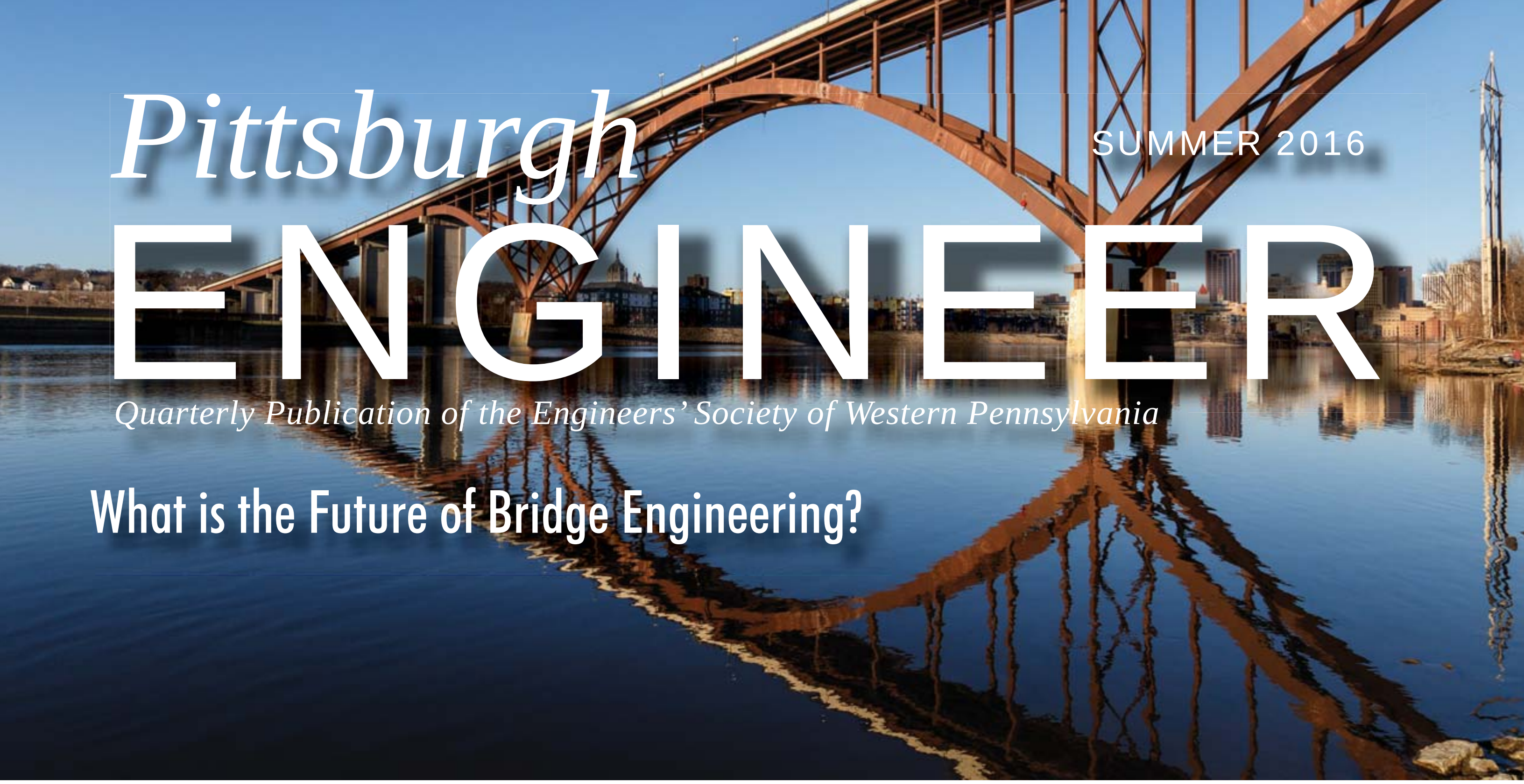
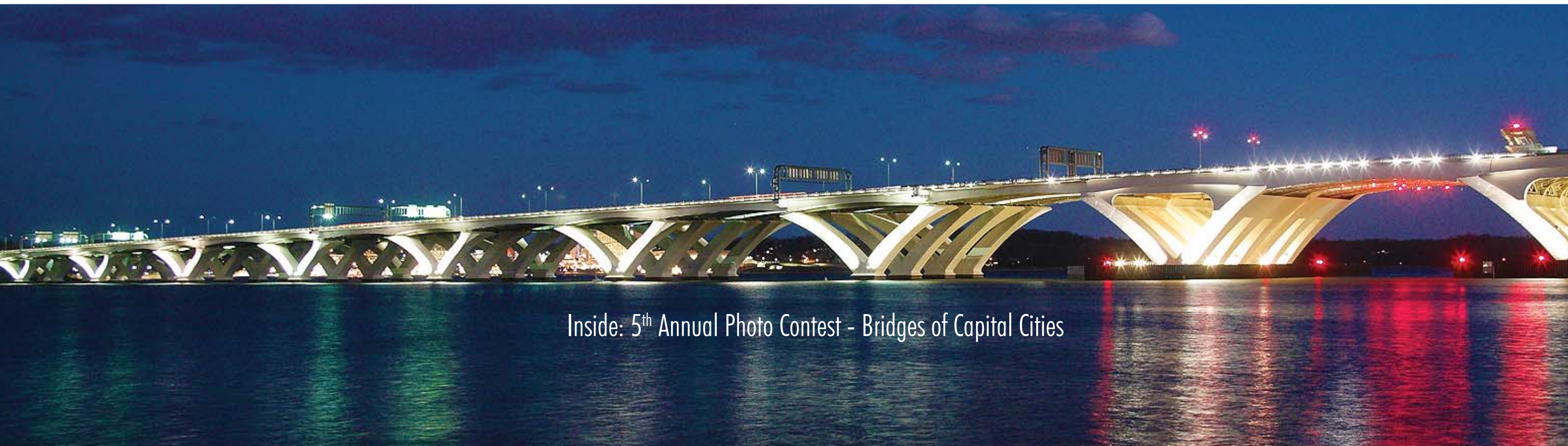
Pittsburgh ENGINEER

