a movable hanging platform.

The contract limited complete bridge closures to between the hours of 11:00 p.m. and 6:00 a.m. to minimize traffic disruptions. However, single lane closures were permitted between the hours of 7:00 a.m. and 3:00 p.m. to allow for necessary nighttime removal preparations. Only one of the twin structures could be closed at a time. In addition, the contract specified the maximum number of construction nights as 150 nights and specified a \$45,000 per night incentive or penalty for the number of construction nights less than or more than the specified maximum, respectively. In addition, the contract specified a \$500 per minute penalty for exceeding the 6:00 a.m. reopening time. The contract was completed using only 130 construction nights with the contractor never exceeding the 6:00 a.m. specified reopening time. The time table for the project was as follows: notice to proceed issued (October 1998), construction began (June 1999), and construction complete (December 1999).

Reference:

News (1999) and Foster (2003)

Summary No. 11: Judge Seeber Bridge, New Orleans, Louisiana

Around mid-afternoon on May 28, 1993, a towboat pushing an empty barge impacted support pier 21 of the Judge William Seeber Bridge a major traffic artery in New Orleans, Louisiana. The impact severed the 2 column bent and caused approximately 145 feet of bridge deck from the 2 supported approach spans to fall onto the barge and into the New Orleans Inner Harbor Navigation Channel. This event closed the navigation channel for 2 days, closed the bridge for 2 months, and resulted in the death of 1 person and serious injury of 2 others.

Boh Bros. Construction Co. immediately, “dispatched personnel and a barge-mounted crane to the accident site in order to assist the Louisiana Department of Transportation and Development (LaDOTD).” This allowed them to start work upon issuance of a work order by LaDOTD. Boh Bros. and LaDOTD partnered together to develop a construction schedule and budget using support and data from within their own organizations as well other subcontractors and material suppliers. Major work items in the project included damage assessment, clean-up and debris removal, reconstruction of the missing support bent, superstructure and deck sections, and testing of the repaired portions of the bridge.

Recognition of the emergency nature of the scenario by all parties (LaDOTD, Boh Bros., subcontractors, and material suppliers) and the implementation of the partnering technique lead to the expediency of the bridge replacement. The key players in the project “reallocated personnel, equipment, and materials from other projects in a concerted effort to service the job.” This strong commitment by all parties allowed the bridge reconstruction to be completed 33% ahead of schedule and 25% under budget.

Reference:

AGC (2003), Highway-Marine (2003)

Summary No. 12: Lions' Gate Suspension Bridge, British Columbia, Canada

The Lions' Gate Suspension Bridge of British Columbia was part of an \$80-million (Canadian) plus bridge rehabilitation. The 1,518-meter, 45-year-old bridge and its deck had significant deterioration by the mid-1990's to the point that the deck was costing an estimated \$3 million (Canadian) a year in maintenance. In addition, the deck needed widening to allow safer lane widths, much of the steel superstructure supporting the deck needed replacing, and seismic retrofits were needed to bring the bridge up to today's standards. This bridge accommodates approximately 70,000 vehicles a day to and from Vancouver; therefore it was necessary to avoid closing the bridge for renovations. To make the project possible with no interruption to normal daily traffic flow, a ten-hour work period took place each night. Construction was planned for closures between 8 P.M. and 6 A.M.

"The existing stiffening trusses, floor beams, stringers, concrete-filled T-grid deck, and steel sidewalks were replaced with an orthotropic steel deck and composite longitudinal stiffening trusses." (Matson, 2001) The original 12.2-meter deck width was extended to 16.8 meters by cantilevering the sidewalk beyond the boundaries of the original superstructure. The deck sections were prefabricated in either 20-meter or 10-meter long section. The 20-meter-long sections were used to replace the north side-span and the main-span of the bridge with the deck sections being lowered and raised from below the bridge. Due to a steep terrain under the south side-span, 10-meter-long sections were developed and were replaced from above with the sections transported over the existing bridge, rotated 90-degrees, and lowered into place. Once the bridge deck had been replaced, an epoxy asphalt ride surface was installed.

A combination of traditional design-bid-build and design-build methods were utilized in the renovation of this bridge. The contract was awarded as a joint venture to American Bridge (Pittsburgh, Pennsylvania) and Surespan (West Vancouver, British Columbia) in April of 1999.

Reference:

Abrahams (2003) and Matson (2001)

Summary No. 13: Seneca River Bridge, Port Byron, New York

On November 12, 1990, a snowplow tried to cross the Seneca River Bridge. However on its travel across the bridge, the snowplow struck a vertical member of the bridge. The snowplow and a 40-foot section of the bridge collapsed into the Seneca River below. This 93-year-old single lane bridge was the only link to Haiti Island, New York. Winter was rapidly approaching and the residents of the island needed vehicular access to the island. Therefore, the bridge required expedient repair. A Reserve infantry Major heard

of the damage caused to the bridge and immediately contacted the county's highway superintendent with a proposal for a potential training opportunity for his reserve unit.

The county's highway superintendent told the Major that the New York State Department of Emergency Management along with the state's Department of Transportation owned several sets of M1 Bailey Bridge parts. It was decided that a Class 30 bridge would be necessary to serve as a replacement bridge. A 140-foot double-single bridge was initially installed to provide access and egress from Haiti Island and was later upgraded to a Class 30 double-double. The original bridge truss superstructure remained in place in spite of the missing 100-foot section of deck and substructure. For expedience, it was determined to leave the original bridge trusses in place and launch the replacement Bailey bridge through the existing trusses.

An initial meeting, with over 30 participants, was held to plan and coordinate the bridge replacement project. On December 1, 1990, after several weeks of planning and preparation, replacement operations began. Within 15 hours, a double-single Bailey bridge was erected, rolled into place inside the original bridge, and was opened to vehicular traffic. The Bailey bridge installation was performed by Echo Company, 2nd Battalion, 391st Regiment, 98th Division (training unit). Three months later the bridge was upgraded to a double-double Bailey bridge that was determined to be a permanent replacement.

References:

Craig (1992)

Summary No. 14: Blake Street Bridge, New Haven, Connecticut

After a storm categorized as a 50-year event caused severe flooding under the Blake Street Bridge in New Haven, Connecticut, the bridge, which was already in poor condition, was closed. The Blake Street Bridge was a three-span, reinforced concrete T-beam system, was 95 ft long and 45 ft wide. Scouring at the piers caused failure of the main pier supports. As a major thoroughfare carrying more than 10,000 vehicles a day the bridge could not be completely closed during construction, due to lack of alternative routes, but needed to be replaced. The focus was shifted to a temporary bridge that could carry traffic during replacement of the original structure. In April of 1996 the bridge was declared an emergency, which could expedite the repair process.

The first phase of construction was establishing the temporary bridge and demolition of the failed structure provided by CDOT emergency funding. Traffic was diverted with a temporary roadway approach to the single-span 101-ft. Acrow Corporation of America panel bridge. The panel bridge was disassembled in storage and transported to the site, which allowed for speedy construction. The bridge was retrofitted with a sidewalk, utility pipe hanger supports, and concrete abutments designed for flood-control.

Phase two was the erection of a permanent structure, which was delayed a year due to insufficient funding. The design was of a single-span structure, eliminating piers in the

water, which is supported on pre-stressed deck units. The final bridge incorporates a 12-inch water main, a 12-inch and six-inch natural gas pipeline, and telephone conduits. Final project took less than four years to complete and the cost was estimated to be approximately \$2-million. Not included in the article were incentives and disincentives.

Reference:

Krahn (2001)

Summary No. 15: I-93 Bridge, Boston, Massachusetts

During a busy Memorial Day weekend in 1999, a routine inspection uncovered deteriorating beams supporting the upper deck of the Central Artery on the I-93 Bridge in Boston, MA gave way, causing the closure of a line of traffic in each direction. Further investigation of the 47-year-old steel structure found that three of four steel beams that support the upper deck had rusted and that at least one had buckled. The weakening of the beams caused a separation in the expansion joints in the upper deck, leading to the closure. Stringer beams running along the perimeter connect support beams that run crosswise under the deck of the highway. The joints had separated by several inches after aging, overloaded beams buckled.

The problem was caused by poor construction, traffic overload, and water corrosion. Designed to handle 75,000 cars a day, the bridge was carrying 300,000 vehicles including large trucks. Construction techniques used to build the bridge have since been discredited. In addition to poorly designed expansion joints that did not keep water off of the structure below, the joint that failed consisted of steel fingers that laced together.

Two construction crews were borrowed from a near-by government site of the Perini Corporation. Repair involved 95 steel workers, engineers, and inspectors working around the clock for three days to erect new support beams, drilling holes and grinding slots in steel work to replace the beams. The bridge was re-opened by the end of the holiday weekend.

Reference:

Palmer (1998), Browning (1999), Wilmesen (1999), and Post (1997)

Summary No. 16: I-80 Bridge Denville, New Jersey

On Friday, June 22, 2001, a tanker carrying 8,200 gallons of fuel had an accident and caught fire. The fuel drained into the river and continued to burn under the bridge. This caused severe structural damage the concrete I-beams over Den Brook, resulting in the closure of the four lane simple span bridge. Upon further inspection, the intense heat cracked five of the six concrete beams supporting the westbound bridge and replacement of the deck and structural members down to the abutments were necessary.

A temporary bridge needed to be constructed while the main structure was repaired. The same day as the accident a team was sent out to analyze the situation and order a

temporary 90-foot long by 30-foot wide bridge with Acrow Corporation, a steel fabricator that specializes in temporary bridges. Only seventeen hours after the order had been made the bridge panels were delivered and work began on assembly. IEW Construction Group Inc., the contractor, worked around the clock to build the bridge, which sits above the existing structure, and finished by 2 a.m. on Monday. The structure was open to traffic five days after the accident, because grading the approaches to the temporary bridge was time consuming.

Due to time constraints to repair the main structure underneath the temporary structure, steel beams were specified. The steel beams could be rapidly obtained and ready for construction. High Steel Structures was contacted for the replacement I-beams by the New Jersey Department of Transportation and IEW Construction Group Inc. High Steel had eight beams at the construction site by August 1st, which allowed for expedient replacement of the bridge. By September 2001, the bridge was completed.

Reference:

ACROW Corporation of America (2000), Press-Release (2001) and High Steel Structures, Inc. (2001)

Summary No. 17: I-45/Pierce Elevated, Houston, Texas

The Pierce Elevated, built in 1961, had reached the end of its useful life and needed to be replaced. To mitigate motorist complaints TxDOT provided the public with extensive information prior to the start of work so that travelers could make adjustments to their routes. Money for the project was received from the federal bridge replacement and rehabilitation fund.

Demolition, by Penhall Co., removed 1.64 miles of the existing three-lane structure in just 17 days. Traylor Brothers won the construction bid, and work was contracted under a plan that called for work 24 hours a day, seven days a week with a penalty/bonus of \$53,000 per day. The decision to use pre-cast bents, constructed offsite, was made because of limited space on both sides of the construction project, the accelerated schedule, and repetitive nature of the work. Tops of the existing piers were saw cut to the appropriate elevation and the lower portions reused. The new pre-cast pier caps were anchored to the top of existing piers via post tension bar dowels. Dowel drilling and placement took an average of 2 hours per bent. Pre-cast inverted “T” caps and deck panels were used to help reduce onsite construction time. The time saving resulted in the northbound project finishing seven days ahead of the 95-day schedule. The contract for the southbound lanes, treated as a separate project, operated in much the same way. But, an additional penalty of \$3,500 per day late fee for going beyond the 325-day contract length for the entire project (north and south bound) was included. The southbound portion was re-opened 23 days ahead of schedule.

Reference:

Feldstein (1996a), Feldstein (1996b), Johnson (1997), Sallee (1997) and Vogel (1999)

Summary No. 18: I-10 San Antonio “Y,” San Antonio, Texas

The upper level of Interstate Highway 10 near downtown San Antonio was constructed from 1989 and 1992 using the “Post Tensioned Winged Segmental Design Concept” (Kelly 1995). In late March 1995, during a routine inspection, personnel found cracking of two cantilever piers. This led to the closure of the upper level holding three lanes of traffic and leaving only two lanes open. The cracking of the piers was determined to be a flaw in the earlier design.

Due to the importance of the freeway, emergency funds from the state were sought for contract traffic control, temporary shoring, and permanent repairs. It was also requested that bonding be waived because the process might delay the work.

H.B. Zachry Company, Economy Form Company (EFCO, a shoring/bracing supplier) originally constructed the elevated interstate, and was willing to help with the repair of the piers. H. B. Zachry Company and Mr. Brian Merrill from the Construction and Maintenance Division worked together to discuss the necessary repairs for shoring and bracing of the piers. The installment of temporary scaffolds would be completed in two days.

Reference:

Kelly (1995) and Neaves (1995)

Summary No. 19: NASA Road 1, Houston, TX

The Texas Department of Transportation decided that NASA Road 1 over IH 45 in Houston, Texas needed to be replaced. The existing structure, a five span, two lane, freeway underpass using non-composite steel, had too low of a clearance. The existing profile grade could not be raised and box beams provided a shallow structure depth and eliminated most deck formwork. Pilot holes were used in pile driving to place piles precisely without templates in soft clay. High performance concrete was used to pour shear keys between the beams and the concrete wearing surface. Bridge rail was slip formed as soon as the composite concrete wearing surface achieved strength.

Advantages to using the high strength concrete included the speed of construction, where elements can be placed quickly without an inordinate amount of effort. In addition, traffic disruption was minimized because trestle piles could be driven in the soft Houston clay faster than shafts could be drilled. Prefabricated elements such as pre-cast piles/columns and pre-cast pre-stressed beams were used to reduce construction time onsite. Very little formwork was required, bridge rail was slip formed as soon as the composite concrete wearing surface achieved strength. Time was also conserved by using alternative curing methods such as: the membrane cure, eliminating concrete surface treatment and permanent marking, as well as, determining the lowest concrete strength required for sequential loading.

The contract included incentive/disincentive of \$10,000/day up to \$100,000. Construction began on Thursday April 4, 2002 at 10pm. On day one, demolition of the

old structure was performed concurrently with pile driving and commenced as soon as the area around new bents was cleared. The formwork for the new bridge was completely assembled ahead of time. On day two, deck demolition continued as spans were lifted out (as a unit) for further breakdown elsewhere. Also, the third bent was also constructed on day two. Progress on day three included: beams arriving (61 hours after demolition began) and where placed, the continuation of abutment work, and overlay formwork begins as spans were still being placed. On day four, the overlay and approach slabs were poured. All construction was accomplished during a short duration and partial road closures. The existing bridge was demolished and the new bridge was completed in just 10 days.

Reference:

Vogel (2002)

Summary No. 20: Sagtikos Parkway Bridge, Long Island, New York

An oxygenated petroleum tanker and a passenger vehicle collided in early October of 1994, causing a severe fire under the southbound Sagtikos Parkway Bridge. The fire produced extreme heat and caused extensive damage to the bridge causing both the southbound Sagtikos Parkway Bridge and the Long Island Expressway underneath the bridge to be closed. Shortly after the incident, a New York State Department of Transportation (NYSDOT) team examined the bridge to determine the extent of the damages. The Sagtikos Parkway Bridge consisted of a "dual four-span bridge having six rolled steel beams" (NSBA, undated). Many of these beams, concrete decking systems and a supporting pier had suffered severe damage and needed to be replaced. Thus the decision was made to replace the entire span and pier.

The westbound lanes of the Long Island Expressway were opened to traffic, after NYSDOT found them to be safe. Temporary shoring was installed by a general contractor, which was working on a nearby State Parkway, enabling the quick opening of two eastbound lanes on the Long Island Expressway and one southbound lane on the Sagtikos Parkway Bridge.

Critical path items for putting the bridge back into use as soon as possible included: "fabricating and delivering replacement steel beams, and forming, placing and curing a concrete deck," (NSBA, undated) which all contributed to the time spent on construction of the new span. NYSDOT had an agreement for temporary emergency bridge items under a standby emergency bridge contract with a local steel fabricator. NYSDOT supplied ten W 36 x 160 rolled I-beams to the steel fabricator. These ten beams came from a NYSDOT stockpile of 12 beams that had been pre-purchased in 1988 for emergency use. Their use was estimated to have reduced the reconstruction schedule by more than two week. (NSBA, undated) Due to the extent of the reconstruction and the high volume of traffic, the expedient repairs would be implemented using staged construction.

The first stage of construction included the erection of the steel beams, placement of the Inverse composite steel beam units, as well as the installation of the steel spans. Stage 1 of the construction was completed in two weeks, only eleven weeks after the fire. Finally, the bridge fully opened within 57 days of the fire.

Reference:

NSBA (Undated)

Summary No. 21: Wantagh Parkway Bridge, New York

The Wantagh Parkway Bridge, constructed in 1929, crosses Goose Creek and was closed for emergency replacement when the New York State Department of Transportation found evidence of tidal scour, in April 1998. Upon further investigation, the bridge piers had been found to be separated from the roadbed. This separation was attributed to tidal scour causing excessive settlement of the pile foundations. Discovery "techniques included use of a narrow-beam, 200-kilohertz, research-grade Fathometer, a global positioning system accurate to within 3 feet, and a 3.5 to 7-kilohertz seismic-reflection profiler," (Strumm, 2003) as well as an acoustic Doppler current profiler. These techniques were used to delineate the tidal scour that occurred underneath the bridge.

A temporary structure was installed by the New York State Department of Transportation while a TAMS replacement design was developed. The temporary structure was constructed adjacent to the original bridge and consisted of twin 2-lane structures each approximately 1,000 feet long and constructed using an Acrow 700-XS Panel Bridge. Construction took place over three months in 2003 under a TAMS fast-tracked design. "The bridge approaches were composed of three 60-foot continuous spans, supported by 160-foot-long, 54-inch diameter concrete cylinder piles" (TAMS, 2003). Special interest was paid to concrete fascia panels, which were necessary to meet the State Historic Preservation Office's requirements.

Reference:

Newsday Staff (2002), TAMS (2003) and Strumm (2003)

Summary No. 22: I-65/I-59 Bridge Replacement, Birmingham, Alabama

At approximately 10:00 a.m. on Saturday, January 5, 2002, a gasoline tanker hit the bridge carrying I-65 southbound at the interchange of I-65/I-59 in Birmingham, Alabama and exploded into a fireball. This interchange is one of the busiest traffic flow areas in the state, with an average of 140,000 vehicles per day. The fire and subsequent heat caused the steel girders to sag up to 10 feet. Alabama DOT (ALDOT) had to close I-65 southbound and northbound immediately. After the damage assessment was finished, ALDOT concluded that the entire bridge needed to be replaced. The original bridge structure was 3-span steel girders with 120-foot center span. AASHTO, Type IV, precast, prestressed high performance concrete girders were utilized in the initial redesign of the replacement project in lieu of steel girders, due to time constraints. To accommodate future widening of northbound I-65 to include another lane and wider

shoulders, the main span length of I-59 was increased from 120 to 140 feet. This precipitated a contractor redesign to use an AASHTO-PCI modified BT-54 high performance concrete girder for the 140-foot-long center span in lieu of the AASHTO Type IV girder. In an effort to help prevent future problems, the designers included 6-foot-high crash walls. The design of the new bridge was completed within 6 days.

The \$2.09 million reconstruction contract was awarded to the Morris Group and Brasfield & Gorrie, a joint contractor venture. The contract time was set at 90 calendar days with a penalty of \$25,000 per day for finishing late and a reward of \$25,000 per day for finishing ahead of the 90-day deadline. The reconstruction began at 12:01 a.m. on Monday, January 21, 2002 with crews working two, 12-hour shifts and was completed in just 37 days, which was 63 days ahead of the original schedule. Each shift consisted of 25 people, and the crews worked several phases of the project at once. The contractors missed only 14 hours of work due to extreme weather conditions during the 37 workdays. ALDOT inspectors were on site 24 hours a day. There were 164 HP 12 x 53 steel piles driven and concrete strength testing was done whenever needed to facilitate getting the work done rapidly. Besides around clock construction, another timesaving innovation was the use of pre-fabricated concrete culvert sections to construct each of the pier footings. The culvert served a dual purpose of providing sheeting and shoring for the excavation and a form for pouring the concrete footings.

Reference:

FHWA (2003), Barkley (2002) and ALDOT (2003)

Summary No. 23: I-610 Houston Ship Channel Bridge, Houston, Texas

On Thursday, December 21, 2000, a freighter's cargo boom struck the northbound side of the Loop 610 Bridge across the Houston Ship Channel. Due to extensive damage to two of the bridge's pin and hanger supported steel girders, the northbound lanes were closed. After the inspection performed by the Texas Department of Transportation, it was evident that the crane had "impacted the bottom flange of the outside girder and tore the flange away from the web, then punched through the slab and impacted the second girder."

Repair involved removing a larger portion of the slab and post tensioning around the damaged area to carry the load of the girders where work was to take place. The damaged section was then cut away and a new section was welded in its place with additional welding at other sites of damage, while all lanes of traffic were closed. Sections of the deck were then repaired by replacing rebar sections and pouring new concrete. Construction repairs finished five days ahead of schedule and complete reopening occurred February 6, 2001, 46 days after the incident.

Reference:

Asher (2001), Urban (2000) and Vogel (2001)

Summary No. 24: Hoan Bridge, Milwaukee, Wisconsin

The Hoan Bridge, started in 1970 but not completed until 1999, failed in December 2000 causing closure to all traffic. The Hoan Bridge carried over 21,000 cars a day, therefore causing it to be a very important traffic link. Over months of laboratory testing it was determined that a combination of severely cold temperatures, heavy loads, and methods of construction involving welding the majority of bridge components caused the incident. The failure included cracking in two of the three steel beams supporting the bridge. The demolition of the damaged section of the bridge was performed using precise explosives. These explosives were placed at ends of 100-ft sections and coordinated so that the falling section would miss the municipal sewage treatment plant located below the bridge. All together the demolition of 270 feet of the bridge was removed without damaging the sewer plant below. Upon inspection other sections of the bridge were found to have minor cracks in steel webs.

As a preventive measure, small holes were drilled in the remaining girders to relieve stress on load-bearing components and stop future cracks. This allowed for reopening of the southbound structure to ease rush hour traffic. Two lanes were opened to the southbound traffic, while one lane was opened for the northbound traffic.

Rebuilding of the destroyed section and replacement of bridge joints were awarded by competitive bid with incentive/disincentive of \$5000 for each day, up to \$100,000. The project was completed in eight months and reopened in October 2001 with a total cost of \$16 million.

Reference:

JOnline (2001) and FHWA (2001)

Summary No. 25: FM 1927 over I-20, Ward County, Texas

An over height load impact that occurred in January 2003 caused serious damage to an external beam on the FM 1927 bridge over the eastbound lane of I-20. The beam was a TxDOT Type C prestressed concrete I-beam spanning 60 feet. The web and lower flange in the midspan region were severely fractured but the prestressing strands remained undamaged by the current incident. In addition, the remainder of the beam as well as the concrete deck was undamaged. The remainder of the four-span prestressed concrete beam bridge was in relatively good condition and remained open to traffic. Two repair options were considered: (1) replacement of the beam and the associated portion of the deck or (2) repair the beam by patching the concrete and adding an adhered layer of carbon fiber reinforced polymer (CFRP) for shear strength and overall beam integrity. The CFRP repair option was selected because of estimated advantages of cost, time of construction/repair, and reduced impact on traffic in the area.

The final design for the repair included the use of epoxy injection to seal cracks, the use of rapid set non-shrink multipurpose grout and rapid set non-shrink concrete to patch the beam, and the use of approximately 150 square feet of CFRP to restore shear strength and beam integrity. The repair work was awarded to V & G Contracting, Inc., Kerrville, TX,

under a negotiated Change Order to the General Maintenance Contract. V & G Contracting executed the concrete repair portion of the work (concrete patching and epoxy injection) using products from CTS Cement Manufacturing Company and a HILTI epoxy injection system. The CFRP installation was completed by Gibson & Associates, Balch Springs, TX, as a subcontractor to V & G Contracting. The strengthening portion of the repair used a Sika, unidirectional carbon fiber fabric and a compatible epoxy adhesive. The entire repair cost \$47,000 and took 5 days to complete. No incentives or disincentive were used.

Reference:

Yang (2002)

Summary No. 26: Ohio Bridge GUE-513-1.80, Quaker City, Ohio

The Ohio Department of Transportation chose to test new techniques when bridge GUE-513-1.80 that carries SR 513 over Leatherwood Creek in the village of Quaker City, Guernsey County, Ohio was scheduled for replacement. The old structure utilized a cast-in-place slab with two spans at 30'-0", for a total length of 60'-0". The new design for the 2,726 square-foot bridge includes post-tensioned (both longitudinal and transverse) precast modular deck slabs and approach slabs. Complete General Construction out of Columbus, OH performed the replacement in just 17 days, with SR 513 closing on June 16, 2003 and reopening on July 3, 2003. In an effort to ease construction, the precast bridge assembly was test fitted at the supplier's yard prior to the field installation. This allowed the individual sections to be checked for fit and joint spacing.

Complete General won the construction contract with a low bid of \$379,000 (\$139 per square foot), which was 14% below the state estimate of \$441,000 (\$162 per square foot). That contract was in the form of an A + B agreement with \$5,000 per day incentives for part B. The use of the precast, post-tensioned deck slabs saved an estimated 75 days of construction time, which equates to an estimated savings of \$150,000 in user costs. One method used to track the progress of the replacement was a web camera that displayed the work progress on an Ohio DOT website.

Reference:

Robinson (2002) and Proctor (2002)

LESSONS LEARNED

Notwithstanding their terrible consequences, the incidents described in the case studies and case summaries provide useful lessons for state DOTs that must plan for rapid responses in the event of extreme incidents. The following is a summary that highlights lessons learned from this research.

1. Quick response to a bridge damage incident is the key to mitigating losses and easing any inconvenience to the traveling public.

2. Temporary panel bridges can accommodate traffic quickly and remain in place while the permanent bridge is under reconstruction. Temporary panel bridges were seen to be effectively used in multiple events reported here-in.
3. Pre-existing contracts and procedures sped up the contracting negotiation process and avoided future contract disputes.
4. Incentive and disincentive clauses in the contracts played a very successful role to motivate design firms, contractors, and material suppliers to finish their work on time or ahead of time.
5. Less time was required to design the new structure when original design drawings and specifications were immediately accessible to designers and state DOT engineers were available to answer questions. Several instances were seen where the original designs were reused or only slightly modified.
6. It is critical to select design firms, contractors, and material suppliers that have the resources and the knowledge to accomplish replacement projects under emergency situations.
7. Using prefabricated or modular elements shortens the bridge reconstruction process.
8. Stage construction techniques minimize the disruption and/or inconvenience to the traveling public and the surrounding community during the replacement project.
9. Commitment of resources, such as manpower, from all parties including state DOTs, design firms, contractors, and material suppliers, accelerates the replacement process.
10. Flexibility in state DOTs' and other government agencies' operational and contracting procedures expedited the reconstruction process.
11. The maturity method was used successfully to expedite the concrete construction process.
12. Partnering among owners, material suppliers, and contractors is helpful in expediting the reconstruction process.
13. Minimizing the distraction during reconstruction was very important. State DOTs took responsibility to deal with all media so that the general contractor and subcontractors could focus on their repair work.
14. Selective waiving or modification of standard state DOT construction specifications, when applicable, can significantly shorten construction schedules.
15. The use of new and innovative construction materials, techniques, and work schedules can significantly shorten construction schedules.
16. Nighttime only construction was effectively used in several cases where high volume daytime traffic requirements restricted the daytime closure of the bridges.
17. The use of pre-purchased or salvaged materials that had been stockpiled for future use was shown to be effective in emergency situations.

Based upon findings of this project, the research team offers the following observations.

1. Options of using competitive bid process to select a contractor to do the repair work should remain open. However, the duration of bidding process should be kept short.
2. Durations of the emergency bridge repair projects need to be estimated more accurately. This will require state DOTs to collect data and conduct schedule analysis.
3. State DOTs should continue to search for new construction technology that could improve the reconstruction process. Areas such as underwater demolition and construction have great potential.
4. To expedite the replacement project, both state DOTs and private firms had to pull out some of their resources from existing design and construction projects. This action had negative impacts on existing projects. State DOTs need to address resource issue in their emergency response plans.

CHAPTER 4. CONSTRUCTION INCENTIVES

The incentive/disincentive (I/D) clause is a contract technique which monetarily rewards a contractor for early completion and penalizes him for late completion of a contract. After reviewing the case summaries completed during the execution of this project as well as a few other bridge repair or replacement cases that were identified but not summarized, it is apparent that the inclusion of an I/D clause in a design or construction contract generally assists in expediting the contract completion time. FHWA recommends that “incentive/disincentive provisions not be used routinely” since they should “be limited to those projects whose construction would severely disrupt highway traffic or highway services, significantly increase road user costs, have a significant impact on adjacent neighborhoods or business, or close a gap thereby providing a major improvement in the highway system.” (FHWA, 1989). It should be noted that incentives should not be random amounts but established by justifiable user and state DOT costs.

A study for by the New York State Department of Transportation reviewed 120 contracts that used A + B bidding and that included incentive/disincentive clauses. Of these 120 contracts, 103 contractors completed their work early and earned incentives in the amount of approximately \$50 million, roughly 2.5 percent of the total contract amounts. In addition, 9 contractors completed their work on time with no rewards or penalties. Only 8 contractors completed their work late and were charged penalties of \$592,000. (Kent, 2003) In addition, a number of bridge repair or replacement projects were identified that used incentive/disincentive clauses, and the majority of these projects finished early. Short summaries of these projects are provided in the following sections. The summaries give the general scope of effort, the amount of the incentive/disincentive, and the effect the I/D clause on the project completion time for the projects. In addition, these projects and their results are summarized in Table 4.1.

Table 4.1. Bridge Projects Using Incentive/Disincentive Clauses

Bridge Project	Incentive/Disincentive	Effect on Project Time
I-40 Webbers Falls Bridge, Oklahoma	Demo: \$50,000/day Design: \$5,000/\$2,400/day Construction: \$6,000/hour	Demo: On time Design: 4 days early Construction: 248 hours early
New York Thruway Bridge, Yonkers, New York	\$5,000/day	Construction finished 8 days early
Century Road Overpass over Highway 16X Alberta, Canada	\$500 per day	Construction finished on time
John Ross Bridge South Africa	R5,000 per day increasing by R1,000 per day for each additional day up to R30,000 per day maximum	Construction finished 10 weeks early

Brooklyn Bridge New York	\$45,000 per night with a penalty of \$500 per minute for exceeding the 6:00 a.m. reopening each morning	Construction finished 20 nights early and never exceeded the 6:00 a.m. reopening time
I-45/Pierce Elevated Houston, Texas	\$53,000 per day	Northbound lane construction finished 7 days early, southbound lane construction finished 23 days early
NASA Road 1 Houston, Texas	\$10,000 per day with a \$100,000 incentive cap	Construction finished 21 days early
I-65/I-59 Bridge Birmingham, Alabama	\$25,000 per day	Construction finished 63 days early
New Hope-Lambertville Toll-Supported Bridge Bucks County, Pennsylvania	\$10,000 per day	Construction finished 7 days early
I-10 Bridge over the San Jacinto River Houston, Texas	\$8,150 per day	Construction finished 35 days early
U.S. Route 22 Bridge Circleville, Ohio	\$50,000 per day	Construction finished 10 days early
SR 72 Bridge Project Lancaster, Pennsylvania	\$10,000 per day with a 20-day early maximum cap	Construction finished 22 days early
Queen Isabella Causeway, South Padre Island, Texas	\$10,000 per day with a 20-day early maximum cap, and an additional \$75,000 per day incentive for early days beyond the 20-day maximum, with a 7-day cap	Construction finished 32 days early
Pickaway County State Route 22 Bridge, Columbus, Ohio	\$50,000 per day	Construction finished 10 days early
SW Second Avenue Bascule Bridge, Miami, Florida	\$10,000 per day with a 20-day maximum incentive cap	Construction finished 20 days early

The I-40 Webbers Falls Bridge in Oklahoma required emergency reconstruction following a barge impact. Incentive/disincentive (I/D) clauses were used in the demolition, design, and reconstruction contracts of the replacement project. Oklahoma DOT contracts provided a \$50,000 per day I/D clause during the demolition phase, a \$5,000/\$2,400 per day I/D clause during the design phase, and a \$6,000 per hour I/D clause during the reconstruction phase of the project. During project execution, the demolition contractor finished on time, the designer finished 4 days early, and the

reconstruction contractor finished 10 days and 8 hours (248 hours) early. For more information see Case Summary No. 2 (CS #2) in Chapter 3.

The New York Thruway Bridge in Yonkers, New York required emergency reconstruction following a gasoline tanker crash and fire under the bridge. An I/D clause was used in the reconstruction contract in the amount of \$5,000 per day with a \$50,000 cap for early or late completion. The contractor finished the work 8 days early and received a \$40,000 award for early completion. For more information see CS #3 in Chapter 3.

The Century Road Overpass over Highway 16X in Alberta, Canada required reconstruction after impact damage from an over-height load. A penalty clause of \$500 per day was used in the contract for the repair of the bridge. The incentive to complete the project early was based on a \$500 per day site occupancy charge. The reconstruction was completed on time in the proposed three week construction period; therefore, no incentive was awarded or disincentive charged. For more information see CS #7 in Chapter 3.

The John Ross Bridge crossing the Tugela River in Natal, South Africa required replacement after a total collapse caused by a flood. The reconstruction contract included a I/D clause of R5,000 (R=Rand, South Africa currency) per day increasing by R1,000 per day for each additional day up to a maximum of R30,000 per day. The contractor finished the reconstruction ten weeks ahead of schedule. For more information see CS #9 in Chapter 3.

The Brooklyn Bridge in New York City, New York was in need of a deck replacement due to normal deterioration. The nighttime deck replacement contract was a design-build contract with a \$45,000 per night I/D clause applied to a replacement period of 150 nights. Also, a penalty of \$500 per minute for exceeding the specified 6:00 a.m. reopening time was included in the contract. The contractor completed the redecking in 130 nights and never exceeded the 6:00 a.m. reopening time. For more information see CS #10 in Chapter 3.

The I-45/Pierce Elevated in Houston, Texas reached the end of its useful life and needed to be reconstructed. The contract included a 24-hour work schedule and a I/D clause of \$53,000 per day. The reconstruction of the northbound lanes and southbound lanes were treated as separate projects. The northbound lanes were reconstructed seven days ahead of schedule, while the southbound lanes were reconstructed 23 days ahead of schedule. For more information see CS #17 in Chapter 3.

NASA Road 1 over I-45 in Houston, Texas needed to be replaced to increase freeway clearance. The reconstruction contract included an I/D clause of \$10,000 per day with a maximum incentive cap of \$100,000. Reconstruction of the new bridge was completed in 10 days, which was 21 days ahead of schedule. For more information see CS #19 in Chapter 3.

Due to extensive fire damage caused by a burning gasoline tanker, the I-65/I-59 Bridge in Birmingham, Alabama required reconstruction. A \$2.09 million reconstruction contract was awarded for the reconstruction of the bridge. Included in the contract was an I/D clause of \$25,000 per day based on the 90-day schedule. The reconstruction was completed in just 37 day, which was 63 days ahead of schedule. For more information see CS #22 in Chapter 3.

The New Hope-Lambertville Toll-Supported Bridge over the Delaware River in Bucks County, Pennsylvania required a 5-month-long, \$6.3 million rehabilitation due to normal deterioration. The rehabilitation contract utilized an I/D clause of \$10,000 per day. The bridge rehabilitation project was completed 7 days ahead of schedule. (DRJTBC, 2004)

Flooding caused scouring and other damage to the I-10 Bridge over the San Jacinto River near Houston, Texas in 1994, causing closure of the eastbound bridge. This emergency bridge replacement project was contracted for a cost of \$7.6 million with a 276 calendar day completion schedule. The contract included a \$8,150 per day I/D clause. The project was complete 35 days early and earned the contractor a maximum \$285,200 early completion bonus. (AGC, 1995)

The old 6-span bridge on U.S. Route 22 in Circleville, Ohio was reconstructed under Ohio DOT's new "Fast Track" bridge program using prefabricated materials, fast concrete curing methods and contractor I/D clauses. The contract to complete the bridge included a \$50,000 per day I/D clause. Reconstruction was completed in 50 days (10 days ahead of schedule) despite bad weather. (ODOT, 2003)

The SR 72 Bridge over the Amtrak railway in Lancaster, Pennsylvania required complete demolition and reconstruction of the existing 2-span structure along with other collateral soil, foundation, and retaining wall work. Because the bridge was determined to be a "vital link in Lancaster," the contract include an I/D clause in an effort to expedite construction. The I/D clause was in the amount of \$10,000 per day with a 20 day maximum early cap. As a result, the contractor opened the bridge to traffic 22 days ahead of schedule. (American, 2003)

The replacement of 5 spans of the Queen Isabella Causeway was required following a barge impact with the causeway in September 2001. The causeway is the sole traffic artery connecting South Padre Island to the Texas mainland, and thus, required emergency procedure to be implemented along with rapid bridge replacement techniques. The \$3.0 million, 87-calendar-day reconstruction contract included a \$10,000 per day I/D clause with a 20 day (\$200,000) maximum incentive cap. During construction, a change order added an additional \$75,000 per day incentive for any days beyond the initial 20 day maximum, up to a maximum of 7 additional days. The bridge was reopened to traffic 32 days ahead of schedule. (Ellington, 2002)

The summer replacement of the Pickaway County State Route 22 Bridge over the Scioto River near Columbus, Ohio, in 2003 was implemented due to significant deterioration of the superstructure and the desire to widen the roadway. Bridge usage and community events provided constraints for bridge closure time requirements. "The bridge could not be closed to traffic before the end of the school year in June, and had to be reopened no later than the beginning of the fall harvest in August." A \$2.7 million design-build contract was awarded to complete the project. The contract contained a \$50,000 per day I/D clause. The project was completed in just 47 days, 10 days early. (Swanson, 2004)

The replacement of the existing drawbridge crossing the Miami River at SW Second Avenue, in the busy central business district of Miami, Florida, in 2001, was precipitated by the need to widen the roadway, to increase the vertical clearance above the river, and to reduce the time required to open or close the bridge. The \$43.5 million contract was bid using the A + B method and included a \$10,000 per day I/D clause with

a 20-day maximum incentive cap. The contractor finished the project 20 days ahead of schedule and received the maximum early finish incentive award of \$200,000. (Cummings, 2004)

In reviewing the results of the above projects and the results of the survey of the 120 New York projects in (Kent, 2003), it is apparent that incentive/disincentive clauses in construction project contracts are effective in reducing the required work days to complete construction, allowing most of the projects to be completed ahead of schedule. It should be noted that the above list of projects is a result of a review of the literature and includes projects that provided general information about the project, information about the I/D clause, and information about project completion time (early, on-time, or late). Even though the majority of the identified projects showed early completion, there is the possibility that projects that ran long or had problems were just not published in the literature. However, the results of the survey of the 120 New York projects is a clear indicator of the effectiveness of the I/D clause.

Incentive/disincentive clauses are not appropriate for every construction contract but are typically reserved for projects where user costs are high and the impact on the driving public is severe. In addition, I/D limits should not be arbitrary amounts but should be based on user costs and state highway agency costs associated with inspection and administration of the project. Several references that provide guidance for selecting appropriate projects and for setting I/D limits were identified. The first reference, "Innovative Contracting Techniques that Consider Driver Impact, A+B Bidding," (Kent, 2003) is more focused on the A+B bidding concept but gives some insight on I/D clauses since they are commonly used in A+B bid projects. The next three references, "Incentive/disincentive (I/D) for Early Completion," (FHWA, 1989), "Guidelines for the Use of Time-Related Contract Provision," (NYSDOT, 1999), and "Incentive/disincentive Guidelines for Highway Construction Contracts," (Jaraiedi, 1995) all provide guidance for selecting appropriate projects, setting I/D monetary limits, and setting project and project phases time schedules. The fifth reference, "Setting Maximum Incentive for Incentive/Disincentive Contracts for Florida DOT Highway Projects," (Shr, 2001) give background information on setting I/D monetary limits and develops a quantitative model for setting the maximum limits. Use of the model is illustrated using Florida DOT project data.

CHAPTER 5. EMERGENCY RESPONSE PLAN

It is a well-established and accepted fact that advanced planning and preparation prior to any kind of emergency (natural, accidental, or terrorist-planned) can minimize the impact of the emergency. As related to the emergency response to damaged highway bridges and their repair or replacement, advanced preparation can minimize additional injury and damage immediately following the initial event by providing more organized and timely responses of the various responsible individuals and organizations. In addition, advanced planning and preparation can also minimize longer-term issues associated with damaged areas and construction zones, such as driver safety, public accessibility, and traffic congestion, as well as minimize potential economic impact on or disruption of services to the local region, state, or nation.

Advanced planning for emergencies is a multi-step process. The large number of highway bridges located in any given state along with the limited resources and man-hours available in any given year dictates one of the first steps in this multi-step process. One of the first steps is to evaluate the bridges in any given state and develop a ranked order of their criticality or priority in terms of the impact of their loss on the general driving public and the surrounding communities. The Texas Department of Transportation (TxDOT) has developed an analytical model to accomplish this task. TxDOT's model is provided in Appendix D via a paper that was presented at the June 2002, International Bridge Conference, in Pittsburgh, PA. (Rummel, 2002) This paper provides the background and development of TxDOT's model for evaluating its critical bridge assets. In addition, the paper by Rummel, et al, provides a brief discussion about secondary issues out-side-of the scope of the analytical model and the National Bridge Inventory database that must also be considered when developing a ranked order of bridges in a given state. It should be noted that the analytical model provided in Appendix E was developed specifically to evaluate and rank order bridges in Texas and should be used as a starting point and not a final tool by other states.

Once the critical bridges have been identified and a ranked order established, an Emergency Response Plan (ERP) should be developed for each critical bridge. By developing an ERP for each critical bridge prior to an extreme event, initial response times can be shortened by identifying key personnel and organizations, along with their contact information, for the specific geographic region of the selected asset. In addition, pre-coordination between these key players will yield very positive benefits in a post-event environment. The development of a variety of response plans, the acquisition of key personal information, and the acquisition of or identification of selected materials, equipment, information, and organizations associated with the selected asset prior to an extreme event will also yield very positive benefits in a post-event environment. An ERP template that addresses many of the key issues has been developed by TxDOT and is provided as Appendix E. It was initially develop for TxDOT use, and it will therefore need to be modified by individual states and adapted to their own internal structure and terminology.

A review of Appendix E brings forth the following comments and recommendations for consideration.

1. In addition to the list of attachments identified on the last page of TxDOT's emergency response template, the development of a list of "Qualified Bridge Design Consultants," who could be used on an emergency basis should be added. Even though TxDOT and other state departments of transportation (DOTs) typically have well trained and experienced bridge designers in-house, work-loads and circumstances following an unplanned extreme event could prevent or hinder the use of in-house designers during the development of the bridge repair or replacement details and could require the use of design consultants. The use of external design firms during the recovery operations following several extreme events was seen in the case summaries in Chapter 3. As an alternative, consultants could be used to take care of day-to-day issues while in-house personnel address the issues associated with the unplanned extreme event.

2. Sub-section E of Section V of Appendix E delineates the "Responsibilities" of the "Area Engineer" "following a catastrophic failure." Several of these responsibilities require the gathering of information and documents after an extreme event. It is believed that the gathering of information and documents prior to an extreme event will lead to a much more efficient and effective response to the event. By having the necessary information and documents readily available to the engineers involved in the decision making process, the engineers can focus their efforts on solving the problem not gathering data and documents. The following items should be considered for use as an Attachment to an ERP for each critical bridge identified and be developed or obtained prior to an extreme event.

A. Identify key equipment and material suppliers who can supply such items as shoring, falsework and temporary bridges that would be readily available to the site. In addition, identify and gather both general and design data on models and configurations of equipment and materials that would be applicable given the site-specific conditions of the critical bridge under consideration.

B. Identify key equipment, materials, and personnel skills that are readily available with-in the DOT or from another government agency such as an adjacent state DOT, military unit (active duty or reserve), or a nation guard unit. The list should include key personnel and contact information as well as equipment, material, and personnel locations, capabilities, and limitations as well as contact information.

C. Obtain information associated with the initial design, fabrication, and construction of the bridge. During the review of several extreme events as potential case studies, a common thread of utilizing initial design, contract, and fabrication documents and other such information during the

recovery and repair operations was seen. This information included such items as design calculations, contract drawings and specifications, shop drawings, and as-builts. Even though this type of information is typically filed for future reference, it can become misplaced or more difficult to locate as time goes along and should most probably be located and stored in the local “district” office that is responsible for the critical bridge under consideration. In addition, the utilization of contractors and fabricators associated with the initial bridge construction was seen during the review of the potential case studies, and it is recommended that they be identified and listed along with their contact information during the development of the ERP for each critical bridge.

3. A timetable should be established within the ERP document that requires a periodic review and updating of the ERP and the various attachments developed as part of the ERP, such as contact lists, equipment and materials lists, and response plans. This will assure that lists, information, and procedures provided in each ERP are current, up-to-date, and applicable. In addition, this will help to ensure that the responsible DOT personnel are familiar with and know where to locate the ERP documents, adding to the effectiveness of the ERP.

In addition to the identification of a state’s critical bridge assets and the development of ERPs for each of those assets, several pre-event emergency response preparations that are more global in nature can be utilized. First, personnel for emergency response (ER) teams can be identified and trained. There should be regional ER teams identified within and associated with specific local geographic regions or areas that will be responsible for the DOT assets within their region. In addition, a state ER team should be identified that will provide general support and guidance to the regional ER teams in a post-event environment. Once ER teams are established, contact information can be distributed within the state DOT and between the ER teams, improving pre and post-event communications. In addition, specialty training can be provided, including simulated emergency events, which is a commonly accepted practice in both the civilian and military arenas. Improved communications and pre-event train will both help to improve any post-event response and recovery.

Second, general materials and equipment can be identified, purchased, and pre-positioned at key locations around the state for use in an emergency. An example of this is the pre-purchase and pre-positioning of components of a reusable truss panel bridge, as described in Chapter 2, that could be used to provide a temporary bridge to accommodate traffic while the permanent repair or replacement is being completed. The use of a temporary bridge following an unexpected event that interrupted normal traffic flow was identified in several cases during the execution of this project. Details of three specific cases where temporary bridges were used are provided in CS #3, CS #14, and CS #16 in Chapter 3 of this report. It should be noted that these 3 cases did not use pre-purchased materials but rather had to acquire the necessary materials on short notice from the supplier. The acquisition of materials on an as needed basis adds an availability uncertainty factor into the emergency response scenario. The commitment to pre-purchase such materials helps to alleviate this uncertainty. The use of pre-purchased pre-

positioned materials was identified in CS #20 of this report where the New York State DOT had pre-purchased twelve W36 x 160 steel I-beams in 1988 and later used them in 1994 in the emergency repair of the Sagtikos Parkway Bridge in New York. (NSBA, undated) It is also the authors' understanding that the Florida DOT owns several truss panel bridges. Another example is the stockpiling of salvaged material for later use. An incident in San Antonio, Texas, prompted the Texas DOT to use salvaged W36 x 230 steel I-beams as temporary shoring when significant cracks were discovered in the main support piers of an elevated section of I-10 near downtown San Antonio. (Kelly, 1995) The salvaged beams were cut into 10-foot lengths and stacked vertically to provide temporary emergency supports. Additional information about the incident is provided in the Salvaged / Stockpiled Materials section of Chapter 2 and CS #20 in Chapter 3 of this report. It should be noted that the use of stockpiled materials (pre-purchased or salvaged) further necessitates the need for ER teams that know what is available and how to use it appropriately.