SUMMER 2016

Quarterly Publication of the Engineers' Society of Western Pennsylvania

What is the Future of Bridge Engineering?





Inside: 5th Annual Photo Contest - Bridges of Capital Cities

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In this issue...

NEW IBC APP

Check out our brand new IBC APP! All of the Conference details at the convenience of your smart phone or tablet. The new APP provides more detail than ever before - full program listing, speakers bios, enhanced exhibitor information, up-to-the-minute announcements, attendee messaging, and much more! Download the APP thru Google Play or the App Store, or use this link https://crowd.cc/s/dgTy - or scan this QR code...

The Gaylord National Resort & Convention Center
National Harbor, MD
Home of the 2016 IBC

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Guest Editor Column

HOW TECHNOLOGY IS IMPACTING BRIDGE ENGINEERING

We are all aware of the tremendous influence that technological advances and innovation is having on our everyday lives. Many of the space-age ideas that were routinely depicted in science fiction movies several decades ago are now reality as self-driving cars, smart phones, communication tools like Skype, Facebook, Bluetooth connectivity and renewable energy sources have impacted our world. When you think that the well of new ideas has dried up, along comes the next revolutionary idea or item. Tried and proven methods are being replaced with innovative approaches that often place engineers in uncomfortable places. Newton's three basic Laws of Motion will never change and the force effects resulting from structural loading will always be present. However, the way in which a Structural Engineer practices is changing as rapidly as the world around them.

As the Engineers Society of Western Pennsylvania prepares for the 33rd Annual International Bridge Conference, we reflect upon how technology is impacting the delivery, performance and evaluation of bridges. This Special Edition of the Pittsburgh Engineer features articles that demonstrate these impacts. As you read through the articles and view the pictures, you will immediately see the influence of technology. Tremendous strides are being made. In addition to the articles, this Special Edition features the results of a photo contest where you will be treated to a sampling of some very special images of bridges in Capital Cities both here and abroad reflecting the International flavor of the Conference and the new venue.

Guest Editors Jane-Ann Patton, George Horas and Thomas Leech

As we welcome the Virginia Department of Transportation and focus on their bridge program, note that technology is impacting their program. Be sure to check in with them as you tour their exhibit and take in the details of the ways in which our industry is being positively influenced by technology.

Our request for articles, for this special edition of the Pittsburgh ENGINEER, asked prospective authors to envision the Future of Bridge Engineering. The response to our request was outstanding with many authors, with divergent backgrounds, sharing their unique visions of emerging technologies that will enhance and change the world of bridge design, construction, inspection, maintenance and research as we now know it.