Many of the lessons that were learned from the emergency response cases reviewed in Chapter 3 of this report are incorporated into the above discussions. However, these additional thoughts should be considered during the development or execution of an emergency response plan. Anything that will shorten either the initial response or reconstruction time will be a key factor in mitigating losses. Additional examples include the use of emergency or pre-existing contracts, the inclusion of incentive/disincentive clauses, the use of prefabricated or modular elements, the use of staged construction or temporary bridging, and the waiving or modifying of standard state DOT construction specification (if applicable). It is also critical to have a commitment and the capability to provide the necessary resources (manpower, materials, and equipment) to get the job done from the key organizations associated with the recovery and reconstruction operations. Thus, it is critical to foster an attitude of "partnering" among the key organizations and to be aware of an organization's capabilities and prior commitment during the development or execution of an ERP. State DOT personnel who are authorized to make command decisions and approvals should be readily available 24-hours a day and should make every effort to minimize media distractions, allowing the contractor to stay focused on the business at hand. It should be noted that the development of well thought out and effective ERP will take a significant amount of time and effort not only of the bridge engineer but of many other key personnel within the state DOT and the local community whose expertise, cooperation, and input will be extremely valuable.

CHAPTER 6. SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

SUMMARY

The destruction of the World Trade Center buildings in September of 2001 exposed the vulnerability of domestic structures and facilities to terrorist attack. A review of terrorist targets in recent years indicates that major transportation infrastructure is high on their list. Because of this, state transportation agencies initiated efforts to investigate and develop methods to lessen the impact of terrorist attack and other extreme events on the countries critical transportation infrastructure. This process can be divided into three parts. Part one is to lessen the probability of attack on any given asset by improving security around the asset and making the asset less accessible, especially the critical components of the asset, and therefore, reducing the probability of attack. This can be done by adding fences around the asset, adding surveillance cameras throughout the area, and restricting access to critical components and secluded regions of the asset. The second part is to improve the asset's survivability should an attack occur. This can be accomplished by strengthening the assets critical components by retrofit or during initial design and construction. The third part is to lessen the impact of an attack through rapid recovery operations by advanced planning and preparation, which includes the identification and develop of emergency response procedures and rapid repair or replacement techniques. This project focuses on the later of these, lessening the impact of an attack by pre-vent planning and identification of rapid bridge construction techniques. In addition, there is a wide range of transportation assets that are susceptible to attack but this project is limited to the nation's bridges. In addition, it soon became apparent that there are a large number of extreme events, other than terrorist attack, that affect the nation's bridges, including vehicle impact, fire, and forces of nature. Therefore, the scope of the project was expanded to include any extreme event, not just terrorist attack.

This project was initiated as a TxDOT funded project in spring of 2002 but was transitioned to a TxDOT-led transportation pooled-fund study in the summer of 2002, obtaining funding support from 9 states. The primary focus of this project was to identify rapid bridge replacement and repair techniques that could be used during recovery operations, following an extreme event, to lessen the effects of the event on the surrounding community. This was accomplished by an extensive review of the literature, individual contacts, and site visits; both civilian and military. Information about the applicable rapid bridge replacement and repair techniques and materials that were identified during this project is provided in Chapter 2 of this report. The techniques and materials in Chapter 2 are divided into 6 categories: superstructure, bridge deck, substructure, member/element repair, floating bridges, and construction/contractor techniques. Background and contact information on each technique and material in each of the 6 identified categories is provided in Chapter 2. Due to the magnitude of material provided in Chapter 2, these materials and techniques were also summarized in various tables within Chapter 2. In addition, a Repair and Replacement Technique Quick Reference is provided in Table 6.1 of this chapter. Table 6.1 identifies each category,

identifies each material or technique in the category, and references the table in Chapter 2 where the material or technique is summarized.

Table 6.1 Repair and Replacement Technique Quick Reference

Category	Company / Material / Technique	Summary Table
Superstructure	AASHTO-TIG: Prefabricated Bridges Publications (13 summaries) Innovative Projects (8 summaries) Research Projects (2 summaries)	Table 2.1 Table 2.2 Table 2.3
	Acrow Corporation: Panel Bridge – 700XS Swift Beam Bridge	Table 2.4
	Bailey Bridges, Inc.: M2 Panel Bridge	Table 2.4
	Big R Manufacture: Modular Bridge	Table 2.4
	Hamilton Construction Co.: EZ Bridge	Table 2.4
	Fort Miller Co.: Inverset Bridge	Table 2.4
	Mabey Bridge and Shoring, Inc.: Universal Panel Bridge Compact 200 Panel Bridge Quick Bridge	Table 2.4
	Steadfast Bridge Co.: Vehicular Truss Bridge	Table 2.4
	U.S. Bridge: Truss Bridge Beam Bridge	
	U.S. Military Bridges: Dry Support Bridge Rapidly Emplaced Bridge System	Table 2.4
Deck	AASHTO-TIG: Prefabricated Decks Publications (16 summaries) Innovative Projects (17 summaries) Research Projects (2 summaries)	Table 2.5 Table 2.6 Table 2.7
	Alfab, Inc.: AM2 Aluminum Landing Mats	Table 2.8
	Creative Pultrusions, Inc.: Superdeck	Table 2.8
	CTS Cement Manufacturing Corp.: Rapid Set	Table 2.8

	Exodermic Bridge Deck, Inc.: Exodermic Panel	Table 2.8
	Garon Products, Inc.: Hy-Speed 500	Table 2.8
Deck (continued)	GeoCHEM, Inc.: PERCOL	Table 2.8
	Mabey Bridge & Shore, Inc.: Mabey Mats	Table 2.8
	Rapid Mat US LLC: Rapid Mat	Table 2.8
	U.S. Army COE, WES: REMR Technical Note CS-MR-7.3	Table 2.8
	Soloco, LLC: Dura-Base Composite Mat System	Table 2.8
	Strategic Highway Research Program: Very Early Strength Concrete Overlays High Early Strength Concrete Overlays	Table 2.8
	The Fort Miller Co., Inc.: Effideck Super-Slab	Table 2.8
	Substructure	AASHTO: Construction Handbook for Bridge Temporary Works Guide Design Specs. for Bridge Temporary Works
Acrow Corporation: Superprop Shore Truss Panel Tower		Table 2.9
California DOT: California Falsework Manual		Table 2.9
EFCO Corporation: Shore Tower Super Stud		Table 2.9
Mabey Bridge & Shore, Inc.: Heavy Prop Mass 50 & Mass 25 Systems Truss Panel Tower		Table 2.9
Salvaged / Stockpiled Materials		Table 2.9
Scaffolding and Shoring Services		Table 2.9
AASHTO-TIG: Prefabricated Substructures Publications (5 summaries) Innovative Projects (11 summaries) Research Projects (2 summaries)		Table 2.10 Table 2.11 Table 2.12
Member / Element	Epoxy Injection	Table 2.13

Repair	Fiber Reinforced Polymer Strengthening / Repair	Table 2.13
	Prestressed Concrete Beams: Evaluation and Repair	Table 2.13
	Steel Girders: Evaluation and Repair	Table 2.13
Floating Bridges / Floating Supports	United Defense Corp.: Upgraded Std. Ribbon Bridge	Table 2.15
	Mabey Bridge & Shoring, Inc.: Uniflote	Table 2.15
	Robishaw Engineering, Inc.: Flexifloat	Table 2.15
Contractor / Construction	Construction Work Schedule: 24-hours 12-hours Nighttime only	Table 2.16
	Innovative Contracting: A + B Bidding	Table 2.16
	Mammoet USA, Inc.: Heavy Lifting Systems	Table 2.16
	Maturity Method for Estimating Concrete Strength	Table 2.16
	Roll-in Construction	Table 2.16
	Staged Construction: Using existing parallel bridge Using temporary bridge	Table 2.16
	Waive Standard Construction Specification	Table 2.16

This project also sought to identify lessons learned from recovery operations of previous extreme events. This was accomplished by conducting three in-depth case studies and reporting their results. These three cases were selected due to their unique and diverse characteristics and recovery approaches. The approach, methodology, and results of the three cases studies are summarized in Chapter 3 of this report, with the full case studies provided as Appendix A, B, and C of this report. The first case study addresses the May 1998 fire incident associated with the I-95 Chester Creek Bridge in Pennsylvania. The second case study addresses the May 2002 barge impact incident associated with the I-40 Webbers Falls Bridge in Oklahoma. The third case study addresses the October 1997 fire incident associated with the New York State Thruway Bridge at Yonkers, New York. In addition, the scope of the project was expanded to include short case summaries of 23 additional extreme events that were identified during the execution of this portion of the project in an effort to maximize the effectiveness of

the report and to provide additional resources should the reader desire further information.

This project also sought to evaluate the effectiveness of incentive/disincentive (I/D) clauses in construction contracts associated with rapid bridge replacement and repair projects. The approach and results of this portion of the project are provided in Chapter 4 of this report. Survey results of 120 New York State DOT contracts that utilized A+B bidding and that included I/D clauses indicated that 103 contractors completed their work early, 9 contractors completed their work on-time, and 8 contractors finished their work late. (Kent, 2003) In addition, eight of the case summaries provided in Chapter 3 of this report provided data on I/D clause amounts and their affect of finish time. Of these 8 case summaries, they all either finished early or on time with the majority of them finishing early. Seven additional cases were identified with sufficient I/D clause data and time affect information. They are also included and summarized in Chapter 4 of this report, with their results similar in that all seven contractors finished early. Also provided in Chapter 4 are five references that give guidance to implementation of contracts with I/D clauses, including selecting appropriate projects, setting I/D monetary limits, and setting project time schedules. (Kent, 2003, FHWA, 1989, NYSDOT, 1999, Jaraiedi, 1995, and Shr, 2001)

This project also sought to provide guidance on the importance of advanced planning and preparation as applied to improving DOT response to any extreme bridge event (natural, accidental, or terrorist-planned). Detailed information on this topic is provided in Chapter 5 of this report. Due to the large number of bridges in state DOT inventories and the limited resources available to apply toward these bridges, the first pre-event planning step is to evaluate a state's bridge inventory and to identify and to rank order the critical bridges in the state. An analytical model developed by TxDOT personnel to accomplish this task was identified and provided in Appendix D of this report. (Rummel, 2002) Development of a rank order of a state's bridge inventory is useful to allocate state resources to the protection and recovery planning of the more critical bridges. Once a ranked order critical assets list is develop, Emergency Response Plans (ERP) can first be developed for the most critical assets followed by the development of ERPs for less critical assets in subsequent years. A template for an ERP was developed by TxDOT personnel and is provided as Appendix E of this report. Additional comments about and suggestions for revisions to Appendix E are provided in Chapter 5 of this report. In essence, an ERP should be developed for each identified critical bridge and should include: 1) general procedures to follow prior to an event should a creditable threat be established and immediately after an extreme event happens, 2) lists of key personnel and corresponding contact information, 3) defined responsibilities for the key personnel, 4) identify materials, techniques, and equipment as well as contractors and suppliers associated with these items that are necessary to repair or replace the critical asset, 5) pre-developed plans addressing traffic control and detours as well as debris management, and 6) copies of documents and lists of companies associated with the design and construction of the bridge (design calculations, contract drawings and specifications, shop drawings, as-builts, design consultant contacts, and contractor contacts). State DOTs should also establish Emergency Response Teams at the local and state levels, identifying and training key response personnel. In addition,

pre-event planning can also include the pre-purchasing and pre-positioning of generic and adaptable bridge components for use following an extreme event.

CONCLUSIONS

The following conclusions are drawn from this research project.

1. There is no “silver bullet” that is applicable to the rapid repair of all bridges following any extreme event. There are too many variables including: type of bridge; bridge dimensions and geometry; type of event (natural, accidental, or terrorist); amount and type of damage; what element is damaged; size, magnitude, and location of debris field; and local conditions such as bridge accessibility, material and equipment availability, traffic demand on bridge, and availability of alternate traffic routes. The “best” repair or replacement procedure will have to be determined on a case-by-case basis once a specific scenario is defined for a given asset.
2. Rapid replacement of critical bridge assets can be broken into 3 categories: pre-event planning, post-event temporary traffic, and post-event permanent repair or replacement. Pre-event planning is addressed in Chapter 5 and includes; the identification of critical bridges within the state, the development of an Emergency Response Plan for each identified critical bridge, the development and training of Emergency Response Teams at the local and state levels, and the pre-acquisition and pre-positioning of generic adaptable bridges and bridge components. Following an extreme event, it is important to re-establish the flow of traffic, at some acceptable level, as soon as possible. This can be accomplished by using temporary repairs, temporary detours, or temporary bridges or some combination of these. The use of these temporary methods and the re-establishment of some level of traffic flow provides state DOT engineers additional time to evaluate, plan, and coordinate the permanent repair or replacement of the damaged asset. Techniques and materials associated with the temporary and permanent repairs and replacements of bridges or bridge elements are addressed in Chapters 2 and 3 of this report.
3. The effective use of temporary repairs, elements, or structures is dependant of the short-term availability of materials and components, which could require state DOTs to pre-purchase, stockpile, and pre-position some materials and components in preparation for an extreme event. If these materials or components are stockpiled and pre-positioned, it is important to have a state-level Emergency Response Team established that know what’s available and where it’s located as well as that is adequately trained in the proper use of the material.
4. A significant and successful engineering effort has focused on the rapid replacement and repair of bridges over the last 10 years to minimize the impact of construction on the general driving public. However, these efforts have been primarily focused on planned and controlled scenarios in lieu of unplanned extreme events. None the less, many of these materials and techniques are applicable to unplanned events if temporary traffic can be re-established at some reasonable level to permit time for the planning, coordination,

and prefabrication of components to occur. Many of the techniques and materials addressed in Chapter 2 and 3 utilize prefabricated bridge elements and systems that can be adapted to rapid bridge construction following an extreme event. The AASHTO-TIG website (AASHTO-TIG, 2001) is a significant resource for the development and use of prefabricated bridge elements and systems and much of its information was summarized in Chapter 2 of this report.

5. Two dominant manufacturers of commercially available modular panel truss bridges were identified, Acrow Corporation of America and Mabey Bridge and Shore, Inc. This type of bridge is composed of a number of modular units and members that are bolted and/or pinned together in a large number of configurations to accommodate various span lengths, roadway widths, and load applications. These bridges can typically be crane lifted into place or cantilevered-launched from one abutment. Their modular parts can also be reconfigured for shoring applications giving them additional flexibility and versatility. Panel bridges and their components, from both companies, have a high potential for use as temporary bridges and temporary shoring and as pre-purchased and pre-positioned materials for emergency applications due to their flexibility, adaptability, and re-use capability. If panel truss bridges and its components are purchased from either manufacturer for pre-positioning and future emergency use, it will be imperative that the state DOT develop and train an emergency response team knowledgeable with their proper use and installation.

6. There were several rapidly placed bridges developed for or by the U. S. military that were identified and considered during the progression of this project but they tend to require specialty equipment for installation or have less adaptability with respect to geometric configurations and load applications. In addition, it appears that the Mabey panel bridge is now widely used by the U. S. military for bridge restoration in war zones. The use of Mabey bridges over Acrow bridges by the U. S. military is thought to be primarily due to availability in the recent theaters of operation. Acrow and Mabey bridges and products are both domestically available in the U. S.

7. A large number of applicable rapid bridge deck repair and replacement materials and techniques were identified and summarized in Chapter 2. Their use applicability is dependant on the type and extent of damage to the existing bridge deck, which can range from minor cracking and surface spalling of concrete to total deck replacement. Products and techniques include; surface mats to improve ride quality while permanent repairs are being planned and executed, high early strength and very early strength materials for surface patching and total deck overlays applied during the night, partial-depth and full-depth prestressed deck panels to expedite reconstruction, and proprietary products like Exodermic deck panels to expedite deck construction. All of these products were found to have applicability for various types and levels of deck damage and will have to be considered on a case by case basis.

8. A large number of applicable guidelines and products addressing shoring were identified and summarized in Chapter 2 along with a large number of prefabricated substructure applications from the AASHTO-TIG. Four manufacturers of shoring

products were identified; Acrow Corporation, EFCO, Mabey Bridge and Shore, and Scaffolding & Shoring Services. All four have shoring products that are modular units that can be connected in various configurations to meet a range of geometries and loads. The one advantage that Acrow and Mabey hold over the other two is that many of their panel truss bridge components can also be used in shoring applications give them dual usage, making them more cost effective for pre-purchase, pre-positioning applications.

9. Three dominant member/element strengthening or repair techniques were identified and included in this report; epoxy injection of concrete members, fiber reinforced polymer strengthening or repairs of concrete members, and heat straightening of steel members. These techniques are well established with a large amount of technical guidance and contact information available. This information is summarized in Chapter 2 and is provided along with technical guidance and contact information. In addition, several significant reports addressing the evaluation and repair of damaged prestressed concrete and steel member were found. Report access information is also provided in Chapter 2.

10. The use of three modified construction work schedules (24-hour, 12-hour, and nighttime only) was found to be commonly associated with and effective during rapid or restricted bridge replacement construction projects during the execution of this research project. Issues that should be considered during selection of the appropriate work schedule include; 1) increases in construction costs associated with accelerated schedules or non-normal work hours, 2) decreases in user and state DOT costs associated with shorter out-of-service periods, 3) changes in costs and problems associated with inspections, problem solving, and material deliveries during typical off-duty hours, and 4) loss of worker productivity, quality control, and safety during non-standard work hours.

11. The use of the Maturity Method for estimating concrete strength was found to be effective in the acceleration of construction schedules. This method uses a temperature-time value of in-situ concrete to predict the concrete's strength and typically permits shorter form removal and non-loading periods than does the conventional cylinder tests and standard specification method, thereby speeding up construction. Additional information about this technique and guidelines for its proper use are provided in Chapter 2 of this report.

12. Staged construction was found to be effectively used in several rapid bridge replacement projects identified and summarized during this research project. Staged construction can use temporary bridges or portions of existing bridges to maintain an acceptable volume of reduced traffic flow during bridge repair or replacement work. Several identified projects that used staged construction are discussed in Chapter 2 of this report and then summarized in Chapter 3.

13. Waiving of selective standard construction specifications can be used effectively to shorten bridge replacement schedules. Standard construction specifications are commonly used throughout the United States and serve a very important purpose; to insure quality control and structural strength and integrity. However, in some cases, they

can be overly conservative and can add significant time, unnecessarily, to the construction schedule. The standard specification should not be arbitrarily waived but only when justified by sound engineering judgment. Several examples where waiving of standard construction specifications shortened construction schedules associated with bridge replacement projects were identified during this research project. These examples are discussed in Chapter 2 of this report and the projects are summarized in Chapter 3.

14. Incentive/disincentive (I/D) clauses in construction contracts provide positive affects on construction schedules. By far, the majority of cases identified in Chapter 4 that implemented I/D clauses finished ahead of schedule. I/D clauses are not appropriate for every construction contract but are typically reserved for projects where user costs are high and the impact on the driving public is severe. Monetary and time limits associated with I/D clauses are not arbitrary but require good engineering judgment and good data on user and DOT costs associated with the project. Several references providing guidance on project selection and setting of I/D monetary and time limits is provided in Chapter 4 of this report.

15. A partnering attitude and a commitment of resources from all parties involved (state DOT, design firm, contractor, material suppliers, and the like) are critical to the successful completion of any rapid bridge replacement project. Several cases addressed in Chapter 3 of this report demonstrate truly amazing results when this combination of attitude and commitment was maintained throughout the projects' recovery operations and construction processes.

16. The A+B bidding technique has been shown to be an effective tool in shortening certain types of construction contracts. The "A" component provides the cost of the project, and the "B" component provides the time schedule required to execute the work. This technique encourages "contractors to more actively manage their work schedule and, when necessary, to adopt innovative and aggressive scheduling and construction management processes." (Kent, 2003) This brings the contractors expertise into play in the reconstruction process and helps to shorten reconstruction to the benefit of the driving public. The A+B bidding technique is typically applicable to a bridge that is on a state DOT's critical list. Guidance for use of the A+B bidding technique is provided in Chapter 2 of this report.

17. Advanced preparations prior to an extreme event will yield positive results during recovery operations in which a damaged asset is returned to full operational capacity. Advanced preparations include: 1) development of Emergency Response Plans for identified critical assets, 2) development and training of Emergency Response Teams at the state and local levels, and 3) acquisition and pre-positioning of generic, adaptable and/or reusable bridges or bridge components. These issues are discussed at length in Chapter 5 of this report.

RECOMMENDATIONS

Recommendations developed during the execution of this project include the following:

1. Each state DOT should develop a ranked order of critical bridges in its inventory using the guidance provided in Chapter 5 of this report. Once the ranked order of critical bridges is developed, an Emergency Response Plan (ERP) should be tailored for each of the more critical bridges identified using the guidance also provided in Chapter 5.
2. At a minimum, each state DOT should establish and train an Emergency Response Team at the state level to respond to and help engineers at the regional level respond to any extreme bridge event. In addition, Emergency Response Teams (ERT) at the regional level should also be established and trained to respond to extreme bridge events in their region. Regional ERTs will typically be one of the first responders and should be knowledgeable of the ERP for any critical bridge in their region.
3. One of the initial and important responses following an extreme event is the resumption of a reasonable volume of traffic flow, temporary traffic. In the cases studied during this project, this was often dependant of the availability of temporary bridge and components as well as other support material and equipment. To insure availability, it is recommend that state DOTs consider the pre-purchase and pre-positioning of adaptable, versatile, and reusable temporary bridging and bridge components. Future research will be required by each state DOT to determine the best mix and quantity of bridge components for pre-purchase as well as determination of the best pre-position location within the state.
4. Because of their overall adaptability, versatility, and reusability as well as their availability in the U. S., the Acrow and Mabey panel truss bridges have a very high potential for effective use by state DOTs for pre-positioning applications, and they receive a recommendation for high consideration of the state DOTs for their use.
5. More data in needed to better predict costs and time schedules association with accelerated bridge construction. It is recommended that state DOTs compile or collect cost and time data of past, current, and future rapid bridge replacement projects for additional evaluation and future use.
6. The A+B bidding technique has been shown to be effective in shortening construction schedules of bridge replacement projects, and its use will often be applicable to projects on a state's critical bridge list. Therefore, state DOT consideration of its use is recommended.

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Appendix A
Case Study of
I-95 Chester Creek Bridge Replacement Project

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Bridge Incident

A gasoline tanker-truck owned by the Samuel Coraluzzo Company of Vineland, New Jersey, hauling 8,700 gallons of fuel and traveling northbound on Interstate 95 (I-95), crashed through the concrete median barrier and exploded after striking a pickup truck traveling southbound on I-95 on the bridge over Chester Creek in Delaware County, Pennsylvania, at about 7:00 a.m. on Saturday, May 23, 1998. Figure 1 shows a sketch of the incident site. The explosion caused a fireball and the charred bridge buckled under intense heat exceeding 2,000°F. The Pennsylvania Department of Transportation (PennDOT) immediately closed I-95's three northbound and three southbound lanes between I-476 and State Route 452 because of the fear that the bridge might be unsafe for the traveling public. The timing of the accident was worse since it was the start of the Memorial holiday weekend. Traffic backups stretched for miles as motorists clogged alternate routes. The fire-damaged bridge on I-95 normally carries 80,000 vehicles per day and is among the most heavily traveled corridors in the United States. The tanker-truck driver, Keith Thomas, and Michael Mazzola who drove the pickup passing the accident site, were killed. Bobby Hill, a New Jersey resident who drove a Starr Tours bus from Trenton, had minor injuries.

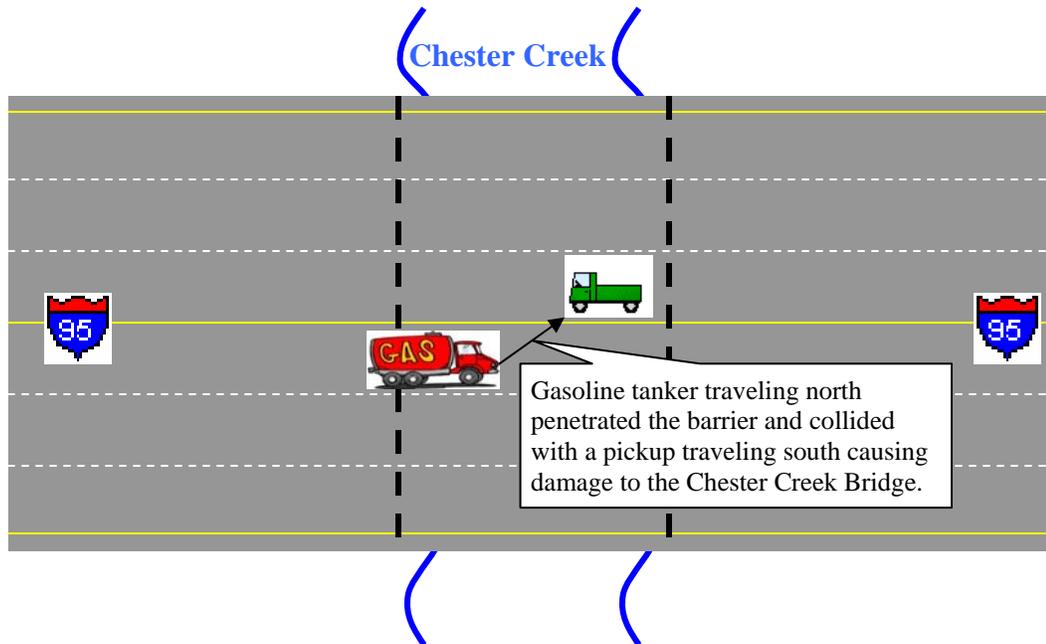


Figure 1 Sketch of Incident Site

Damage Assessment

The 360-foot long, 3-span continuous bridge was built by the Buckley and Company, Inc. of Pennsylvania in 1965. The superstructure of the bridge includes steel girders and frames with a concrete deck. The steel girders were supported by concrete piers. There are three traffic lanes both in northbound and southbound directions. PennDOT bridge engineers evaluated the bridge just after the accident and declared that the southbound structure was unsafe due to severe damage caused by the fire and that the northbound structure was undamaged. The flames scorched most of the 360-foot long concrete deck and caused the steel superstructure to sag, but not collapse. Three of the four 360-foot long steel girders on the bridge had damaged sections. Each girder was made of five segments welded together.

Three segments on each of the three damaged girders required replacement. Nine girder segments under the southbound lanes of the bridge were damaged. Each girder segment was 6 feet, 8 inches high and between 65 to 80 feet long and required special fabrication, along with reinforcing rods and steel pans for the bridge deck. Part of the concrete deck needed to be torn down and rebuilt. Approximately two-thirds of the superstructure needed to be replaced. The foundation of the bridge was not damaged. The substructure had one pier, which required some minor concrete repairs with Gunite.

Detour and Temporary Transportation

PennDOT established detours for northbound and southbound traffic as soon as it closed I-95's three northbound and three southbound lanes between I-476 and State Route 452. Southbound drivers were instructed to first exit I-95 at I-476, take I-476 north to exit 3, go Route 1 south to Route 452, and then follow it south back to I-95. Southbound long-distance travelers were to take exit 15 at I-95 to I-76 east over the Walt Whitman Bridge, then exit 1A for I-295 south over the Delaware Memorial Bridge and back to I-95. Northbound drivers were instructed to take Route 452 north to US Route 1 north, then go to I-476 south and back to I-95, or take Route 202 north to US Route 1 north to I-476 south and back to I-95. PennDOT instructed northbound long-distance travelers to bypass the area entirely by taking I-295. The detour map is presented in Figure 2.

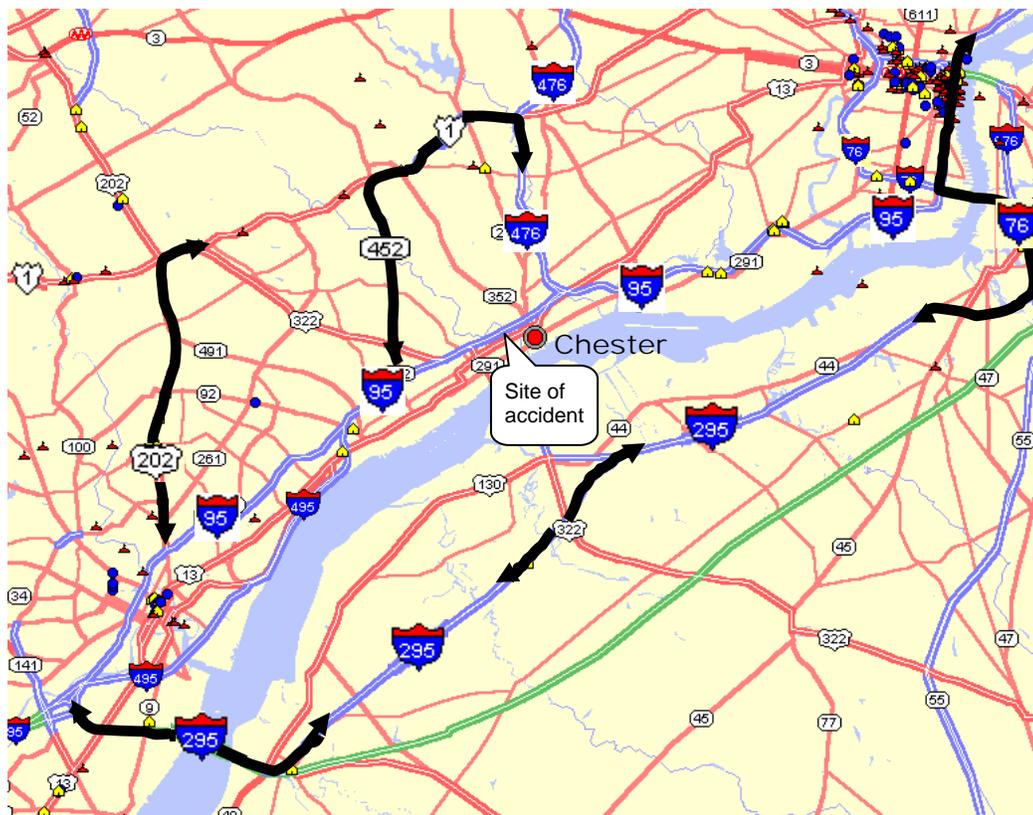


Figure 2 Detour Map

Just hours after the crash, Governor Tom Ridge of Pennsylvania declared a disaster emergency. The declaration allowed government agencies such as PennDOT to expedite their response to the accident in order to protect public health and safety. The declaration set aside the normal government constraints, allowing agencies to hire, purchase and contract without following the usual government rules and regulations. The Secretary of PennDOT immediately awarded the repair contract to Buckley and Company, Inc., who built the original bridge and had previously successfully repaired a similar project. The repair work included two major parts. First, the contractor built four temporary traffic lanes to reopen I-95 to the traveling public before Monday, May 25. Second, the contractor replaced the damaged bridge and reopened six lanes of I-95 by July 15, 1998 (original finish date). Buckley was paid on a time-and-materials (force account) basis with mark-ups specified in the PennDOT's standard specifications PUB 408. Subcontractors were also paid on a time-and-materials basis and Buckley received 8% mark-up on top of subcontractors' costs. All overtime wages were paid directly with the standard PennDOT mark-up of 40% applied labor. Material suppliers were paid using lump sum contracts.

Building temporary traffic lanes began Saturday evening on May 23. Buckley along with several subcontractors and PennDOT crews made temporary crossovers. Nearly 200 construction workers labored throughout Saturday night and for much of Sunday to remove about 140 concrete median barriers. Each barrier was 34-inch high and weighed two tons. A three-quarter mile stretch was modified to carry two lanes in each direction using the northbound side of the I-95. The width of each lane was 11 feet instead of normal width of 12 feet. Figure 3 shows a sketch of temporary traffic lanes at incident site. Two temporary lanes of northbound I-95 opened to traffic on Sunday, May 24 at 1:15 p.m. At 3:55 p.m. of the same day two temporary southbound lanes reopened to the traveling public. The 40-mph speed limit was implemented and monitored closely by state police. With four temporary lanes in service before Monday, May 25 when substantial increases of holiday traffic would occur, PennDOT and Buckley shifted their focus to replacing the 360-foot long, 3-span continuous bridge.

Design for Replacement

The replacement was identical to the original bridge, which was designed by Sanders and Thomas, Inc., a design firm in Florida. The shop drawings necessary for fabrication were found in PennDOT's bridge archives and provided to Buckley. Since the repair work used the original shop drawings, there was no need for PennDOT to approve the drawings. This saved considerable time during the replacement process. Some requirements in the standard specifications were waived based on engineering judgments in order to expedite the replacement process. For example, all time-based specifications for concrete maturity were waived and 50% of the ties in the bottom rebar for the bridge deck were waived.

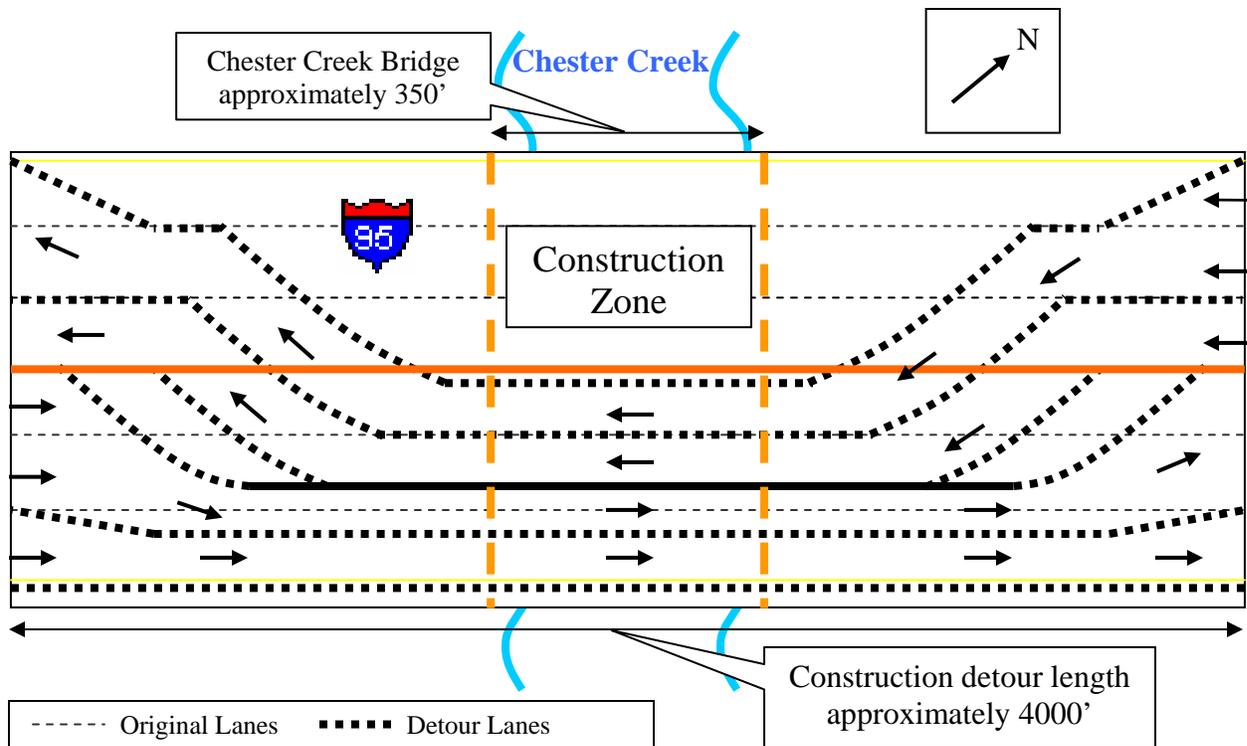


Figure 3 Sketch of Temporary Traffic Lanes at Incident Site

Bridge Replacement

The entire replacement was conducted in three stages. The stages were demolition, material preparation, and reconstruction. Demolition and material preparation were performed simultaneously. On May 29 Buckley along with Eastern-States Wrecking Company started to remove the 52-foot wide concrete deck and work was completed by June 2. Over the next two days crews removed nine damaged steel girder segments and set the stage for reconstruction. Demolition was carried on 7 days per week and 12 hours per day.

Shortly after receiving the repair contract, Buckley contacted High Steel Structures, Inc. of Lancaster, Pennsylvania on Sunday, May 24 to determine if the company could fabricate the replacement girder segments with cross frames under very tight schedule. The fabrication and delivery of the steel beams were the critical activities in the replacement process. The response from High Steel was yes. To meet the schedule requirement, which was to deliver the nine girder segments by June 15, High Steel was planning to work around the clock and reschedule other work. On May 26, after examining the bridge drawings, High Steel ordered the steel material needed for the replacement girder segments from Bethlehem Steel Plant in Sparrows Point, Maryland. The response from Bethlehem Steel was also very quick. On Friday, May 29 High Steel was able to begin taking delivery on the steel plate. That night High Steel production crews began working 24 hours a day, seven days per week, on the project. The fabrication of nine, 65 to 80 foot long girder segments, each standing 6 feet, 8 inches high, weighing 15 to 20 tons, was completed in only ten days, which was seven days ahead of the original delivery date of June 15. Normally, this amount of fabrication work would take three to four weeks to complete. Under the Pennsylvania State Law, High

Steel can only ship one girder per load. A special permit was granted by the Governor to allow High Steel to deliver three girders per load in order to expedite the reconstruction.

Buckley installed the nine steel girder segments on June 8 and 9. After that, construction crews set 14-foot wide steel deck pans between the four rows of girders. Next, reinforcing bars were installed in place for the concrete deck. A total of 38 truckloads of concrete were placed to form the new 10-inch deck on Tuesday, June 16. While the concrete cured, construction crews poured new parapet walls on the bridge. The compressive strength of the concrete deck exceeded the required 4,000-psi less than a week after the deck pour. On June 25, PennDOT moved two lanes of traffic back to southbound I-95 before the start of the morning rush. Interstate Safety Services of Clarks Summit, Pennsylvania supplied 2,800 feet of new concrete barriers to replace the road's central median on June 27, which was two days ahead of schedule. Installation of the median started the following day. During the reconstruction process, construction was conducted 12 hours per day and 7 days per week. Because of the good weather, hard work, and quick delivery of supplies, the bridge was reopened to the public on June 29. Buckley continued to perform structural work underneath the bridge after the traffic had been restored and all repair work was completed on Friday, July 3, 12 days ahead of the original target date of July 15. Based on past experience, similar repair work like this would require approximately 6 months under normal conditions. If using conventional bidding procedures, the entire repair process could take even longer. Table 1 presents the major events during the repair process. Officials from PennDOT stated that the repair project cost less than the original \$4,000,000 estimate. Buckley received \$500,000 overtime pay.

Table 1 Date for Major Events

Date	Events
05/23/98	Accident occurred.
05/23/98	PennDOT awarded repair contract to Buckley & Company, Inc.
05/24/98	Two temporary lanes in each direction opened to traveling public.
05/24/98	Buckley awarded steel girder fabrication to High Steel Structure, Inc.
05/26/98	High Steel ordered steel material from Bethlehem Steel.
05/29/98	High Steel started to receive steel plate.
05/29/98 to 06/02/98	Demolition of the 52-foot wide concrete deck.
06/03/98 to 06/04/98	Remove nine sections of fire-damaged steel girders.
06/07/98	Fabrication of nine girder segments was completed.
06/08/98 to 06/09/98	Buckley installed the steel girders.
06/16/98	New 10-inch concrete deck was poured.
06/25/98	PennDOT moved two lanes of traffic back to southbound of I-95.
06/27/98	Interstate Safety Services delivered 2,800 feet concrete road median.
06/28/98	Installed the concrete road median and mark traffic lanes.
06/29/98	Bridge was reopened and traffic was restored.
07/03/98	Entire repair work finished. 12 days ahead of original schedule.

Lessons Learned

There were many factors contributing to the success of the repair project. In order to document what can be learned from this project, the research team conducted this case study. During the study, the research team reviewed literature including information posted on web sites, interviewed people involved in the repair project via the telephone, and performed surveys. The survey questionnaire, which was sent to PennDOT and Buckley & Company, Inc., consisted of questions in five aspects including contracting method, engineering, construction, PennDOT support (to Buckley only), and material supplier and vendor. The responses of the survey are attached at the end of this report. Notwithstanding its terrible consequences, the I-95 Chester Creek Bridge incident provides useful lessons for state DOTs that must plan for enhanced responses in case of future incidents. The following is the summary that outlines lessons learned during the reconstruction of the bridge.

1. The Secretary of PennDOT was able to award the repair contract without bidding it under the state emergency declaration. This saved considerable time for the reconstruction of the bridge.
2. Using established contracting documents, which is the time and materials plus mark-up percentages that are specified in PennDOT's standard specifications PUB 408, speeded up the contracting negotiation process and avoided future contracting disputes.
3. Temporary traffic lanes should be constructed first, and made available to the traveling public as soon as possible. Doing this will reduce the pressure of traffic congestion and ease the inconveniences of traveling public.
4. Utilizing the state police to enforce the speed limit in the temporary traffic lanes provided a safe environment for bridge repair activities.
5. Plans and shop drawings were available in the PennDOT's bridge archives and provided to the contractor and material suppliers immediately. Without the complete plans and drawings, the repair process could take much longer.
6. Some requirements of the specifications, such as time-based specifications for concrete maturity and 50% ties in the bottom rebar for the bridge deck, were waived based on the engineering judgments to expedite the repair process.
7. Commitment and dedication of the necessary resources from all the parties made the repair project a success. Buckley had ample resources to complete the work, which was one of the main reasons PennDOT selected Buckley to do repair work. PennDOT's chief construction engineer was on site all the time, so decisions were made on the spot without a formal submission process.
8. The most critical activity in the repair process was the fabrication of the steel beams. The steel fabricator rearranged the existing fabrication schedules and worked 24 hours per day and 7 days per week to support the project. The standard inspection functions required on PennDOT projects were performed at the steel plant and fabrication shop. Those beams were delivered ahead of the original anticipated schedule.
9. Under the Pennsylvania State Law, the material supplier was allowed to ship only one steel girder per load. To expedite the reconstruction, the Governor of Pennsylvania granted permit which allow the supplier to ship three girders per load. The effort not only speeded up the material delivery and but also saved cost.

10. The general contractor and subcontractors were very organized and efficient. Numerous repair operations were conducted concurrently. The general contractor had great confidence on the performance of subcontractors and material suppliers.
11. PennDOT took responsibility to deal with all media and let the general contractor and subcontractors focus on their repair work.

Although the repair project was finished 12 days ahead of the original schedule with a good quality and safety record, there are areas, which could be improved in the future. Considerations for the future improvement are summarized as follows.

1. Options of using competitive bid process to select a contractor to do the repair work should remain open. However, the duration of bidding process should be kept short. This means that state DOTs need to prepare bid packages quickly (e.g., within 24 hours) and contractors need to bid the repair work fast (e.g., within 24 hours). In order to shorten the bid process, state DOTs should developed emergency procurement/contracting procedures and documents and identify the qualified contractors for emergency work in advance.
2. Durations of the emergency bridge repair projects need to be estimated more accurately. This requires state DOTs to collect data and conduct schedule analysis.
3. State DOTs should continue to search for new construction technology that could speed up the reconstruction process. One of the areas that has potential is the time-based maturity requirements for concrete.

Survey Responses

Researchers contacted the Pennsylvania Department of Transportation (PennDOT) and the contractor responsible for repairing the I95 bridge over Chester Creek. Following the initial contact, researchers prepared a questionnaires to collect information pertinent to the case study and sent the questionnaires PennDOT and the contractor, Buckley and Company, Inc. Both questionnaires and responses are given in the following text.

**QUESTIONNAIRE
For
I-95 Chester Creek Bridge Repair Project**

Responses from PennDOT

Contracting Method

1. What contracting method had been used to repair the bridge?

The secretary of transportation awarded the repair contract to a contractor who had previously successfully completed a similar repair project. The secretary was able to award the work without bidding it by an emergency declaration.

2. What kind of financial incentive method had PennDOT used to speed up the repair project? Was the incentive method effective? What other kind of incentive methods might be used to speed the repair process?

The Dept. used no real incentive method to speed up the work. The contractor was paid on time and materials with specification 408 mark-ups. This job was completed early by gentleman's agreement between the governor and Bob Buckley and a lot of Philadelphia pride.

3. Did Buckley & Company subcontract any portion of work to subcontractors? If yes, what contracting method had been utilized?

The subcontractors were paid on time and materials basis with mark-up. Buckley received 8% on top if the subcontractors submitted costs.

4. What kind of financial incentive method had Buckley & Company used in the contracts with the subcontractors and vendors/suppliers? Was the incentive method effective? What other kind of incentive methods might be used?

Buckley used the time and materials plus mark-up as the incentive to subcontractors. One major incentive of this approach is that all overtime wages are paid directly with the standard PennDOT mark-up of 40% applied labor.

Engineering

1. What is the name and address of the firm who designs the I-95 Chester Creek Bridge? Did Buckley get the drawings from the design firm or PennDOT for the repair work?

I believe that the bridge was originally designed by Sanders and Thomas, Inc., about 1989. The bridge was reconstructed in 1991. The shop drawings

necessary for fabrication were found in PennDOT's bridge archives and provided to Buckley. Also another contractor provided shop drawings to Buckley.

2. What requirements in the specifications had been waived based on the engineering judgments in order to expedite the repair process?

All time-based specifications for concrete maturity were waived; compressive breaks were the only measure of concrete strength. I.E. PennDOT does not permit live loading on decks until 14 days, the bridge was open to unrestricted I-95 traffic in 11 days after pouring the deck.

3. What is the type of bridge foundation? Was foundation damaged in any way?

Foundation was driven H pile. The foundation was not damaged in any way. The sub structure has 1 pier, which required some minor concrete repairs.

Construction

1. Did Buckley & Co. work 24 hours /day, seven days/week during demolition? If not, what were the work hours per day?

Demolition was performed by Eastern-States Wrecking. Eastern-States worked 12 hours per day until the demo was completed including weekends.

2. Did Buckley & Co. work 24 hours /day, seven days/week during replacement of bridge (e.g., install new girders; pour concrete deck, and so on)? If not, what were the work hours per day?

On many days the project worked 24 hours/day due to the subcontractors involved and involvement with live traffic. In general most days were just double shifted.

3. What kind of new construction technologies and methods had been developed and implemented in the repair project?

No new technologies were developed; we didn't have time.