John Dietrick

IBC 2016 Chairman's Welcome

By John Dietrick

On behalf of the Engineers' Society of Western Pennsylvania (ESWP) and the IBC Executive Committee, welcome to the Gaylord National Resort and the 33rd Annual International Bridge Conference! This year our Conference is making history, as we have moved our venue to the Nation's Capital after over three decades of successful conferences in Pittsburgh, PA. We believe that this new venue will create even more interest and enthusiasm for IBC, which has grown into the pre-eminent international technical bridge conference and exhibition.

Our Conference begins on Tuesday, June 7 with a variety of activities that include a tour of the Turner Fairbanks Research Center in McLean, VA. The Center houses the Federal Highway Administration's Office of Research, Development, and Technology, which includes over 20 laboratories dedicated to some of the world's most innovative bridge research. Our program on Tuesday also includes an International Welcome Reception, as well as an Exhibit Hall Welcome Reception.

We are honored to have the Virginia Department of Transportation (VDOT) as our Feature Agency this year. On Wednesday, June 8, VDOT will host a session focusing on the many bridge projects and recent developments taking place around the State. VDOT will also host an open house, and they invite you to stop by and learn more about VDOT and their bridge program.

Our Keynote Session will also take place on Wednesday, and we are excited to be joined this year by Mr. Jian Wei Chen, Vice President of Chongqing Construction and Investment Company, one of the largest bridge construction companies in China. He will share insights into the exciting growth and expansion of bridge construction in his home country. Additionally, US Transportation Secretary Anthony Foxx has been invited as our keynote speaker, and we look forward to his perspectives on the recently passed transportation funding bill and other developments affecting US infrastructure.

Throughout the four days of IBC, we will be offering a tremendous Technical Program that includes presentations that cover the entire spectrum of bridge engineering. We received a record number of abstracts this year, and the extraordinary level of interest in presenting at IBC is reflected in the quality of the Technical Program. As in the past, we also are offering a wide variety of workshops throughout the conference. This year, we are happy to partner with the Deep Foundation Institute (DFI), which has helped to sponsor a session dedicated to foundations and geotechnical issues associated with bridges. DFI will also have a dedicated area in our Exhibit Hall – we thank them for their participation in this year's technical program.

Our Awards Dinner will take place Thursday, June 9, and again this year our Awards Committee was extremely impressed with the many outstanding projects nominated. The list of IBC award winners this year is second to none, and we are pleased to present Dr. Dennis Mertz of the University of Delaware with the John J. Roebling Lifetime Achievement Award, in recognition for his many years of service to our profession.

The response we have received from exhibitors this year has been outstanding, and we anticipate the Exhibit Hall at our new venue to be filled with booths from across our industry and from all over the globe. This year, our new Exhibit Hall will host all lunches and evening receptions during the conference, while enabling exhibitors to attend our technical sessions.

We are excited about the Monumental Move that the International Bridge Conference has made this year. Like Pittsburgh, our nation's capital boasts of many outstanding bridges, and maintains a proud legacy of bridge building that includes the recently-constructed Woodrow Wilson Bridge over the Potomac River, within easy view of the National Harbor. We are also excited about the opportunity the conference offers our many international participants to visit our capital city. The IBC Magazine this year captures this theme with a photo contest focused on Bridges of Capital Cities.

Please join me in thanking the volunteer Executive Committee members, as well as the ESWP Staff, for their efforts leading up to this conference. The conference is a result of the many hours of hard work and service from these dedicated individuals. As you walk around and enjoy the conference this year, feel free to stop and talk to any of our committee members and provide feedback - we are always looking for ways to make your conference experience the best it can be.

We look forward to seeing you at this year's conference!

About the author...John Dietrick, P.E., S.E., is the General Chair of the 2016 International Bridge Conference and a Senior Vice President and National Bridge Practice Director for Michael Baker International.

THE FUTURE
OF BRIDGE ENGINEERING

By Adam Matteo

American society is committed to continual growth. We never stop building, expanding, improving. While we will undoubtedly continue to grow, for the first time we face a challenge of a different nature: our highway network is now over 100 years old, and financial reality dictates that we focus primarily on maintaining the system we have.

The 20th century delivered impressive achievements that advanced the field of bridge engineering:

- The great suspension bridges of Othmar Ammann and David Steinman
- The interstate highway system
- The widespread adoption of pre-stressed concrete
- Advancements in understanding seismic response, geotechnical behavior and fatigue
- Improvements in computer modeling and construction practices

New materials such as low-permeability concrete and corrosion-resistant steels are being used to prolong the lives of structures that must perform in difficult environments.