4. What were the most difficult challenges during the repair process?

Fabrication of structural steel

1) Shop drawing recovery

2) A question of steel plate

- Special rolling at Sparrows Point Baltimore Plant

- Fabrication at high steel in Lancaster 24th/7d

5. Under the normal conditions, how long will it take to finish the repair project?

Past experience indicated this job would be in construction for 6-8 months with conventional design and bidding adding 9 months for a total time of 1½ years.

6. What are the major reasons that Buckley & Company can finish the repair project early (e.g., more resources, new construction technologies)?

Buckley had ample resources to complete the work; this is why they were selected. Bob Buckley is also the local president of the Philadelphia Chapter of the PA Associated Contractors. Bob had they “sway” to get materials and necessary contractors.

7. People working at night shift may face the following problems such as sleep deprivation, fatigue, stress, poor visibility, irregular eating routine, and social/domestic issues. These problems may result low productivity and accident. How did Buckley & Co. address these problems during the repair process?

Buckley chose to work 2 10-hour shifts. Night work was limited to work involving traffic. The steel fabricator worked 24 h/ 7 day, but this was all shift work @ the plant.

8. In emergency repair situation nighttime construction is necessary because of the time issue. Is there a need to conduct a study on nighttime construction? For example what is the safety standard or procedure during nighttime construction? How to improve the productivity during the nighttime construction? What topics do you think that need to be addressed for the nighttime construction?

Nighttime work has become a part of construction in urban locations. Safety and quality of construct are impacted as a result of night work. Better lighting would improve safety and quality.

9. If a similar incident happens in the future, what different actions will PennDOT take from the construction standpoint?

I don't believe construction methods will change noticeably. I would like PennDOT to waive all time based maturity requirements for concrete. Concrete can't read a calendar.

10. When did the repair work complete? June 29 or July 3?

Work of all sorts continued until July 3rd when we opened to traffic. I believe the “bridge proper” was completed about June 29.

11. Can you provide us some photos taken during the repair process?

Possibly the search for photos has, so far been fruitless. I will continue to look, and if possible provide what is available.

12. Were there any ways, if taken by PennDOT or the contractors, which could finish the repair project even faster?

I do not believe that any improvement in shortening the duration of the project is possible.

Material Supplier and Vendor

1. Were the material suppliers/vendors able to provide the materials according to the construction schedule?

Yes. Buckley was able to coordinate delivery with supplies to support the schedule.

2. What were the difficulties that the material suppliers/vendors had during the repair project?

The suppliers had to “break in” to their existing fabrication schedules to support the project. This meant delaying deliveries to other customers.

3. What actions had been taken to make sure the quality of the materials under this circumstance?

The standard inspection functions required on PennDOT projects was performed it was just faster, longer and more exhausting.

4. What actions had been taken to expedite material delivery under this circumstance?

The Dept. recommends you contract Buckley & Co.

5. Was it possible that Buckley & Co. might finish the repair project earlier if material suppliers/vendors had improved their performance?

Doubtful that work could have been performed any earlier.

**QUESTIONNAIRE
for
I-95 Chester Creek Bridge Repair Project**

Responses from Buckley & Co., Inc.

Contracting Method

5. What contracting method had been used to repair the bridge?

PennDOT had awarded the emergency repair contract to Buckley & CO., Inc. on a T&M basis without a competitive bid process. The decision to award the emergency contract to Buckley was made the very 1st day of the fire.

6. What kind of financial incentive method had PennDOT used to speed up the repair project? Was the incentive method effective? What other kind of incentive methods might be used to speed the repair process?

There was no financial incentive other than the T&M mark-up percentages that are specified in PennDOT's standard specifications PUB408.

7. Did Buckley & Company subcontract any portion of work to subcontractors? If yes, what contracting method had been utilized?

All subcontractors from Buckley & Co. were based on T&M. We subcontracted portions of the work (e.g., partial demolition, steel erection & rebar installation).

8. What kind of financial incentive method had Buckley & Company used in the contracts with the subcontractors and vendors/suppliers? Was the incentive method effective? What other kind of incentive methods might be used?

There were no financial incentives given to the Subs because none were given to Buckley & Co. from PennDOT. We would have shared any incentive from the Owner if one was provided.

Engineering

4. What is the name and address of the firm who designs the I-95 Chester Creek Bridge? Did Buckley get the drawings from the design firm or PennDOT for the repair work?

URS, King of Prussia, PA. PennDOT gave us the plans directly since because the superstructure had been replaced just 9 years prior to the accident, so all plans & shop drawings were available.

5. What requirements in the specifications had been waived based on the engineering judgments in order to expedite the repair process?

Only 1 requirement waived- 50% ties in the bottom rebar for the bridge deck.

6. What is the type of bridge foundation? Was foundation damaged in any way?

The concrete foundations were damaged slightly, and were repaired with Gunitite.

Construction

13. Did Buckley & Co. work 24 hours /day, seven days/week during demolition? If not, what were the work hours per day?

We worked 7 days a week, but only 12 hours per day during demolition.

14. Did Buckley & Co. work 24 hours /day, seven days/week during replacement of bridge (e.g., install new girders, pour concrete deck, and so on)? If not, what were the work hours per day?

We worked 7 days a week, but only 12 hours per day during this phase.

15. What kind of new construction technologies and methods had been developed and implemented in the repair project?

None.

16. What were the most difficult challenges during the repair process?

Steel fabrication and delivery that was ahead of schedule; and at times, dealing with the media at the project site.

17. Under the normal conditions, how long will it take to finish the repair project?

6 months.

18. What are the major reasons that Buckley & Company can finish the repair project early (e.g., more resources, new construction technologies)?

The critical path for the early completion was early fabrication and delivery of the Steel beams- - no new technologies employed. We worked with the trades and those Subs that we had confidence in to perform the work in the most efficient manner.

19. People working at night shift may face the following problems such as sleep deprivation, fatigue, stress, poor visibility, irregular eating routine, and social/domestic issues. These problems may result low productivity and accident. How did Buckley & Co. address these problems during the repair process?

By only working 12 hours per day during the long hours of sunlight in May- June we, avoided this problem.

20. In emergency repair situation nighttime construction is necessary because of the time issue. Is there a need to conduct a study on nighttime construction? For example what is the safety standard or procedure during nighttime construction? How to improve the productivity during the nighttime construction? What topics do you think that need to be addressed for the nighttime construction?

N/A.

21. If a similar incident happens in the future and Buckley & Co. is responsible for repairing the bridge, what different actions will the company take from the construction standpoint?

None.

22. When did the repair work complete? June 29 or July 3?

On June 29 the bridge was opened, but we continues to perform structure work underneath after the traffic had been restored.

23. Can you provide us some photos taken during the repair process?

Yes.

PennDOT Support

1. What kind of supports from PennDOT during the repair project had been very helpful?

PennDOT's Chief construction engineer was onsite at all times, so decisions were made on the spot without a formal submission process to waist time. Also, PennDOT took responsibility to deal with all media issues and let us build the bridge (we wanted no direct media contact).

2. What kind of supports/helps would you like to have from PennDOT, but PennDOT didn't provide last time?

None.

3. Were there any ways, if taken by PennDOT or the contractors, which could finish the repair project faster?

None that we are aware of.

Material Supplier and Vendor

6. Were the material suppliers/vendors able to provide the materials according to the construction schedule?

Yes. In particular, High Steel Structure manufactures the replacement beams by working 24/7 at their offsite facility and had begun procurement/fabrication the day the order was placed. Other supplies expedited their procurement/deliveries based upon the critical path for steel fabrication

7. What were the difficulties that the material suppliers/vendors had during the repair project?

Other than the obvious tight schedule for all supplies, the steel fabricator had to acquire raw materials on a moment's notice (we believe they borrowed materials from other order/project that were subsequently replaced).

8. What actions had been taken to make sure the quality of the materials under this circumstance?

Inspections were performed at the supplier's plants.

9. What actions had been taken to expedite material delivery under this circumstance?

We placed all material orders immediately upon award of the project and the delivery of the plans.

10. Was it possible that Buckley & Co. might finish the repair project earlier if material suppliers/vendors had improved their performance?

The critical delivery that ensured early completion was that of the steel beams. Those beams were in fact delivered ahead of the original anticipated schedule.

Acknowledgments

We would like to thank Mr. Rex Mackey of PennDOT, Mr. Robert Buckley, Mr. Craig Hoogstraten, and Mr. David Warner of Buckley & Company, Inc., and Mr. Steve Bussanmas of High Steel Structures, Inc. for their vital input and cooperation during the case study.

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Appendix B

Case Study of I-40 Webbers Falls Bridge Replacement Project

By:

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And

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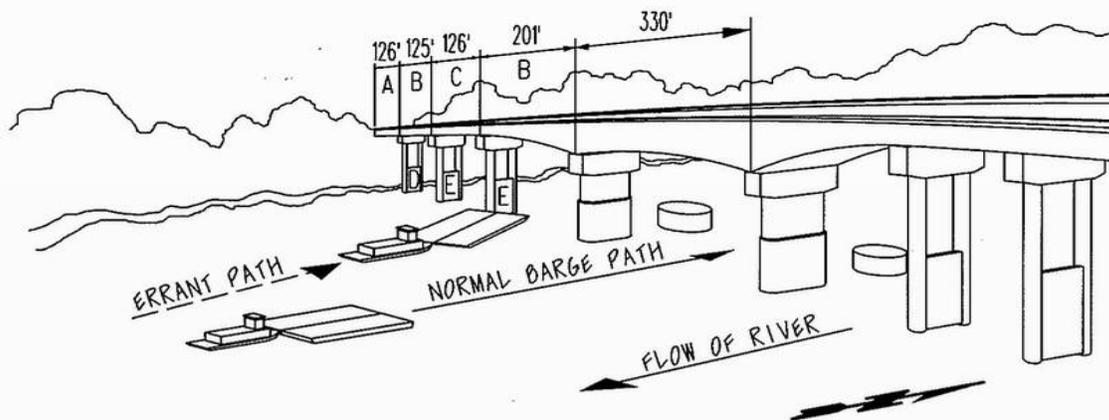
July 2004

I-40 WEBBERS FALLS BRIDGE INCIDENT

It was a typical Sunday morning on a Memorial Day weekend of May 26, 2002. The towboat Robert Y. Love pushing two empty barges, owned by the Magnolia Marine Transport Company of Vicksburg, Mississippi, moving upstream on the Arkansas River hit the I-40 Webbers Falls Bridge around 7:47 am. The bridge is part of McClellan-Kerr Arkansas River Navigation System. The incident caused part of the bridge to fall into the river. Oklahoma Department of Transportation (ODOT) had no choice but to close I-40 near the bridge and the Navigation System. I-40 is one of the nation's three major east-west interstate highways. The route is traveled daily by about 22,000 vehicles, carrying goods and materials coast to coast.

DAMAGE ASSESSMENT

The 64-foot wide, 1988-foot long, four-lane bridge was built in 1967 over the Arkansas River near Webbers Falls, Oklahoma. The original structure was a continuous haunched steel girder bridge with a 200 feet/330 feet/200 feet approach span/main span/approach span configuration and a reinforced concrete deck. The steel girders were supported by 12 concrete piers. Figure 1 shows what happened on the morning of May 26, 2002. The barge was about 300 feet outside the regular navigation channel (main channel) when it rammed into the unprotected piers of the bridge, knocking down two piers (indicated as E piers) and damaging one pier (shown as D pier). Four spans of approximately 500 feet were also damaged. Span 1 (shown as A) was damaged, but did not fall. Span 2 (shown as B, 125 feet long) and span 4 (shown as B, 201 feet long) partially fell into the river. Span 3 (shown as C) completely collapsed into the river. Many drivers were unaware of the collapse of the bridge and eleven vehicles plunged 62 feet into the river. A total of 14 people died in the incident. Figure 2 shows the damaged bridge.



I-40 OVER THE ARKANSAS RIVER

- | | |
|--|----------------------------|
| A = Damaged Span | D = Partially Damaged Pier |
| B = Partially Fallen Span | E = Damaged Pier |
| C = Completely Fallen & Submerged Span | |

Total Bridge Length = 1988.5'
Total Piers = 12

Figure 1 I-40 Bridge Incident Sketch (Provided by ODOT)



Figure 2 Overview of the Damaged Bridge (Provided by ODOT)

DETOUR ROUTES

Shortly after the incident, ODOT established the detour routes for the traveling public as shown in Figure 3. Eastbound drivers were instructed to take exit 278 at Warner, go south on SH-2, turn east on SH-9, turn north on US-59 and rejoin I-40 near Sallisaw at exit 308. The eastbound detour was 57 miles long. Westbound travelers were directed to take exit 291 at Gore, go north on SH-10, turn west on US-64, turn south on SH-100 and rejoin I-40 east of Muskogee Turnpike at exit 287. The westbound detour was six miles long. In order to reduce traffic volumes on area highways, ODOT instructed long-distance travelers from northern Oklahoma including Kansas to go south on I-35, then east on US-412/Cimarron Turnpike to avoid area traffic congestion. Long-distance drivers from northeastern Oklahoma, Tulsa, and surrounding areas were directed to go east on US-412/Cherokee Turnpike, turn south on I-540, and turn east onto I-40 in Ft. Smith, Arkansas. Travelers coming into Oklahoma from Texas to access I-40 east of Warner, Oklahoma were instructed to take I-30 from Texas into Arkansas, and then take I-40 into Oklahoma.

Due to the large increase of traffic volumes on the detour highways, it was necessary for ODOT to take immediate action in the form of heavy maintenance including overlays on portions of the detour highways to prevent pavement failures which would endanger the traveling public. Several emergency maintenance contracts were issued to resurface highways pavements. Glover Construction Company of Muskogee was awarded contracts to resurface 7.7 miles of SH-2 beginning in Porum, 0.62 miles of SH-100 starting in Gore, and 4.8 miles of US-59 in Le Flore County. Tiger Industrial Transportation System, Inc. received a contract to resurface 5.9 miles of SH-9 in Haskell County. Also, ODOT inspected 42 bridges on the detour routes and

DEMOLITION

Demolition started as soon as the recovery effort ended. ODOT awarded a lump sum contract, a total of \$850,000, to the Jensen Construction Company for demolition work necessary to remove the damaged sections of the bridge on June 3, 2002. The duration of the contract was 16 days. Jensen would receive \$50,000 per day bonus for each day it finished ahead of the schedule and penalized \$50,000 per day for each day over the schedule. The demolition work was accomplished on time.

The demolition crews knocked down the remaining piers first, then began breaking up the concrete on the spans. Spans 1 and 2 were brought down using explosives and debris was removed from the site. Span 3, which had fallen completely into the river, had to be removed using underwater demolition. The working environment for the underwater demolition was hazardous due to poor visibility. Demolition of the damaged chunk of the span 4 was the most challenging task. This span was partially damaged. One end rested on the barges and the other end was still attached to the un-damaged bridge as shown in Figure 2. The remainder of the bridge structure could have been further damaged if the crews had not exercised caution during the demolition. To prevent this from happening, the Magnolia Marine Transport Company had to stabilize the barges and the crews had to constantly monitor the movements of the bridge and barges. Combinations of demolition devices including a wrecking ball, some explosives, concrete shears and other cutting devices were being used to meet the different demolitions needs at the site. The debris removed from the accident site was piled on a five-acre site on the river's west bank and was trucked or floated away.

DESIGN FOR REPLACEMENT

ODOT contacted the pre-qualified design consultants to prepare plans for the repair work on the day of incident. Design contract was awarded to the Poe & Associates Inc., of Oklahoma City on May 28, 2002. The design contract specified that the cost of the design should be no more than \$137,000 and the design firm should furnish biddable plans within 16 days. ODOT provided an incentive of \$5,000 for every day the design firm beat the 16-day schedule and a disincentive of \$2,400 for every day over 16. Poe & Associates started the design on May 29 and finished on June 9, four days ahead of schedule. The scope of the design included three new pre-stressed concrete beam spans, replacement of an existing structural steel span, three piers, and associated details. Typically, the design of such kinds of structures would take four to six months. With the help from ODOT and steel detailer, Poe & Associates accomplished the design in just 12 days, which was a tremendous time saver for the repair project. ODOT providing the original drawings immediately to the design firm and ODOT engineers being on call 24 hours per day, 7 days per week to quickly answer any questions that the designers had, were major reasons for this success. The most difficult challenges for the design firm were coordinating the design team members and keeping up with each designer's progress from day to day to ensure quality control and design checks. Each design element received at least one check, and sometimes two. Another challenge was to keep designers mentally focused while working from 12 to 14 hours per day for 12 consecutive days.

+

The designers for the repair work made several changes on the original plans and specifications in order to expedite the repair process. Before the incident, spans 1, 2, and 3 were 126 feet, 125 feet, and 126 feet continuous steel plate girders, respectively. After the incident, three 130 feet pre-cast, pre-stressed concrete girders were utilized in the spans 1, 2, and 3 in lieu of the original steel plate girders. Using concrete girders reduced the material delivery time, but increased the bridge dead load. The existing abutment could not be utilized due to load increase. Because of this, the span lengths were changed from 125 feet to 130 feet for spans 1, 2, and 3. This allowed the new abutment to be built 15 feet behind the existing abutment without removing the old abutment seat and steel piling. The original bridge was built as separate superstructures with a small gap between the directional travel lanes. This gap was eliminated in spans 1, 2, and 3 of the new structure so that one concrete pour could be made instead of separate pours.

Span 4 was the end span of the bridge main span. The end 125 feet of span 4 was rebuilt with the same structural type, steel plate girder to match the undamaged structure, but with a thicker web to eliminate transverse and longitudinal stiffeners. Before connecting the new steel girders with the existing girders in span 4, a treatment procedure, heat-straightening, was implemented to the existing girders to repair the damages. In this repair process, a limited amount of heat was applied in specific patterns to the deformed regions of damaged steel in repetitive heating and cooling cycles to produce a gradual straightening of the material. To give the contractors some flexibility, the specifications allowed contractors to pour concrete deck either for full width or with a construction joint at centerline.

The old piers had two columns supporting them. The new piers were three column structures supported by drilled shafts. Pier 3 (shown as E in Figure 1 towards undamaged bridge) was rebuilt at the original station. Its three columns were spaced to straddle the existing spread footings that were left in place. Figure 4 shows the substructure layout. The solid lines indicate the new pier structure and the dash lines represent the old pier structure. Figure 5 presents the details of pier 1 (shown as D in Figure 1) and 2 (shown as E in Figure 1 that is in the middle of three piers). The new piers were 9 feet in diameter (under web wall portions) which was 2 feet larger than the old one. Figure 6 shows the new pier structure under construction. The new piers were constructed with a construction joint at the top of web walls which were full column width with some chamfering at the ends for ease of forming. Substructure concrete was permitted to be loaded after it reached 75% of design strength.

Besides these changes, new specifications allowed using high early strength concrete, steel stay-in-place forms, steel diaphragms for pre-stressed concrete beams, and concrete maturity method. The concrete maturity is a method for determining real-time in-place concrete strength. As soon as the concrete reached 100% design strength and had a minimum of three days curing, contractors were permitted to remove the concrete forms and apply moment loadings to the structure. The concrete maturity procedure is specified by the American Society for Testing and Materials (ASTM) C 1074, Standard Practice for Estimating Concrete Strength by the Maturity Method.

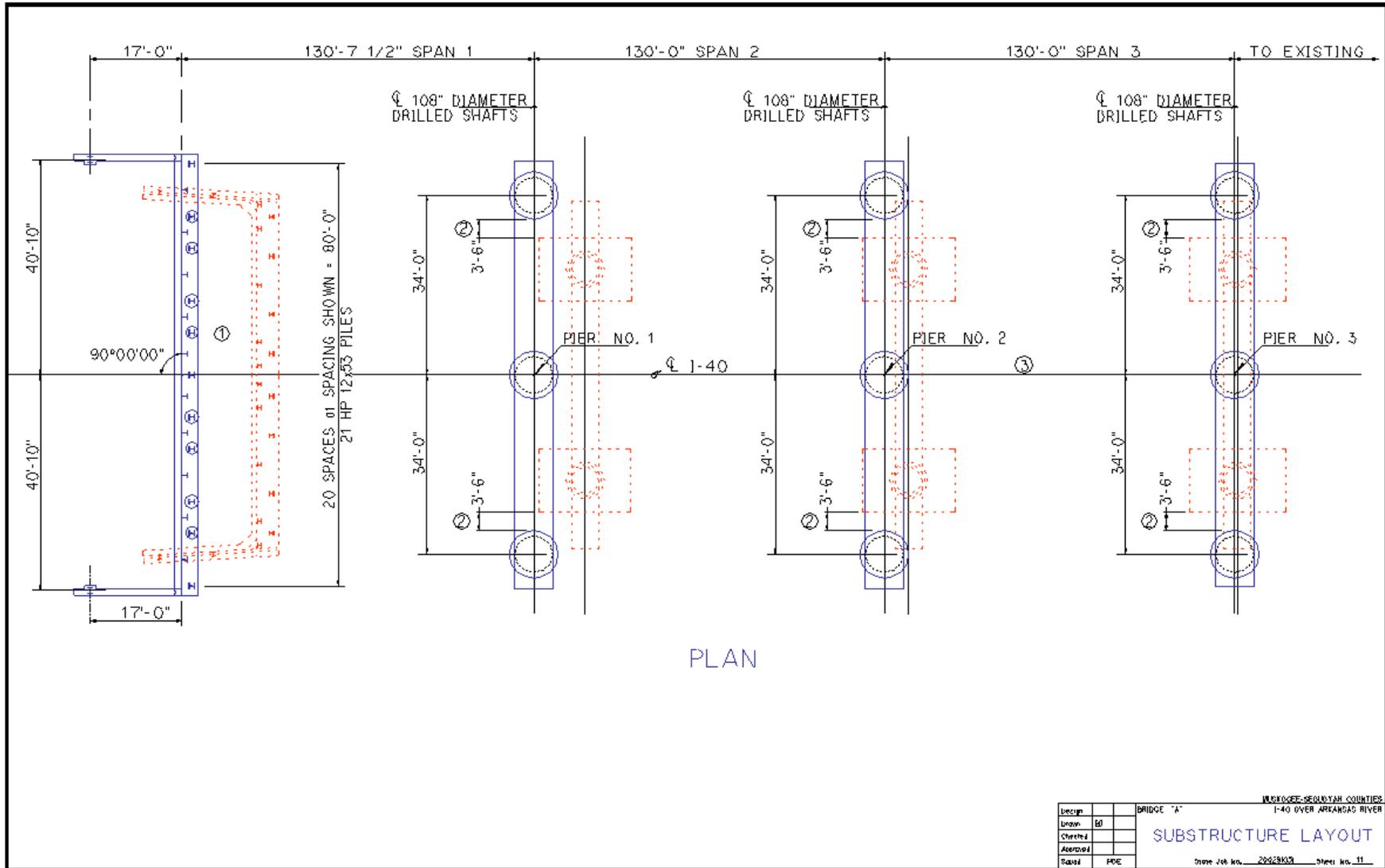


Figure 4 I-40 Bridge Substructure Layout (Provided by ODOT)

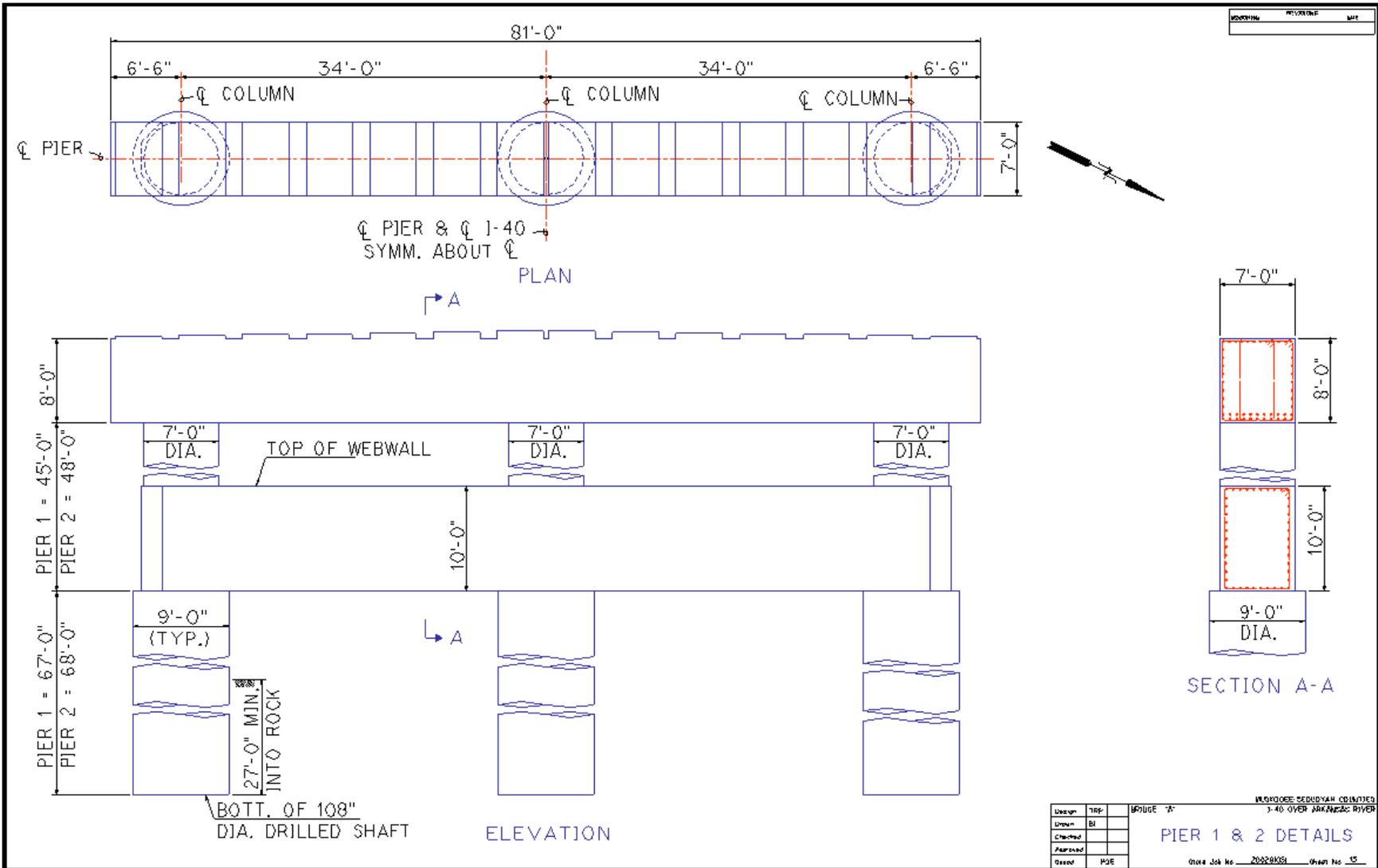


Figure 5 I-40 Bridge Pier 1 and 2 Details (Provided by ODOT)



Figure 6 New Pier Structures (Provided by ODOT)

BRIDGE RECONSTRUCTION

The contract of the bridge reconstruction was awarded using A plus B competitive bid method. A plus B method is one of the innovative project delivery methods that has been developed and implemented in the construction industry in recent years. A represents the cost of the project and B indicates the duration of the project. Using this method, the owner will evaluate the bid proposals based on not only the cost, but also the schedule. This is the perfect method for the emergency bridge reconstruction project since time is of the essence. In the bid document, ODOT specified 72 days as the maximum time allowed to complete the reconstruction. ODOT held a pre-bid meeting on the Saturday of June 8, 2002. The potential bidders had an opportunity to visit the site to assess the damage of the bridge and the site conditions. The contract was issued to Gilbert Central Corporation of Fort Worth for \$10.9 million with a 57-day schedule on June 12, 2002. The contract had a \$6,000 per hour bonus/penalty clause without cap either way. ODOT would pay Gilbert an additional \$6,000 for every hour it was ahead of the original schedule and penalize the company \$6,000 an hour for every hour it was behind the schedule. The reconstruction started at 6:00 pm on June 12, 2002 with two 12 hours shift per day, 24 hours per day, and 7 days per week. On average, there were 70 to 80 workers on the site. The project finished at 10:00 am on July 29, 2002, with a total time of 46 days and 16 hours, the fastest completion of a project of its type in US history. Reconstruction was ahead of the original schedule by 10 days and 8 hours and Gilbert received \$1,488,000 bonus. ODOT also benefited from the early completion of the project since traffic engineers estimated that the total user cost was \$430,000 per day for every day that the bridge was not open. Under normal conditions, it would take at least six months to finish the reconstruction.

The major scope of repair work involved constructing a 524-foot-long combination concrete and steel girders that would tie into the undamaged four-lane bridge structure, three piers, four spans, an abutment, a 30-foot-long concrete approach slab and a 40-foot-long roadway section. Reconstruction began on the west side of the bridge and moved toward the still-standing roadway in the center. To make sure that the project would be constructed as fast as possible, both ODOT and Gilbert committed necessary resources and furnished experienced supervisors and crews. ODOT created special construction residency and the assistant bridge engineer for design was on call 24 hours per day, 7 days per week. A 13-member team of inspectors was formed to oversee the reconstruction of the bridge. Some of the inspectors were retired ODOT employees. The average experience for the 13 bridge inspectors was 20 years. Inspectors were also sent to the steel fabrication shops to make sure that the steel plate girders were fabricated as designed and satisfied all the standards. Under normal circumstances, ODOT probably would have only two inspectors assigned to the project.

Gilbert Central Corporation, a subsidiary of Peter Kiewit Sons', Inc., had built two bridges in Tulsa and was the contractor on major repairs to Oklahoma City's cross-town expressway. The company was also working on a large bridge at Dallas-Fort Worth Airport and an \$800 million bridge in the San Francisco Bay area. To meet the challenge of the I-40 bridge, Gilbert deployed multiple crews working concurrently, employed a full time on-site scheduler to prepare daily CPM and resource schedules, and mobilized back-up equipment. The company had experienced decision makers on site to quickly respond to any issues/questions during the reconstruction. To make sure that safety would not be compromised during the repair project, Gilbert offered \$2,000 safety bonus to each crew member if he/she had no accident during the course of the project.

One of the major challenges during the reconstruction was the delivery of steel plate girders. Right after the incident, ODOT decided to replace most of the damaged steel girders with pre-cast, pre-stressed concrete girders, with the exception of span 4 that was tied into the existing bridge, because ODOT anticipated that steel suppliers couldn't meet the aggressive reconstruction schedule. Span 4 required 210 tons of steel including four replacement girders, 12 cross frames, four lines of stringer beams, and lateral bracing. Delivery of structural steel was a critical activity on the CPM schedule. The National Steel Bridge Alliance (NSBA) and several steel fabricators assured ODOT that steel delivery could meet the ambitious schedule. On June 2, 2002, Tensor Engineering sent its premier bridge detailer to the steel design firm White & Associates of Oklahoma City to work on the design drawings. The designers utilized heavier webs to eliminate the need for most of the stiffeners, which ultimately sped up the fabrication process. All design drawings were sent via e-mail to speed the process. Tensor Engineering sent the mill orders to the fabricator, Trinity Industries, Inc., on June 12, 2002. Shop detail drawings were completed over the next five days and were approved by ODOT in the shop the day they were submitted.

One of the challenges during the design of shop drawings was how to match the existing field splice. The fabricator requested the last 5 feet of the existing damaged girders and used the splice plates to match-draw new splice plates. New splice plates were bolted into position on the new girders in the shop and then connected to the existing girders in the field. Bethlehem Steel Company received the order to provide the needed steel materials on June 19, 2002 and started to ship the materials on June 24, 2002. The company was willing to disrupt its regular production schedule to meet the required delivery schedule. Thanks to the hard working people in the steel

industry and the bonuses provided by the Gilbert Corporation, the delivery of steel girders beat the schedule by six days.

Besides efforts from the industry, coordination among federal, state, and tribal governments was crucial to putting the bridge back into commission on the fast track. As the sole owner of the Arkansas Riverbed and banks at Webbers Falls, the Cherokee Nation controls the land around the reconstruction site. From day one, the Cherokee Nation contributed land and manpower and facilitated the project by making work areas easily accessible to contractors. The Federal Highway Administration (FHWA) approved \$3 million in federal emergency relief funds to get the repair work started immediately. Through the repair process, FHWA provided technical expertise and assistance to ODOT, particularly in the areas of bidding and contract administration. Both agencies worked together to streamline the bid review and approval procedures and get the reconstruction contract ready to put out for bid. ODOT also received technical help and cooperation from the US Army Corps of Engineers, US Coast Guard, and other State DOTs. Figure 7 shows the bridge re-opened to the traveling public on July 29, 2002.



Figure 7 I-40 Bridge Re-Opened to the Traveling Public (Provided by ODOT)

LESSONS LEARNED

There were many factors contributing to the success of responding to the I-40 tragedy. In order to document what can be learned from this extreme event, the research team conducted this case study. During the study, the research team reviewed literature including information posted on the web sites, interviewed people who were involved in the repair of the bridge via the telephone,

and performed surveys. Notwithstanding its terrible consequences, the I-40 Webbers Falls Bridge tragedy provides useful lessons for state DOTs that must plan for enhanced responses in case of future incidents. The following is the summary that outlines lessons learned from this extreme event.

1. Quick response to the incident was the key to mitigate the loss and ease the inconvenience of the traveling public. Response actions included, but are not limited to, stabilizing the damaged structure immediately to prevent further damage on property and traveling public, providing the required construction equipment and manpower for rescue and recovery efforts, establishing detour routes and making the detour information available to the general public as quickly as possible to ease the traffic congestion.
2. Using established contracting methods and procedures sped up the contracting negotiation process and avoided future contract disputes. During the repair process, ODOT utilized both traditional contracting methods such as Cost-Plus, Time & Materials, and Lump Sum, and innovative contracting method such as A+B. All of them delivered positive results.
3. Huge incentive and disincentive clauses in the contracts played a very successful role in motivating design firms, contractors, and material suppliers to finish their work on time or ahead of time. Particularly, using A+B contracting method and huge incentive in the reconstruction reduced the duration from 72 days to 46 days and 16 hours.
4. The duration of design of the new structure was shortened due to the original design drawings and specifications being provided quickly to the design firms and ODOT engineers being on call 24 hours per day, seven days per week to answer any design related questions.
5. Commitment of the necessary resources such as manpower from all parties, which included DOT, design firms, contractors, and material suppliers, accelerated the repair project. During the repair process, all parties worked over time. Contractors rebuilt the bridge with two shifts around the clock.
6. The spirit of cooperation among the parties involved in the repair project was very high. People worked together as partners. This partnership atmosphere built trust, improved communications, reduced conflicts, and overcame the bureaucracies and other adversities during the repair process. Suggestions and ideas on how performance could be improved were discussed daily.
7. Getting strong support from the community enabled the execution of the repair project to run effectively and smoothly. The Cherokee Nation, who controlled the land around the site, contributed land and manpower and facilitated the project by making work areas easily accessible to contractors.
8. Changing the normal DOT operational procedures expedited the reconstruction. For example, ODOT approved the shop drawings the day they were submitted. Under normal condition, it would take weeks to get approval. Also, ODOT inspectors were sent to the steel plant and fabrication shop to conduct quality inspection since the fabrication of the steel girders was the critical activity in the schedule.
9. The maturity method was used successfully to expedite the concrete construction process. Time-based specifications for concrete were modified to implement the maturity method.

Although the repair project was finished more than 10 days ahead of the original schedule with a good quality and safety record, there are areas for State DOTs to consider for future improvements. These potential improvements are summarized as follows.

1. Duration of the emergency bridge repair project needs to be estimated more accurately. This requires state DOTs to collect real project data and conduct schedule analysis.
2. State DOTs should continue to search for new construction technology that could improve the construction process. Areas such as underwater demolition and construction have great potential.

SURVEY RESPONSE

The survey responses from ODOT, Poe & Associates, and Gilbert Central Construction, Inc. are given in the following text.

ODOT

1. What kinds of construction techniques were utilized to expedite the reconstruction of the bridge?

The Contractor had all their decision makers on site. The Contractor had multiple crews working concurrently in different areas. The Contractor employed a full time on-site scheduler and provided daily CPM and resource schedules. The Contractor mobilized back-ups for critical equipment. The Contractor utilized concrete maturity meters to determine the strength parameters for various components required before the next construction phase could commence.

2. What kinds of difficulties did contractors face during underwater demolition and construction?

During various stages of both the demolition and construction efforts, the visibility was virtually non-existent for the divers and the river current was difficult to work with.

3. Did demolition finish on time? (The contract specified 16-days duration with a \$50,000 per day bonus/penalty. The ODOT presentation given by Mr. Steven Jacobi showed the demolition took 20 days.) Were penalties applied to the contractor?

There were actually two contracts with the same company. One of these contracts was a lump sum contract for the "recovery efforts" that did include some demolition. The other contract did have an incentive/disincentive clause in it. The presentation you saw combined these efforts into one time frame. (It should be noted that Steve Jacobi gave the presentation because he was already going to the workshop and is not necessarily knowledgeable on the subject.)

4. Did design finish on time? (One paper said that the design firm finished the design in 12 days, 4 days ahead of original schedule. The ODOT presentation given by Mr. Steven Jacobi showed the design took 18 days.)

Initial design decisions were made by ODOT Bridge Division Staff and the search for an engineering consultant began on Day 1. The work order for the engineering contract was issued on the morning of Day 4. The time charges on the contract stopped when the construction plans were submitted for letting purposes on Day 16. In the presentation, the design phase ended on Day 18 when the construction contract was awarded. The original design contract contained a 16 day completion schedule and it was officially completed in 12 days, 4 days ahead of schedule.

5. Was A + B contracting method used in the subcontracts?

A + B Contracting was used for the construction contract. The Contractor had complete control of his subcontractors and was at liberty to work out any deal with them, so there was not any A + B directly attributable to subcontractor work.

6. Were there any bonus/penalty clauses in the contracts with subcontractors, steel suppliers and/or fabricators?

There were no bonus/penalties in ODOT's construction contract that specifically named the deliverables or the timeframes of the deliverables of any subcontractor, supplier or fabricator. The Contractor had complete control of his subcontractors and was at liberty to work out any deal with them.

7. What actions were taken to expedite structural steel delivery?

The shop drawings associated with the structural steel were included in the Engineering Contract. The National Steel Bridge Alliance (NSBA) negotiated a deal with the mill to get a special mill run just for this project.

8. What actions were taken to ensure quality of steel materials, fabrications, and reconstruction under such tight schedule?

The construction materials used met the ODOT Construction Specifications. An ODOT contractor for fabrication (Contract Inspector) was sent to the fabrication sites during fabrication phases. A special construction residency was formed at the construction site, just for the purposes of the reconstruction efforts. The ODOT inspection personnel used were the "best and brightest" from across the entire state. The Assistant Bridge Engineer for Design was on-call 24-7 with a set of plans, shop drawings, etc., and was authorized to make decisions on the spot.

9. What actions were taken to ensure safety and productivity during the nighttime construction?

The Construction Contract did not include any special safety or productivity specifications. This was essentially left up to the Contractor.

10. What were the most difficult challenges during the bridge repair process?

The magnitude of the time constraints was the biggest challenge.

11. What was the reconstruction sequence? (Provide us with construction milestones during the reconstruction.)

I do not have this information. Someone from ODOT construction should be able to supply you with this.

12. Under normal conditions, how long would it typically take to finish this type of repair project?

Approximately, 6 to 9 months.

13. What were the major reasons that Gilbert Central Corporation could finish the reconstruction early?

The biggest reason for success was that the reconstruction effort was a single priority for all involved; ODOT, Contractor, Other State and Federal Agencies, Subcontractors, Fabricators, Suppliers, etc. Also, the huge incentive / disincentive helped make it a priority.

14. How difficult was it for the design firm to get the original drawing and specifications?

It was not too difficult. Most broad scale engineering decisions were made by ODOT Bridge Division Staff prior to the engineering contract. These decisions were never wavered from and what was left was a very good execution of structural design and detailing.

15. What kinds of modifications were made to the original bridge design in order to expedite the reconstruction?

The original bridge had the first three spans configured as a 3-125' continuous fracture critical plate girder. Span 4 was the end span of a 200'-330'-200' continuous fracture critical plate girder with variable depth. The end 125' of Span 4 was rebuilt with the same structural type, but with a thicker web to eliminate transverse and longitudinal stiffeners. This put Pier 3 at its original station. The new Pier 3 was constructed with three columns supported by drilled shafts. These three columns were spaced to straddle the existing spread footings that were left in place. The first three spans utilized 130' Prestressed Concrete Bulb Tees. The PC Beams were used so that a different industry would be involved with the fabrication; production time and delivery dates were the issue. Because of the additional weight of the PC Beams, the existing abutment could not be utilized. So, the original span lengths were changed from 125' to 130' for the first three spans. This allowed the new abutment to be placed 15' behind the existing abutment. This allowed us to build the new abutment without removing the existing abutment bridge seat and steel piling. The original bridge was actually constructed as separate superstructures with a small gap between the directional travel lanes. This gap was eliminated on the first three spans of the new structure so that one concrete pour could be made instead of separate pours.

16. What kinds of specifications were waived during the redesign or reconstruction of the bridge?

I do not know of any specifications that were waved during this effort. Some specifications involving strength of concrete and minimum time between events were redefined due to the use of the concrete maturity meters. The cure time for the last concrete deckslab was not waved, but a water system was put in place so that the full length of water curing could be accomplished under traffic conditions.

17. If a similar incident happens in the future, what different actions will ODOT take from the construction stand point?

I am not really sure what we would do any different. After reviewing the actual CPM of the construction process, there might have been an opportunity to shave a few hours off of the time here and there, but things were accomplished in just about the shortest time possible.

This questionnaire was completed by:

Gregory D. Allen, P.E.
Assistant Bridge Engineer – Design
Bridge Division
Oklahoma Department of Transportation
gallen@odot.org 405-521-2606

Gilbert

18. What kinds of construction techniques were utilized to expedite the reconstruction of the bridge?

Gilbert used high strength concrete, built rock-field barge to set steel girders.

19. What kinds of difficulties did contractors face during underwater demolition and construction?

Ask demolition contractor.

20. Did demolition finish on time? (The contract specified 16-days duration with a \$50,000 per day bonus/penalty. The ODOT presentation given by Mr. Steven Jacobi showed the demolition took 20 days.) Were penalties applied to the contractor?

Ask demolition contractor.

21. Did design finish on time? (One paper said that the design firm finished the design in 12 days, 4 days ahead of original schedule. The ODOT presentation given by Mr. Steven Jacobi showed the design took 18 days.)

Ask design firm.

22. Was A + B contracting method used in the subcontracts?

No.

23. Were there any bonus/penalty clauses in the contracts with subcontractors, steel suppliers and/or fabricators?

Gilbert used bonus and penalty clauses in the contract with structure steel supplier.

24. What actions were taken to expedite structural steel delivery?

Dimensions and sizes of steel structures were checked in the fabrication shop.

25. What actions were taken to ensure quality of steel materials, fabrications, and reconstruction under such tight schedule?

Double check every component.

26. What actions were taken to ensure safety and productivity during the nighttime construction?

A full-time safety staff was on site the first month. Everyone would receive \$2,000 safety bonus at the end of the project if there was no accident.

27. What were the most difficult challenges during the bridge repair process?

New steel structures match with existing structures.

28. What was the reconstruction sequence? (Provide us with construction milestones during the reconstruction.)

Send to us at a later time.

29. Under normal conditions, how long would it typically take to finish this type of repair project?

6 months.

30. What were the major reasons that Gilbert Central Corporation could finish the reconstruction early?

Resources and commitment. People and equipment were available.

31. How difficult was it for the design firm to get the original drawing and specifications?

N/R

32. What kinds of modifications were made to the original bridge design in order to expedite the reconstruction?

Using pre-stressed concrete girders and maturity method.

33. What kinds of specifications were waived during the redesign or reconstruction of the bridge?

Curing time of concrete was reduced if the strength reached 100% level.

34. If a similar incident happens in the future, what different actions will your company take to expedite the reconstruction?

N/R

35. What kinds of supports from ODOT during the project were very helpful?

People and resources were available on site. ODOT decision maker was on site to answer any questions and other ODOT people were on call 24/7.

36. What kinds of supports/helps would you like to have from ODOT, but ODOT didn't provide last time?

None.

Questionnaire for I-40 Bridge Repair Project

By Tim R. Purkeypile, P.E.
Project Manager
Poe & Associates, Inc.

Answer 1. Visit with contractor or Oklahoma Dept. of Transportation (Mr. Greg Allen – Assistant Bridge Engineer).

Answer 2. Visit with contractor or Oklahoma Dept. of Transportation (Mr. Greg Allen – Assistant Bridge Engineer).

Answer 3. Visit with contractor or Oklahoma Dept. of Transportation (Mr. Greg Allen – Assistant Bridge Engineer).

Answer 4. The actual design time from when notice to begin was received to plan submittal was 12 days by our firm (Poe & Associates). Bridge collapse was May 26, 2002; May 27, 2002 was a Holiday; Interview & Negotiations was May 28, 2003, Began Design May 29, 2002; Completed plans & Submitted June 9, 2002; Bid Opening, Bid Award, & Notice to Begin was June 12, 2002. The 18 days was time from bridge collapse to Bid Opening.

Answer 5. Visit with contractor or Oklahoma Dept. of Transportation (Mr. Greg Allen – Assistant Bridge Engineer).

Answer 6. Visit with contractor or Oklahoma Dept. of Transportation (Mr. Greg Allen – Assistant Bridge Engineer).

Answer 7. Visit with contractor.

Answer 8. Visit with contractor or Oklahoma Dept. of Transportation (Mr. Greg Allen – Assistant Bridge Engineer).

Answer 9. Visit with contractor.

Answer 10. The most difficult challenges for us as the design team was probably coordinating our team & keeping up with each members progress from day to day to ensure quality control and design checks. Everything we did received at least one check. and sometimes two. Another difficult challenge was working 12 consecutive days for 12-14 hours straight and keeping our mental focus.

Answer 11. Visit with contractor.

Answer 12. The design would typically take 4-6 months. The Dept. of Trans. did an outstanding job of expediting everything from the interview to Bid opening to receiving needed information such as geotech., answering design questions, etc. Everyone associated with this project was on call 7-24. The steel detailer was also a part of our design team.

Answer 13. I'm not being biased or anything, but it had to be the great quality of plans that Poe & Associates submitted. Very few plan questions were addressed. Gilbert Central used experienced and great numbers of employees. Visit with contractor.

Answer 14. The original drawings were supplied to us by the Dept. immediately.

Answer 15. The spans were lengthened out to miss the existing footings and abutment piling and P.C. Beams were used on 130' spans. The piers were designed with 3 columns in order to straddle the existing 2 column piers. An option to use steel diaphragms was given to the contractor. Pouring of the concrete deck was given an option for full width or with a construction joint at centerline to give the contractor some flexibility. The piers were designed and constructed with a construction joint at the top of web walls which were full column width with some chamfering at the ends for ease of forming. Substructure concrete was allowed to be loaded at 75% of design strength. Stay-in-Place form were allowed for construction of bridge deck. Some of the original steel plan sheets were allowed to be used in these construction plans with modifications. Bridge was allowed to be open prior to completing painting, installing vibration dampeners, and installing handrailing.