While lacking the glamour of constructing grand new crossings, maintaining a highway system worth trillions of dollars represents a daunting challenge in its own right. We may be capable of building our infrastructure anew, but the cost would be prohibitive. Current and future bridge engineers must rehabilitate, repair and preserve the most durable structures possible within very tight fiscal constraints. The future of bridge engineering is to build durable new bridges, but more importantly, to keep the current inventory in the best possible state of repair with our existing resources.

AN AGING SYSTEM

The average age of a highway bridge in Virginia is 48 years. Bridges built before 2003 are commonly expected to have a 50-year service life, so most are near or beyond the point of scheduled replacement. If Virginia replaced bridges as they turn 70, however, the cost over the next 35 years would be a prohibitive $44 billion. Fortunately, new techniques and materials allow us to extend service life indefinitely with timely intervention and proper care.

Water and de-icing agents, applied steadily over decades, continually attack steel components of bridges. Intrusion of chlorides into concrete bridge elements fosters corrosion of steel reinforcing, which in turn causes spalling. Without the protection of concrete, steel reinforcing becomes further exposed to the elements, accelerating the corrosion and deterioration cycle. This process is the primary cause of bridge deterioration.

The Virginia Department of Transportation acknowledges that the best way to address the problem is through system preservation. This approach represents a cultural change for an industry that typically provides only necessary repairs, and then replaces the structure after deterioration progresses too far. This is known as the "worst first" approach.

The new challenge for transportation officials is to embrace timely repair and preservation, rather than replacement at the end of usable life. All physical systems and assets deteriorate over time. Our job is to recognize when and how to invest in their improvement and longevity. With the age and state of deterioration of the highway network, many of its critical components are reaching a "tipping point." We can act now with targeted repairs and economically provide decades of additional service, or we can wait and eventually face the overwhelming task of replacing assets at a significantly higher cost. The latter option is no longer practical because the demand for the transportation network continues to grow unabated, but the public's willingness to invest in it is limited.

TARGETED REPAIRS

What does "targeted repairs" mean? Specifically, we should repair only those portions of a structure that require repair. While this makes intuitive sense, common practice doesn't usually follow this path. Many portions of a bridge deteriorate simultaneously, which often leads to more aggressive measures, including full replacement. One example of targeted repairs can be found in the example of a corroded girder end. Located under an expansion joint that has leaked for decades, the first photo shows the end of a steel girder that has corroded to an extent that its structural integrity has been compromised. Because this girder was among many in this condition, and the deck was also in poor condition, the traditional approach has been to replace the deck and all of the girders. However, in this case the engineers employed a combination of targeted repairs and preservation techniques to give the bridge as many as 25 years before major work is required again. The photo below shows the same girder after repair. While the girder is not new, it is certainly adequate to serve its purpose.

Severely Corroded Steel Girder. Corrosion Caused Primarily by Leaking Expansion Joints

Steel Girder after Repair

In addition to the structural steel deterioration, the bridge had problems with the deck, joints and piers. A low-permeability concrete overlay, placed over a hydromilled surface, was installed on the deck. The hydromilling process removed the majority of the chloride contamination from the concrete and provided an excellent substrate for the overlay. The low-permeability overlay will prevent the intrusion of chlorides for decades to come, while providing an

BRIDGE PRESERVATION

Bridge repairs make little sense if the original causes of deterioration are not addressed. Leaking expansion joints allowed for the intrusion of chloride-laden water, which in turn caused the girders to corrode. In the project's first phase of work, the leaking expansion joints were replaced with more durable materials. In the second phase the joints will be eliminated entirely using a detail known as a "link slab." Virginia has successfully used link slabs to eliminate joints wherever practical. A link slab, shown in the photo below, provides a smooth, low-maintenance deck where a

Link Slab

leak-prone expansion joint had been.

When evaluated in its entirety, the rehabilitate-and-preserve option will provide 25 to 30 years of service before a similar treatment is needed. Further, the next rehabilitation should be significantly less expensive, as the link slabs should also preserve the paint, substructure and girders. A comparison of the two intervention options is shown below.

I-64 OVER SHOCKOE VALLEY BRIDGES COMPARISON OF INTERVENTION OPTIONS	
Rehabilitation Option	
Rigid Overlay with Hydromilling	$6M
Structural Steel Repairs	$2M
Painting	$11M
Substructure Surface Repair	$2M
Joint Elimination (Phase II)	$1M
Total (Rehab Option)	**$22M**
REPLACEMENT OPTION	
Replace Structures (same size)	$125M

Hydromilling in Preparation for Placement of Overlay

NEW BRIDGES

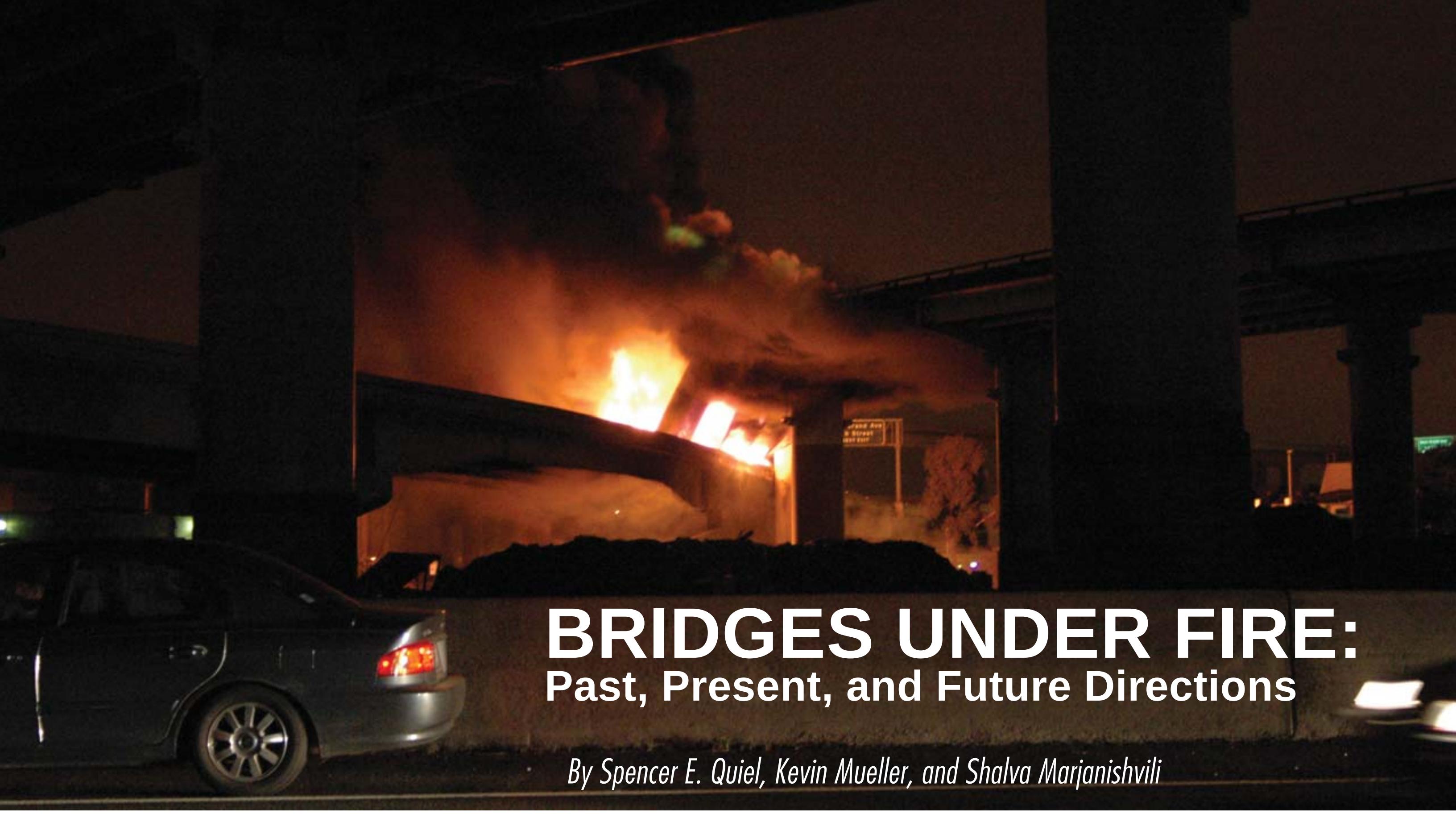
Although existing bridges pose our greatest challenges, we also continue to build new structures while recognizing that their design presents different types of obstacles. Design standards address problems such as fatigue and seismic susceptibility, but the major concern will be durability.