Answer 16. The LRFD Specifications were used for the design of the new concrete P.C.B. spans and the 16th edition specs. were used on the steel section to be consistent with the original design.

Answer 17. Nothing, don't see how it could've went any smoother.

Answer 18. ODOT was basically apart of our design team and had answers and was on call 7-24.

Answer 19. ODOT was basically apart of our design team and had answers and was on call 7-24.

ACKNOWLEDGEMENTS

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Appendix C

Case Study of Replacement of New York Thruway Bridge in Yonkers, NY

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Bridge Incident

A gasoline tanker-truck owned by the Mystic Bulk Carriers Inc. of Astoria, New York, hauling 8,800 gallons of Texaco gasoline, traveled northbound on the Central Park Avenue (Route 100) in the early morning on Thursday October 9, 1997. The driver was making a U-turn on the Central Park Avenue as it passed underneath the New York State Thruway I-87 (also called Gov. Thomas E. Dewey Thruway) and was hit from behind by a Chrysler Eagle sedan traveling southbound on Central Park Avenue. After the collision, the gasoline truck exploded underneath the Thruway. The explosion caused a huge fire, which killed the sedan driver and damaged the overpass bridge on the Thruway in the City of Yonkers. The total bridge span, skews 53 degree with the Central Park Avenue, is 79.3 feet. The total clear span from abutment to abutment is 76.0 feet without any piers in between. South sidewalk is 7.4 feet, north sidewalk is 16.4 feet, roadway curb-to-curb clear distance is 52.3 feet, and minimum vertical clearance at the curb of south sidewalk is 14.5 feet.

Structural engineers assessed the damages and concluded that the bridge was unsafe for the traveling public. This left the New York State Thruway Authority no choice but to close the bridge immediately. The Thruway is one of the busiest commuting routes to New York City, which is used by 2,500 to 3,000 vehicles per hour in each direction in peak hours and 65,000 vehicles per day. Figures 1 and 2 show the damaged bridge in Yonkers.



Figure 1 Damaged Bridge in Yonkers (provided by NY State Thruway Authority)



Figure 2 Damaged Bridge in Yonkers (provided by NY State Thruway Authority)

Detour Routes

Shortly after the incident, the New York State Thruway Authority developed an emergency plan to handle the situation. The plan involved three major parts including 1) establishing temporary traffic detour routes, 2) demolition of the damaged bridge and replacing it with two two-lane temporary bridges, and 3) replacing the bridge with a permanent structure. Southbound traffic always had one lane thru a service road. This lane was used as detour immediately and expanded to two lanes within the first three days. Also, detours were set the first day of incident at the northbound.

Figure 3 is the traffic detour map issued by the Thruway Authority. The Thruway Authority instructed drivers traveling southbound to take Exit 4 (southbound), follow a newly expanded two-lane detour, and rejoin the Thruway after about 2,000 feet later, near Exit 4 northbound. Northbound travelers were instructed to take Exit 5 (northbound) to Route 100 to Sprain Brook Parkway, turn left onto Sprain Brook Parkway northbound, exit at Tuckahoe Road westbound, and return to the Thruway at Interchange 6. The southbound detour was about 0.5 miles, and the northbound detour was 1.3 miles.

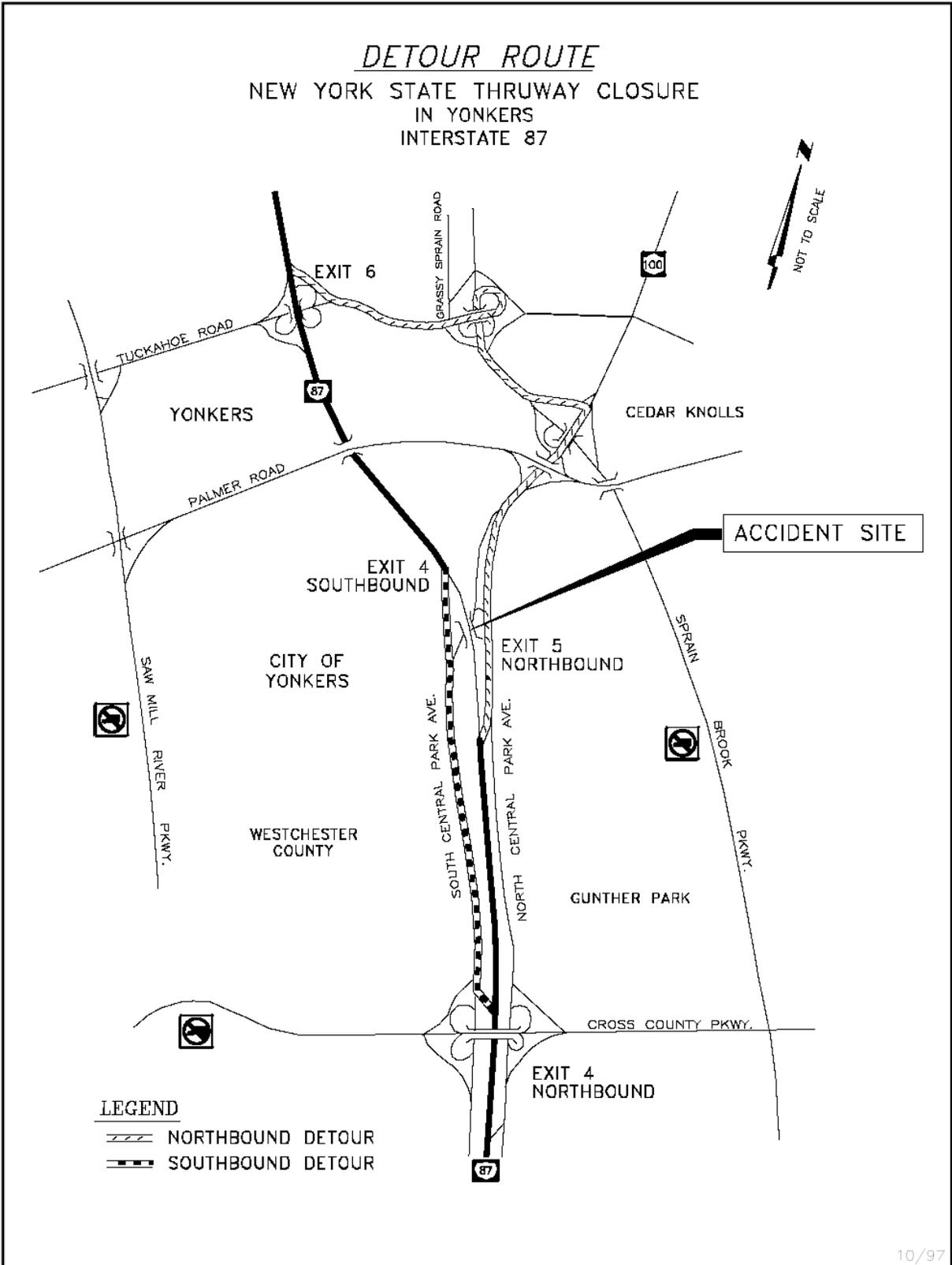


Figure 3 Traffic Detour Map (provided by NY State Thruway Authority)

Demolition and Temporary Bridge

It was determined that the use of temporary bridges would be the fastest and best way to accommodate traffic while the permanent bridge was under construction. Demolition of the damaged bridge started immediately to provide space for erection of two two-lane temporary bridges, one for southbound traffic and another for northbound traffic. The bridges were selected as a temporary measure to handle traffic while a new permanent bridge was being designed and constructed. Mabey Bridge & Shore, Inc. of Maryland manufactured the temporary bridges, and they were erected by Yonkers Contracting, see Figure 4. These panel bridges were prefabricated steel truss structures similar to British Bailey bridges that were developed during World War II for use in remote combat areas. The southbound temporary bridge was about 147 feet long and the northbound bridge was about 155 feet long in order to span over the existing abutments, so that repair work on the permanent abutments could be done without interfering with the traffic above. Temporary bridges were shifted about 3 to 5 feet to the east and the supports of the bridges were built on cantilever over the sidewalk of the Central Parkway Avenue. Each bridge weighed more than 100 tons. A ten-man crew assembled the temporary bridges and installed them using stationary launch rollers and a crane. Stationary launch rollers were used to move the temporary bridges horizontally and the crane was utilized mainly for vertical lifting of the bridges. The temporary bridges were ready for use by the traveling public in only 11 days. On October 20, 1997, the northbound temporary bridge was opened to traffic at 10:30 a.m., and the southbound bridge was opened to traffic at 12:00 noon. With the completion of the temporary bridges, the temporary detour routes were no longer necessary.



Figure 4 Two temporary bridges in Yonkers (provided by NY State Thruway Authority)

Design for Replacement

To expedite the bridge replacement process, the Thruway Authority decided to use the Inverset Bridge System that was developed by the Fort Miller Company of Schuylerville, New York in the early 1980s. A purchase contract was issued to the Fort Miller Company at the end of October, which required the company to provide 12 Inverset units (modular pre-stressed bridge units containing a combined superstructure and deck as a single unit). Each Inverset unit was fabricated to span the entire distance but provided only a portion of the bridge's width and were installed side by side to complete the bridge's lateral dimension. Each modular unit was cast upside down with the steel I-beam supports on top and concrete deck cast on the bottom. After curing in a controlled inside environment, the completed unit was turned right side up and transported to the site for placement. At the site, the units were set with a crane onto the repaired bridge abutments.

The replacement bridge built using the Inverset units was designed jointly by the Engineering Department of the Fort Miller Company and the Thruway Authority Bridge Design Unit. Due to the emergency nature of the project, the development of the design and shop drawings were expedited along with the review and approval process by the Thruway Authority. The design and review process required very close coordination including hand-delivering submittals instead of using US mail, single point of contact between design and reconstruction, and frequent conference calls to discuss progress and problem solve.

The Inverset units were placed upon the existing repaired substructure. New pedestals were cast to fit the non-conventional spacing of the Inverset units. Pre-cast parapets, which attached to the deck with bolts through the Inverset deck, were installed to expedite completion. The ends of the Inverset units were modified to work as back wall to reduce the height of abutment. Due to large skew, this modification made possible for a jointless bridge. This design detail was very unique and made the bridge very simple and reduced reconstruction time. Another important feature of the Inverset design was that the units were cast with an integral riding (sand blast form liner) finish. This allowed immediate use of the bridge that was installed in the winter months without the required waterproofing and asphalt overlay. Both waterproofing and overlay were installed the following summer. Besides waiving waterproofing and overlaying of the bridge deck as separate phases in the future, the design specifications also waived concrete curing duration based on cylinder tests results.

Bridge Reconstruction

The reconstruction contract, a total of \$2.45 million, was awarded to Felix Equities Inc. of Lincolndale, New York on October 31, 1997. A staged construction technique was implemented in order to minimize the disruption and/or inconvenience to the traveling public and surrounding community. The first stage of reconstruction, which was started on November 29, 1997 and finished on December 8, 1997, was to rehabilitate the abutments. The abutments cracked and delaminated. The surface concrete and front-face rebar were removed to a depth of 6 inches and replaced with an 11-inch high performance concrete facing. Since this was done under winter conditions, the entire concrete facing for the abutments had to be tented and heated to maintain curing temperatures. The second stage was to rebuild the southbound bridge using the first three Inverset units that were delivered to the site on December 9, 1997. The 2 temporary panel bridges had been installed on the far eastern portion of the abutments, leaving room for installation of the first three Inverset units to be placed on the far western portion of the

repaired abutments. About a week later, this stage was completed, and southbound traffic was routed onto the new structure, allowing the removal of the southbound temporary bridge. During the third stage of the reconstruction, the second three Inverset units were installed where the southbound temporary bridge had been removed. Construction of the permanent bridge continued until sufficient width was available to accommodate 4 lanes of traffic, 2 southbound and 2 northbound. At this point, the northbound traffic was rerouted from the temporary bridge onto the completed portion of the permanent bridge, and the northbound temporary bridge was removed. In the last stage, reconstruction of the remaining portion of the bridge (northbound) was completed including the installation of the last 6 Inverset units that was finished on February 10, 1998, approach slabs, and the pre-cast barrier parapet.

The Fort Miller Company and the Thruway Authority jointly inspected the fabrication of the Inverset units including the steel beam fabrication that was done in Buffalo, New York. The units were installed in accordance with the New York State Department of Transportation (NYSDOT) Inverset specification, which was already in place. All other NYSDOT's specifications were also followed during reconstruction. No compromise was made on quality and safety during replacement process. Using Inverset units, easy and simple design, and emergency bid provisions saved valuable reconstruction time and reduced the impact on the public. Under normal conditions, it would take two years to replace the damaged bridge. The contract specified a \$5,000 per day bonus/penalty for early/late completion with a \$50,000 cap for either scenario. The contractor received a \$40,000 bonus (8 days @ \$5,000/day) for early completion of the project.

Reconstruction of the bridge required lane restrictions and some infrequent closures on Central Park Avenue, which runs underneath the bridge. To minimize the impact on the public, work activities were scheduled between rush hours and construction was avoided on holidays and weekends. Closures of Central Park Avenue were limited to times necessary to erect new structure. These closures were limited to times between 9 p.m. and 6 a.m. Short-term traffic stoppages, not to exceed five minutes, occurred at various times throughout the reconstruction. Pedestrian traffic was maintained on Central Park Avenue, except at infrequent times. Table 1 provides the time sequence of major events from the accident to the completion of the bridge replacement.

Table 1 Date for Major Events

Date	Event
10/09/97	Incident occurred
10/09/97 to 10/12/97	Demolition of damaged bridge and setup temporary detours
10/09/97 to 10/20/97	Two 2-lane temporary bridges erected
10/22/97	Permanent plans available to contractors for bid development
10/27/97	A pre-bid meeting held with the potential bidders
10/29/97	Contract letting
10/31/97	Contract signed and purchase orders issued
11/01/97	Contractor mobilized
12/8/97	Rehabilitation of abutments finished
12/17/97	Southbound traffic permitted on 2 lanes of permanent bridge
01/12/98	Northbound traffic permitted on 2 lanes of permanent bridge
02/10/98	Northbound bridge completed
02/26/98	Permanent 7 lane bridge completed and in service
03/13/98	Project completion

Lessons Learned

There were many factors contributing to the success of reconstruction of the New York Thruway Bridge. In order to document what can be learned from this extreme event, the research team conducted this case study. During the study, the research team reviewed literature including information posted on web sites, interviewed people who were involved in the repair of the bridge via the telephone, and performed written surveys. Notwithstanding its terrible consequences, the Thruway Bridge tragedy provides useful lessons for state DOTs that must plan for enhanced responses during future extreme events. The following is a summary of lessons learned from this extreme event.

1. Using temporary panel bridges to accommodate traffic while the permanent bridge was under construction eased the inconvenience of the traveling public. Installation of the panel bridges was relatively easy and quick. It is recommended that state DOTs consider stockpiling panel bridges and other temporary resources for emergency use.
2. Using the Inverset Bridge System shortened the bridge reconstruction process. NYSDOT had Inverset specifications in place that made the implementation easier to carry out.
3. Since the Inverset units were produced inside the fabrication plant, winter weather had no impact on material delivery. This was very critical to the expedited reconstruction schedule.
4. Using the staged construction technique minimized the disruption and/or inconvenience to the traveling public and surrounding community during the replacement project. Work activities were scheduled between rush hours and construction was avoided on holidays and weekends. The entire operation was conducted in an orderly fashion.
5. The Thruway Authority's willingness to expedite the shop drawing review and approval process was very critical to the effectiveness of the bridge replacement.

6. Partnerships between the owner, the material suppliers, and the contractor established during the reconstruction, built trust, improved communications, reduced conflicts, and helped overcome bureaucratic obstacles and other adversities typically associate with this type of short fused project.

Survey Responses

The survey responses from the New York State Thruway Authority and the Fort Miller Company are given in the following text.

New York Thruway

1. How long did it take to expand the southbound traffic detour at Exit 4 into two lanes?

That was the first thing done. Traffic was expanded to two lanes within the first three days. Detours were set the first day, Northbound. Southbound traffic always had one lane thru a service road and then had two lanes once the lanes were expanded from the service road. Because access from Central Park Ave was blocked, these lanes provided immediate access.

2. How long did it take to demolish the damaged bridge? Was there anything unique about the demolition?

A few days, nothing was unique. The work was done from below.

3. How long did it take to install the temporary bridge? Was there anything unique about temporary bridge and its supporting system?

The temporary bridge was installed in eleven days. The unique thing about the temporary bridge design was, that the Temporary bridge was shifted about 3-5-feet to the east and the easterly support of the bridge was built on cantilever over the sidewalk of the Central Parkway. This allowed to make easy and simple future stages.

4. When was the rehabilitation of bridge abutments started and finished?

Abutment rehabilitation started approximately on or before 11/29/97 and the abutment were available for panel installation on 12/8/97

5. When was the reconstruction of the southbound bridge deck started and finished?

Phase –I Southbound started approximately on or after 12/12/97 and on or after 12/17/97 completed. At this phase Three panels were installed and the Southbound Traffic was shifted from Temporary Bridge on this newly built bridge. After shifting Southbound traffic phase –II started and additional 3-panels were installed and after completion of phase-II Northbound traffic was shifted on this newly built portion of the bridge.

6. When was the reconstruction of the northbound bridge deck started and finished?

Don't remember, but I believe, northbound was completed on around 2/10/98.

7. How many Inverset bridge deck panels were used in the southbound and northbound of the bridge? Were the panels installed at one time? What was the panel installation sequence?

6-panels were used in the southbound with total width of 55.96' with varying panel width and 6-panels in the northbound with total width of 63.33 with varying panel width. They

were installed one at a time. Starting from east one panel at a time. In phase –I, 3-panels. In phase-II, 3-panels. And in phase-III 6-panels.

8. How long did it take to produce the required Inverset bridge panels?

Don't remember.

9. Which firms/organizations were involved in the re-design of the bridge?

Re-design was completed by Thruway forces. Mr. Don Klugo for the Highway portion and Younus Samadzada for the Structural portion.

10. What changes did the designers make in order to use the Inverset System?

Inverset was selected for ease and speed of construction and certain details completed in the shop. The required waterproofing installation and overlay could be done in a later dated, which was difficult to do during winter season.

11. What kinds of modifications were made to the original bridge design in order to expedite the reconstruction?

The end of the inversets were modified to work as back wall to reduce the height of abutment and also due to large skew this modification made possible for a jointless bridge. This detail was very unique and made the design very simple and reduced construction time.

12. What kinds of specifications were waived during the redesign or reconstruction of the bridge?

Waivers of concrete closure cure durations, waiver of asphalt paving temperatures.

13. Were there any bonus/penalty clauses in the contracts with contractors and material suppliers?

Yes, bonus: \$5000 per calendar day or \$50,000 whichever is smaller, if the Northbound and Southbound traffic shifted before January 14, 98 on the newly built bridge and \$5,000 per calendar day or \$50,000 whichever smaller if the mainline and ramps work completed before March 6, 98 to accommodate three lanes in each direction. Penalty: \$5,000 per calendar day for failure to shift the northbound and southbound traffic on newly built bridge on January, 14, 98 and %5,000 per calendar day for failure to complete mainline and ramps to accommodate three lanes in each direction on March 6, 98. Lastly, \$500 per calendar day to complete the project on March 13, 98. The project completion date was March 13, 98 and the project was completed ahead of time on February 25, 98.

14. What actions were taken to ensure quality of material fabrications and reconstruction under such tight schedule?

The Bridge superstructure was prefabricated under controlled conditions and all contract work was completed under inspection as required. No specifications were changed for this work.

15. What actions were taken to ensure safety and productivity during reconstruction?

No specifications were changed for this work. All work was completed as shown in the contract plans.

16. What were the most difficult challenges during the bridge repair process?

None.

17. Under normal conditions, how long would it typically take to finish this type of repair project?

Two years construction season.

18. What were the major reasons that reconstruction of the bridge finished early?

Easy and simple design details. Using emergency bid provisions. Initial closure of the roadway to traffic.

19. If a similar incident happens in the future, what different actions will you take to expedite the reconstruction?

Each incident will require different action based on location, timing, type of structures and a lot more. We have recently introduced an annual bridge repair contract that has a contractor on call for emergency bridge repairs that was not part of our program previously.

20. What kinds of support from New York State Thruway were very helpful during the project?

Limiting of involvement of too many individuals during design and evaluation. We established single points of contact between design and construction and had frequent conference call meetings to discuss progress and problem solve.

21. What kinds of supports/helps would you like to have had from New York State Thruway, which were not provided last time?

Can not think of.

Fort Miller

14. How long did it take to expand the southbound traffic detour at Exit 4 into two lanes?

The accident occurred October 9, 1997. Within 11 days the NY State Thruway Authority had built a four-lane temporary bridge.

15. How long did it take to demolish the damaged bridge? Was there anything unique about the demolition?

N/R

16. How long did it take to install the temporary bridge? Was there anything unique about temporary bridge and its supporting system?

N/R

17. When was the rehabilitation of bridge abutments started and finished?

N/R

18. When was the reconstruction of the southbound bridge deck started and finished?

The entire project took five months.

19. When was the reconstruction of the northbound bridge deck started and finished?

The accident occurred October 9, 1997. The four-lane temporary bridge was in service in 11 days at which time work on the damaged abutment and the Inverset procurement process began.

20. How many Inverset bridge deck panels were used in the southbound and northbound of the bridge? Were the panels installed at one time? What was the panel installation sequence?

12 Inverset units were used to replace the bridge. The work was done in 3 stages. The first 5 units (Southbound) were delivered Dec. 9, 1997. About a week later traffic was placed on the Inverset units and one of the Maybe Bridges was removed. The 6th unit was placed in the next (second) stage after which the second Maybe Bridge was removed. During the third stage the 6 Southbound units were placed.

21. How long did it take to produce the required Inverset bridge panels?

Fort Miller received a contract by the end of October and delivered the first five units Dec. 9, 1997.

22. Which firms/organizations were involved in the re-design of the bridge?

The Inverset Bridge was designed jointly by the Engineering Department of the Fort Miller Co., INC. and The New York State Thruway Authority Bridge Design Unit. Due to the emergency nature of the project the design and preparation of the shop drawings by Fort Miller was expeditiously reviewed and approved by the NYS Thruway Authority. This took very close coordination including hand-delivering submittals instead of using US Mail.

23. What changes did the designers make in order to use the Inverset System?

The new bridge was placed upon the existing (rehabilitated) substructure. New pedestals were cast to fit the non-conventional spacing of the new Inverset beams.

24. What kinds of modifications were made to the original bridge design in order to expedite the reconstruction?

The deck of the new Inverset bridge replicated the original bridge. However, precast parapets, attached to the deck with bolts through the Inverset deck, were installed to expedite completion. Another important feature of the Inverset design was that the Inverset units were cast (upside down) with an integral riding (sand blast form liner) finish. This allowed immediate use of the bridge that installed in the winter months without the designed asphalt overlay. The design overlay was installed the following summer.

25. What kinds of specifications were waived during the redesign or reconstruction of the bridge?

The Inverset bridge was installed in accordance with a NY State DOT Inverset Specification, already in force. In general, all other NYS DOT specifications were followed.

26. Were there any bonus/penalty clauses in the contracts with contractors and material suppliers?

N/R

27. What actions were taken to ensure quality of material fabrications and reconstruction under such tight schedule?

The Inverset units were fabricated with joint Fort Miller / NY State Thruway inspection. This included inspection of the steel beam fabrication (including painting) that was done in Buffalo, NY, approximately 300 miles west of the precast plant.