Corrosion is the leading cause of bridge deterioration, and many existing structures were not designed to withstand the corrosive environments in which they were built. So as we move forward it is vital to select materials and techniques that will mitigate the corrosion risk. VDOT has adopted a philosophy of using durable, high-quality materials in conjunction with construction details that will preserve the condition of bridges. This approach may come with higher costs, but they pale in comparison to the value of longer-lasting structures. This philosophy is evident in the short list of materials and techniques that VDOT employs on its new bridges:

- Jointless Bridges: Deck expansion joints are prohibited on new VDOT bridges without the written permission of the State Structure and Bridge Engineer
- Corrosion Resistant Reinforcement: Any bridge element that could be subjected to salt must use corrosion resistant reinforcement
- Three-Coat Zinc-Based Coatings: Applied to new and recoated structures
- High Performance Concrete: All concrete used on Virginia bridges must include pozzolans, which reduce permeability and protect against alkali-silica reaction
- Weathering Steel: Where appropriate, weathering steel is used in new structure to avoid the need for coatings
- Low Cracking Deck Concrete: New bridge decks in Virginia must use Low Cracking Deck Concrete. This concrete limits the total amount of paste allowed, which results in lower water volumes and fewer drying shrinkage cracks.

We have a better understanding now of structural behavior, to go along with an ever-increasing menu of options for materials. Future materials will most certainly be lighter, less susceptible to corrosion and easier to deploy. Developing these materials in partnership with industry will allow us to deploy products that meet the challenges that we will face together.

About the author...Adam Matteo, PE, serves the Virginia Department of Transportation as Assistant State Structure and Bridge Engineer for Bridge Maintenance. He establishes policy for the maintenance of over 19,000 bridges and large culverts. He has 30 years of engineering experience in structural design, bridge maintenance and construction management. Before joining VDOT he worked as an engineering consultant, managing an office that performed bridge design, bridge inspection and bridge maintenance services in the mid-Atlantic region.



BRIDGES UNDER FIRE:
Past, Present, and Future Directions

By Spencer E. Quiel, Kevin Mueller, and Shalva Marjanishvili

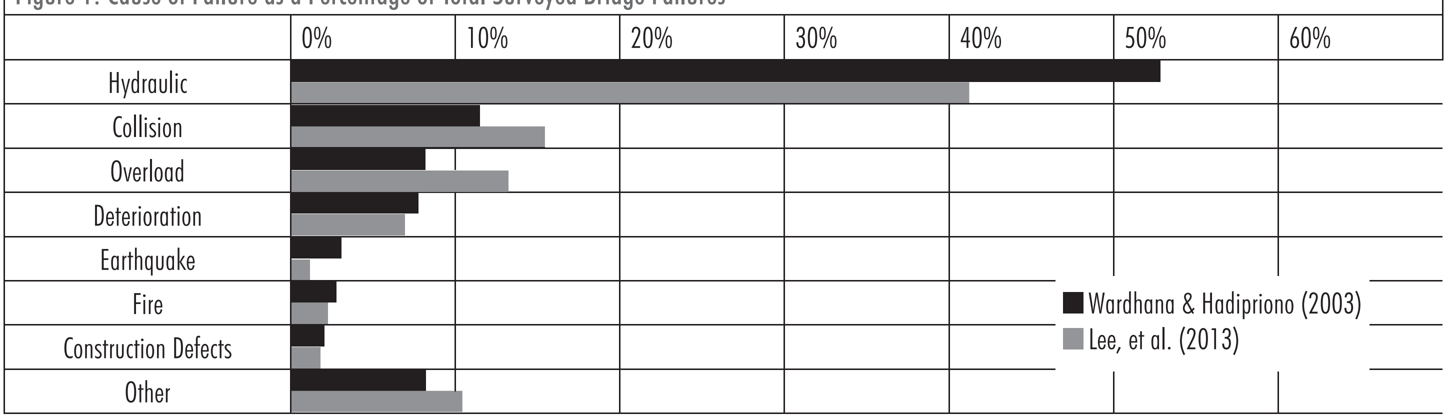
2007 tanker truck fire at the MacArthur Maze freeway interchange near Oakland, CA. (Photo by Philip Liborio Gangi, http://liboriogangi.tripod.com/FreewayFire.htm, used with permission)