28. What actions were taken to ensure safety and productivity during reconstruction?

N/R

29. What were the most difficult challenges during the bridge repair process?

N/R

30. Under normal conditions, how long would it typically take to finish this type of repair project?

N/R

31. What were the major reasons that reconstruction of the bridge finished early?

From Fort Miller's point of view it was the very intense and comprehensive partnering that occurred between all project participants during the design, fabrication and erection process.

32. If a similar incident happens in the future, what different actions will you take to expedite the reconstruction?

N/R

33. What kinds of supports from New York State Thruway were very helpful during the project?

From Fort Miller's point of view the Thruway's willingness to meet on a moment's notice and to expeditiously review and approve shop drawings was very helpful in expediting the project.

34. What kinds of supports/helps would you like to have had from New York State Thruway, which were not provided last time?

N/R

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The authors would like to thank Mr. Younus Samadzada of the New York State Thruway Authority and Mr. Peter Smith of the Fort Miller Company for their vital input and cooperation during the case study. A special thanks goes to State DOTs who provided financial support and guidelines for this research project. These DOTs include Texas, Georgia, Illinois, Minnesota, Mississippi, New Jersey, New Mexico, Ohio, and South Carolina.

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Appendix D

**“Transportation Security Activities in Texas” (Rummel, 2002)
Article presented at International Bridge Conference, 2002.**

Transportation Security Activities in Texas

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(IBC-02-A3)

KEYWORDS: Transportation Security, Infrastructure Security, Vulnerability Analysis, Critical Structures, Security Countermeasures, Emergency Response Plans

ABSTRACT: Texas has the largest bridge inventory of any state, with nearly 33,000 on-system and 17,000 off-system bridges. This inventory, coupled with the state's extensive land area, shoreline, and border with Mexico, makes transportation security a challenging task for the state.

The Texas Department of Transportation (TxDOT) has embarked on a five-step approach to transportation security. The first step is identifying the state's most critical bridges. TxDOT recognizes that budget constraints require focusing on only the most critical structures. Second, once the most critical structures are identified, options are developed for deterrence, surveillance, and protection of those structures, tailored to each specific location. Third, because in-house expertise is not sufficient to cover all the aspects that are needed in this wide-ranging effort, research in cooperation with outside experts in various specialized security-related fields is initiated. Fourth, military transportation needs are addressed because our highways and bridges form a vital link in the defense transportation network of this country. And finally, a process is developed that will provide the training, procedures, and communication channels--both internally and with other federal, state and local agencies--to ensure that TxDOT is prepared to deal with potential security threats.

IDENTIFYING THE CRITICAL BRIDGES

TxDOT uses a two-step process to rank critical bridges across the state. The first step is an automated ranking of all the bridges listed in the National Bridge Inventory (NBI) for the state. This

ranking is accomplished through the use of a Microsoft Access program using the Texas Bridge Criticality Formula given in Eq. (1). The formula accounts for several criteria that are measured using data available from the National Bridge Inspection database that can be downloaded to the Access program.

The criteria incorporated into the formula were those items TxDOT considered important, based, in part, upon the responses to an AASHTO/TRB Task Force survey that helped define and prioritize these criteria. The joint survey, titled "Security and Emergency Response Survey of State Transportation Agencies", was a cooperative effort of the AASHTO Task Force on Transportation Security and the TRB Task Force on Critical Transportation Infrastructure Protection. The criteria included the economic impact due to disruption of commerce, which was quantified in the TxDOT formula in terms of Average Daily Truck Traffic. General passenger transportation needs and risks to public safety were considered in terms of Total Average Daily Traffic (ADT) and Detour Length. Connectivity, which represents the ripple effect within the highway system, was considered in terms of the ADT of intersecting routes, and whether the bridge in question represented an interstate-to-interstate interchange. Another criterion was whether a damaged bridge could restrict navigation access to important waterways, and was determined by whether a Coast Guard permit was required for that particular structure. Given Texas' border with Mexico and the importance of international trade, another criterion was whether the bridge was an international crossing. The inclusion of the bridge on the Strategic Highway Network, which functions as a system of primary routes for the movement of military personnel and supplies, was another consideration. And finally, the bridge type and maximum span length were used to determine a repair/replacement

index, which represents a measure of the cost and ease of repair of a particular structure.

As part of the formula, the relative importance given to each criterion can be adjusted by the use of a weighting factor to reflect the value TxDOT assigns to each different criterion. Should the relative importance change in the future, the various weighting factors can easily be changed and a new listing of bridges can be obtained.

TEXAS BRIDGE CRITICALITY FORMULA-The following equation represents Texas' formula for ranking bridge criticality.

(1)

Criticality Index = $\{[(\text{Truck ADT} \times \text{Truck ADT Factor} / \text{Max. Truck ADT}) + (\text{ADT} \times \text{ADT Factor} / \text{Max. ADT}) + (\text{Detour} \times \text{ADT} \times \text{Detour Factor} / \text{Max. Detour} \times \text{Max. ADT}) + (\text{Intersect Rt. ADT} \times \text{Intersect Rt. Factor} / \text{Max. Intersect Rt. ADT}) + (\text{Interstate Intersection} \times \text{Interstate Intersection Factor}) + (\text{Navigation Importance} \times \text{Navigation Factor}) + (\text{International Importance} \times \text{International Factor}) + (\text{Military Importance} \times \text{Military Factor})] / 8\} \times \text{Replacement Factor}$

BASIC ELEMENTS OF THE FORMULA-The Texas Bridge Criticality Formula has the following elements and definitions.

Commerce Criteria

- Truck ADT = Average Daily Truck Traffic based on Item 109 of the Bridge Inspection Data Base (BIDB) for the subject bridge.
- Max. Truck ADT = The maximum Truck ADT for any bridge in the BIDB for the entire state.
- Truck ADT Factor = Numeric factor, nominally between 0 and 1, that relates the relative importance of this criterion to the other criteria in the formula.

Transportation Needs Criteria

- ADT = Average Daily Traffic based on Item 29 of the BIDB.
- Max. ADT = The maximum Truck ADT for any bridge in the BIDB for the entire state.
- ADT Factor = Numeric factor, nominally between 0 and 1, that relates the relative importance of this criterion to the other criteria in the formula.
- Detour = Bypass, Detour Length based on Item 19 in the BIDB.
- Max. Detour = The maximum Detour Length for any bridge in the BIDB for the entire state.
- Detour Factor = Numeric factor, nominally between 0 and 1, that relates the relative

importance of this criterion to the other criteria in the formula.

Connectivity Criteria

- Intersect Rt. ADT = Average Daily Traffic on the Intersecting Route
- Max. Intersect Rt. ADT = The maximum Average Daily Traffic on the Intersecting Route for any bridge in the BIDB for the entire state.
- Intersect Rt. Factor = Numeric factor, nominally between 0 and 1, that relates the relative importance of this criterion to the other criteria in the formula.
- Interstate Intersection = 1 if both main and intersecting routes are Interstate Highways, or 0 if one or both are not Interstate Highways.
- Interstate Intersection Factor = Numeric factor, nominally between 0 and 1, that relates the relative importance of this criterion to the other criteria in the formula.

Navigational Access Criteria

- Navigation Importance = 1 if the bridge requires a Coast Guard Permit based on Item 38 in the BIDB, or 0 if no Coast Guard permit is required.
- Navigation Factor = Numeric factor, nominally between 0 and 1, that relates the relative importance of this criterion to the other criteria in the formula.

International Access Criteria

- International Importance = 1 if the bridge borders on Mexico based on Item 98 on the BIDB, or 0 if it does not.
- International Factor = Numeric factor, nominally between 0 and 1, that relates the relative importance of this criterion to the other criteria in the formula.

Military Movement Criteria

- Military Importance = 1 if the bridge is located on the Strategic Highway Network based on Item 100 in the BIDB, or 0 if it is not.
- Military Factor = Numeric factor, nominally between 0 and 1, that relates the relative importance of this criterion to the other criteria in the formula.

Replacement /Repair Index

- Replacement Factor = Structural Complexity x Span Length Factor, where:
Structural Complexity = one of three numeric factors based on if the superstructure type's complexity is rated low, medium or high. These numeric factors nominally range between 0 and 2. All bridge superstructure types from Item 43 of the BIDB were rated as being low, medium or

high and the numeric factor are assigned accordingly.

Span Length Factor = one of three numeric factors based on the length of the main span of the bridge. These numeric factors nominally range between 0 and 2. Span lengths based on Item 48 of the BIDB are grouped as less than 150', 150' to 300' and more than 300', with numeric factors assigned accordingly.

Through the use of the Microsoft Access program, the Criticality Indexes for all bridges in the NBI for the state were calculated and ranked. The information contained in the NBI Database for the top ranking bridges was verified to ensure that any errors in the data from the NBI Database would not skew the results for the Criticality Index calculations.

The second step of the procedure to determine the most critical bridges involved incorporating the addition of other bridges not included in the automated process. As with most state transportation departments, Texas is divided into a number of districts. These districts also evaluated the bridges in their geographic areas of responsibility and provided input on bridges that they felt were critical. Given their local perspective, they were able to identify issues, including site-specific conditions, which were not identifiable in the NBI data. These local factors included the lack of adequate capacity on available detour routes; being the only access to schools, hospitals, large office complexes, or industrial areas; important utilities carried across the bridge; proximity to hazardous facilities such as chemical plants and refineries; and location on hurricane evacuation routes.

The structures that were obtained from the two independent processes were then merged into a final listing of critical bridges. An initial listing of 80 critical bridge locations was obtained through this process. This listing is being used as the basis of further analysis for threats, vulnerabilities and possible countermeasures.

DETERRENCE, SURVEILLANCE, and PROTECTION OPTIONS

The second item in the five-step approach to transportation security is developing deterrence, surveillance, and protection options. The primary purpose of such countermeasures is to reduce either the potential for or consequences of attacks on critical structures.

Among the deterrence techniques that have been examined for Texas' bridges are:

- Eliminating parking areas beneath the bridges,
- Restricting ingress and egress routes from adjacent areas through the use of fencing or other barriers,
- Limiting access to important bridge components by securing or removing ladders and inspection platforms,
- Providing additional lighting,
- Limiting and monitoring access to plans of existing bridges, while ensuring our compliance with Open Records legislation.

Some of the surveillance options being considered for transportation security include:

- Clearing of vegetation to provide clear lines of sight,
- Installing motion sensors and other active sensors to monitor sensitive areas,
- Installing closed-circuit television (CCTV) surveillance cameras to operate in conjunction with existing Intelligent Transportation System (ITS) environments,
- Notifying local law enforcement officials of which bridges have been determined to be critical and requesting increased patrols.

Protection options for critical bridges under consideration include:

- Providing barriers or other protection for bridge columns that are outside the roadway clear zone to protect against an intentional ramming attack,
- Providing pass-through gates in continuous concrete median barriers to enable rerouting of traffic and access for emergency vehicles,
- Installing advanced warning systems to warn motorists of potentially hazardous conditions on a bridge.

The options for deterrence, surveillance, and protection selected for a particular location must be carefully analyzed to ensure that the costs associated with the selected options are commensurate with the benefits derived. Especially for the equipment- and personnel-intensive items, the long-term maintenance and operating costs must be considered, as well as the initial capital outlays. Many of these options are much less expensive if they are incorporated into the original design of a project rather than retrofitted at a later time.

SECURITY RESEARCH ACTIVITIES

The third step in the TxDOT security approach is sponsoring research on those issues for which there was limited in-house experience. In sponsoring such research TxDOT realized that the topics chosen must add value to the process, be implementable in a reasonable time period, and provide cost-effective solutions. The topics selected were non-traditional for Department of Transportation-sponsored research in that transportation security is simply not an issue that has been examined in depth before. Similarly, TxDOT's research partners in academia have not investigated these subjects in the past, and, therefore, they will also need to involve outside resources.

The first area that was selected for research effort was the design of bridges for security, to result in design solutions that reduce the threat and mitigate the consequences of terrorist acts.

With respect to bridge design for security, fundamental differences could exist between the forces imposed upon a structure from a natural disaster and those from a terrorist attack. Bridges that are hardened for natural disasters such as earthquakes, floods, and wind, are not necessarily hardened for terrorist attack. Solutions are needed that reduce the threat and mitigate the consequences of such attacks. We need innovative design solutions that are based on an assessment of consequences of terrorist threats instead of replicating designs based on consequences of natural disasters.

To meet these requirements, TxDOT has sponsored a research project on "Design of Bridges for Security." This project was awarded in March 2002 to the Center for Transportation Research at the University of Texas at Austin. It is a two-phase project, with Phase I being a literature search and work plan. A report on Phase I will be presented later this summer. Phase II will be contingent on the results of Phase I and will include guidelines to implement cost-effective measures to improve bridge security.

A second area of research that was selected concentrated on quickly responding to the possible consequences of a terrorist attack. This research seeks to identify strategies and technologies to restore the use of a bridge quickly in the event it is damaged or destroyed in an attack. The process may use simple technologies that already exist. The benefits of this research will carry over into

situations involving bridge loss due to floods and earthquakes, as well.

In this area, TxDOT has sponsored a research project on "Rapid Bridge Replacement." This project was awarded in March 2002 to Texas Tech University. This project is also a two-phase project, with Phase I as a literature search of all expedient and cost-effective repair and replacement techniques. This work will be completed later this summer. Again, Phase II will be contingent on the results of Phase I. Phase II will evaluate all the techniques and incentives for rapid bridge replacement from both civilian and military sources. Phase II will also demonstrate case studies as examples.

Both of the aforementioned projects were initially internal TxDOT-sponsored research projects. Recognizing the value that these projects will have to other states, as well as the advantages of getting other states' perspectives on these subjects, the projects are being changed to Texas-led pooled-fund projects. As such, the project scopes will be broadened and more funding will be made available. Solicitations to other states to participate in these pooled-funded projects have been made. A kickoff meeting has been scheduled for September 2002. At this meeting the respective researchers will present the results of their Phase I work and their proposed work plans for their Phase II efforts.

Still another area that TxDOT envisions as an important aspect for the security of our bridges is the field of surveillance technologies. With respect to research with surveillance systems, an FHWA-sponsored pooled-fund project is being initiated to look into this field. This project will look at low-cost, easy-to-implement protection and optimization issues for various bridge types. The project will also examine state-of-the-art technology and how that technology can best be used.

ENSURING MILITARY MOBILITY

The fourth step in TxDOT's transportation security approach is making sure that military mobility needs are met. It should be noted that addressing military mobility needs is already part of TxDOT's standard operating procedure, but these procedures were reviewed to ensure that they met the military's needs was in order. In Texas, the National Guard coordinates all military movements. TxDOT assists the National Guard by providing approved routes and checking bridge capacities.

Most large-scale military movements in the state use the Strategic Highway Network (STRAHNET).

TxDOT also provides numerous pre-approved non-STRAHNET routes for single-vehicle moves. These are re-evaluated every two years to account for the changing conditions of the highway and bridge elements as well as additions of new construction to the system. TxDOT will routinely approve bridges on a route within 10 days and can accommodate same-day reviews.

TxDOT recently participated in a Military Mobility Exercise sponsored by the Federal Highway Administration that simulated large-scale movements of military equipment and personnel. The purpose was to improve the coordination between the military and affected civilian agencies to ensure the effective movement of forces from their home bases to various ports of embarkation.

ENSURING PREPAREDNESS

The fifth and final step in TxDOT's transportation security approach is ensuring preparedness to deal with the consequences of possible security threats. This preparedness includes training, procedures, and internal and external communication to ensure an expedient and effective response to all forms of security threats or actions.

Prior to the events of September 11, TxDOT had participated in a number of different exercises. Several of TxDOT's districts participated in a Weapons of Mass Destruction Exercise. These have been held in the urban areas and involved participation by local, state, and federal agencies such as the Federal Bureau of Investigation, Drug Enforcement Administration, and US Army. The exercises were designed to prepare for events such as large hazardous materials (HAZMAT) incidents and biological agent dispersals. These exercises are designed to optimize coordination among the local, state, and federal agencies that could be involved in weapons of mass destruction events.

TxDOT was one of 25 state agencies that participated in a Foreign Animal Disease Exercise last year at Texas A&M University. Although the exercise was focused primarily on preventing the spread of hoof-and-mouth disease, the same methods used during this exercise could be applied in cases of a bioterrorism attack. Should some sort of outbreak occur, TxDOT maintenance crews would help contain affected areas by blocking roadways and controlling access to the affected area.

TxDOT has developed an Emergency Highway Traffic Regulation Plan, which is a system of traffic management and control devised to regulate the use of highways and to expedite and facilitate urgent vehicle movement by highway just before, during, and just after a national security emergency. In addition, site-specific emergency response procedures are being developed for each of the bridges that have been determined to be critical to the state's transportation system. These emergency response procedures will include such areas as traffic control plans, detour plans, debris management plans, sources for key components, lists of qualified contractors, emergency response contacts and lists and phone numbers of key personnel.

TxDOT is also a resource agency for the Texas Governor's Task Force on Homeland Security. This task force coordinates efforts to detect and deter threats to the state. Its purpose is to assure Texans of state and local preparedness to respond to such threats. It assesses the ability of state and local governmental agencies to respond to threats and to effectively provide victim assistance and aids coordination among federal, state and local efforts. The Task Force has developed recommendations on how to improve Texas' ability to detect, and to develop and coordinate a response to, terrorist events. It also helps coordinate state efforts with the Federal Office of Homeland Security.

TxDOT is currently participating with the New Mexico State Highway and Transportation Department and Sandia National Laboratories in the development of the Integrated Transportation Analysis (ITA) system. The ITA is a web-based application for sharing intelligence information in real time among state DOTs, the US Department of Transportation, and the nation's security and law enforcement agencies. The initial demonstration of the system took place on July 3, 2002. It is hoped that the ITA system will provide integration of national level security assets, information, alerts and warnings into a common pathway that can be delivered through the US DOT/FHWA and on to the various state DOTs.

A final aspect of ensuring preparedness includes the field of training. The American Association of State Highway Transportation Officials (AASHTO) Task Force on Transportation Security is sponsoring terrorism recognition and awareness training in cooperation with the Washington State DOT. When developed, this training will be given to all TxDOT personnel, with special emphasis on those

employees who spend significant time in the field, such as maintenance personnel. These are the individuals who have the best opportunity to observe and report the kind of suspicious activities that can help to prevent or minimize the consequences of terrorist action.

SUMMARY

The tragic events of September 11, 2001 require that transportation agencies across this country elevate the security of their critical transportation infrastructure to a central priority. Achieving that goal will be difficult and costly but necessary. TxDOT is currently in the early stages of determining the security needs related to its transportation assets and will continue to partner with other public agencies, with academia, and with private industry to address these needs. With limited funding available, the addition of true value from any security implementation strategies must be ensured.

This is a process that will require a sustained, long-term effort and a new perspective on the way that State DOTs do business. The TxDOT five-step approach to transportation security can act as a resource for states that have yet to begin this process. Cooperation and the sharing of information will be crucial for success in the ultimate goal of ensuring the safety and security of the traveling public.

ACKNOWLEDGEMENT

A project of this scope requires the talents and hard work of a number of people. Many individuals are responsible for the progress that has taken place to date, but the authors would like to specifically acknowledge the efforts of those individuals in TxDOT's Bridge Division and Maintenance Division who have worked many hours to develop this program while still attending to their other work responsibilities.

Appendix E

Emergency Response Procedures Template

Developed by the

Texas Department of Transportation

EMERGENCY RESPONSE PROCEDURES

BRIDGE

I. Background

Districts are required to develop a coordinated emergency response plan for each identified critical structure within their district.

The tasks and events that follow a catastrophic failure of a major highway structure must be accomplished expediently to lessen the impact on the economy of the, community, region, state and the nation.

Therefore a response plan including a coordinated traffic control plan with appropriate detour(s) and a debris management plan should be developed and incorporated into these procedures.

An action plan to expedite recovery, repair and /or reconstruction should also be included as part of these procedures. Sources for spare components, materials and supplies should be identified as well as contractors capable of repairing or reconstructing the critical facility. Key personnel that would be involved should be identified and provisions for contacting them during non-duty hours should be listed.

Prior coordination with State, Federal and local response and recovery agencies is necessary to assure a timely response and assistance is available to manage the incident.

BRIDGE DIVISION

The Bridge Division has identified individuals that would deploy upon short notice to inspect a structure when requested by the district. The Bridge Division is prepared to provide assistance to the district to immediately assess damages, identify requirements, and assist as appropriate in response and recovery operations.

Maintenance Division

The Maintenance Division can provide assistance with:

- Emergency contracts
- Coordination of the State's and TxDOT's response to a catastrophic bridge failure.
- Obtaining assistance from other states, FHWA and other state agencies.

II. PURPOSE

The purpose of this document is to establish procedures for the District Staff to effectively coordinate TxDOT's response to the threat of or the catastrophic failure of the _____ Bridge.

III. SCOPE

These procedures are applicable to the District Staff and serve as a guide for other agencies for planning, response and recovery actions related to an emergency incident at the _____ bridge.

IV. RESPONSIBILITIES during increased threat conditions

Notify law enforcement of need for increased security patrols.

Phone numbers and contacts for:

- Local law enforcement
- DPS
- Coast Guard
- River Authority Security
- Port Authority Security
- Corps of Engineers

V. RESPONSIBILITIES following a catastrophic failure

Implement traffic control plan. Assess the damage and determine the course of action to rapidly repair/replace the structure and to provide suitable detour(s): coordinate with State, Federal and local response and recovery operations to assure timely response and assistance is provided to cope with and manage the incident.

A. Maintenance Section Supervisor

- Notify District Maintenance Director and Area Engineer
- Proceed to incident site
- Implement Traffic Control Plan
- Coordinate with Incident Commander
- Assist with restricting access to the incident site
- Update Road Condition Report

B. District Engineer

- Notify Administration
- Obtain approval for Emergency Contracting

C. Director of Maintenance/Director of Operations

Notify: Maintenance Division personnel
Bridge Division personnel
Key District personnel
DPS/Law enforcement

Other Notifications, as appropriate:

Local law enforcement
Coast Guard
River Authority Security
Port Authority Security
Corps of Engineers
TNRCC Regional Office

D. Traffic Operations

Review and update as necessary previously developed coordinated Traffic Control Plan and Detour Plan
Location of barricades cones variable message board signs, etc.

E. Area Engineer

Contact the Association of General Contractors
Determine availability of appropriate equipment and labor.
Identify key equipment and material suppliers, who can supply such items as shoring, falsework and temporary bridges.
Identify TxDOT facilities that have temporary bridges in storage (along with the capabilities and limitations of those structures).
Obtain as-built plans from_____
Debris removal and disposal (Emergency contract considerations, Identify contractors capable of performing debris removal and disposal. Review the previously developed debris removal plan.

F. Chief Accountant

1. Assign task numbers to track expenditures
2. Disseminate task numbers to all involved

G. District Public Information Officer

1. Obtain relevant information and disseminate to media and other appropriate PIOs.
2. Monitor Road Condition Report

H. Director of Construction

1. Determine availability of inspection workforce
- 2.

I. Director of District Design

1. Provide initial damage assessment.
2. Work on repair details.

J. Director of Administration

1. Purchase of services and materials as needed.
- 2.

K. Deputy District Engineer

1. Coordinate the efforts of the District's response.
- 2.

L. Transportation Planning

1. Set-up CSJ(s) for the project (s)
2. Obtain necessary permits and easements.

VI. RECOVERY OPERATIONS

Response efforts will continue to be coordinated by the district with the appropriate, federal and state agencies and local jurisdictions.

District Engineer

Date

ATTACHMENTS:

Traffic Control Plan
Detour Plan
Debris Management Plan
Source for Key components
Qualified Contractors
Emergency Response Contacts
List and Phone Numbers of Key Personnel