Transportation infrastructure is susceptible to fire due to the constant presence of vehicle traffic and the potential for crashed or overturned vehicles and their contents to become fuel sources, especially semi-trucks hauling fuel and other flammable or combustible cargo. Several recent studies have highlighted the frequency of fire-induced damage to bridge structures relative to other natural and man-made hazards. Table 1 and Figure 1 together summarize the results of two recent studies which examined the causes of bridge failure in the US over the past 30 years. In accordance with the broad definitions used by their source data (which primarily consisted of state DOT's), these surveys have loosely defined bridge "failure" as total or partial collapse which resulted in significant repair or replacement. These studies indicate that the majority of bridge failures occurred due to hydraulic effects (flood and scour), collision, overload, and deterioration. However, fire represents one of the next most statistically significant causes of bridge failure, at least comparable to or exceeding those due to earthquake. Fire-induced failures also exceeded those due to construction defects, wind, or steel fatigue. Bridge failure due to terrorism (including intentional or accidental blast and sabotage) was not reported as a statistically significant cause of bridge failure in either study.

Table 1: Recent Survey Studies of Bridge Failure Rates

Authors	# of Bridges Surveyed	Survey Timeframe	Survey Geography	Data Sources
Wardhana & Hadipriono (2003)	503	1989 to 2000	Entire US	NYDOT and other unspecified sources
Lee et al. (2013)	1,062	1980 to 2012	Entire US	Unspecified

Figure 1: Cause of Failure as a Percentage of Total Surveyed Bridge Failures



The data in these studies absolutely does not discount the importance of research and design of bridge structures to resist earthquake, wind, blast, construction defects, and steel fatigue – these hazards have and will continue to pose a significant threat to bridge infrastructure and warrant the attention and resources that have been devoted to resisting them. However, these studies highlight that fire is also a frequent and significant threat to our bridge infrastructure. To date, fire exposure has typically received less attention and fewer resources as a subject for bridge research and a hazard consideration for bridge design and retrofit than all other hazards. Because of their confined environment, tunnels have received significantly more consideration than bridges with regard to designing for fire. Little guidance, however, is provided in either the relevant US or European standards for the design of bridges regarding the approach to calculating applicable fire hazards.

According to NFPA 502 (NFPA 2013), the primary structural elements of bridges or elevated highways, regardless of their overall length, shall be protected to meet the following, in the following order of importance: (1) maintain life safety; (2) mitigate structural damage and prevent progressive collapse; and (3) minimize economic impact. This document also states that critical structural members need to be protected from high-temperature exposure, but only truss and cable-supported bridges or elevated highways require an engineering analysis. While the type of "engineering analysis" is not defined, its results should determine the acceptable risk due to fire, including possible collapse scenarios. However, little guidance is provided regarding the available approaches and performance objectives for such an analysis.

A single or several passenger vehicles involved in a collision can themselves present a threat to bridges and tunnels due to the combustion of their contents, including the on-board hydrocarbon fuel and, increasingly common, hybrid batteries. However, the more severe threat is presented by large semi-trucks transporting large quantities of combustible cargo, hydrocarbon fuel, or other hazardous materials. Tanker trucks hauling gasoline and diesel, which are common and necessary to meet our society's current transportation demands, have provided the fuel for most of the recent severe fire events involving bridge structures, including but certainly not limited to the collapse of the MacArthur Maze I-80//I-580/I-880 interchange overpass in Oakland, CA, USA in 2007; the near-collapse of the I-65 overpass near Birmingham, AL, USA in 2002; and the severe damage leading to demolition of the Route 22 overpass at I-81 near Harrisburg, PA, USA in 2013.

To date, most bridge collapses due to tanker truck fires have involved common highway overpasses (typically supported by steel girders), which represent the majority of our bridge inventory. However, recent events have shown that long-span bridges (particularly signature or landmark bridges) have also been frequently susceptible to vehicle fires. Table 2 summarizes several recent fire incidents for long span bridges in North America which involved burning vehicles. All of the incidents in Table 2 did not result in significant damage or collapse since the fires involved either passenger vehicles or semi-trucks carrying non-hazardous cargo. However, the incidents in Table 2 underscore the potential for the occurrence of vehicle fires on the deck of a long-span bridge. Since most long-span bridges must accommodate the transport of fuel and other hazardous cargo, it is reasonable to expect that fire events such as those which have collapsed common overpass bridges are at the very least a statistically possible hazard that should be considered in their design.

Table 2: Recent Vehicle Fire Incidents on Long-span Bridges

Date	Name	Location	Type	Fire Source	Incident Outcome
March 2007	Mezcala Bridge	Guerrero, Mexico	Cable-Stayed	Tractor-Trailer	1 stay cable ruptured due to fire; No collapse but extended closure
July 2009	Manhattan Bridge	New York, NY, USA	Suspension	Tractor-Trailer	Minor damage; Partial temporary bridge closure
June 2012	Brooklyn Bridge	New York, NY, USA	Suspension	Passenger car	Minor damage; Partial temporary bridge closure
August 2013	Queensboro Bridge	New York, NY, USA	Cantilevered Truss	Tractor-Trailer	Some damage to structural steel; Partial temporary bridge closure
April 2014	Zakim Bridge	Boston, MA, USA	Cable-Stayed	Tractor-Trailer	Casing of 1 stay cable partially charred; Partial temporary bridge closure

Cable-stayed bridges have emerged as a popular structural form for many recent bridge construction projects, and a vehicle fire on the bridge deck poses a significant threat to the integrity of the stay cables. Several recent cable-stayed bridge projects have required the development of a Threat, Vulnerability, and Risk Assessment (TVRA) to determine design scenarios to mitigate the effects of blast and fire. For fire, these scenarios typically involve the specification of a tanker truck threat with fuel type and volume – these scenarios apply for both accidental fires (due to vehicular collisions) and intentional fires (due to sabotage). The Post-Tensioning Institute (PTI) has included some considerations for fire resistance in Section 4.5 of their guideline document for the design of stay cables (PTI 2012), but there is a disconnect between these provisions and the typical TVRA fire threats. The PTI provisions are oriented toward the requirement of fire ratings based on standard fire tests in a qualified laboratory. Based on an owner's pre-established fire ratings requirements, the stay cable assembly is subjected to a temperature time history that simulates a worst-case exposure to a hydrocarbon fire. The steel strands must demonstrate "fire endurance" of 30 minutes or greater, as determined by the time needed for the steel to reach 300°C. Also, the assembly is then tensioned to 45% of maximum ultimate tension strength and heated to 300°C, and it must resist these conditions for at least 30 minutes. However, the PTI document does not provide guidance regarding methods for calculating the extent of fire exposure or the resulting cable deterioration based on realistic fire scenarios that are typically provided in a TVRA.

Researchers at Lehigh University and Hinman Consulting Engineers, Inc. have collaboratively developed FLaME (Fire Loading and Mitigation Evaluator), a 3D Matlab-based modeling tool that links the actual geometry of a bridge structure with the realistic exposure to a tanker truck fire (Quiel et al, 2015). The streamlined framework at FLaME's core synthesizes numerous calculation techniques based on both first principles and empirical data to quantify the extent of damage caused by a specified fire hazard. Due to its computational efficiency, this framework can be used to develop an envelope of performance for a series of fire hazard scenarios. These results can then be used to evaluate the risk of damage and the effectiveness of potential fire protection strategies. The calculation of a bridge's response to a vehicle-based fire hazard generally consists of four steps:

1. Determine the fire's characteristics (e.g. footprint, flame height, duration, and intensity)
2. Calculate the heat transfer from the fire to the structural elements
3. Calculate the temperature increase of the structural elements
4. Calculate the material and mechanical response of the bridge structure

New research by the authors has incorporated a more performance-based approach into this framework by accounting for realistic variation in the fire hazard, including its combustion parameters, spill footprint, and location. For a network or grouping of bridge assets (such as the MacArthur Maze interchange), the authors have also begun to incorporate traffic information to determine which bridges may be most susceptible to fire and which pose the greatest loss if they fail. By considering the likelihood and severity of a fire event, the prioritization of fire protection among a group of bridges in a network, interchange, or inventory can be developed.

FLaME has been successfully deployed for a study of both highway overpasses and a long-span cable-stayed bridge. Figure 2 shows how a tanker truck fire can be represented as a 3D solid flame, and the contour of fire effects can be calculated for several potential fire locations. The time history of exposure, which accounts for realistic burnout of the hydrocarbon fire, can then be used to identify the amount of fire resistance needed for a particular hazard. This tool can enable bridge designers, DOT's, and other bridge owning authorities to determine the extent of fire mitigation needed to withstand a range of fire scenarios while minimizing the additional cost of the mitigation.

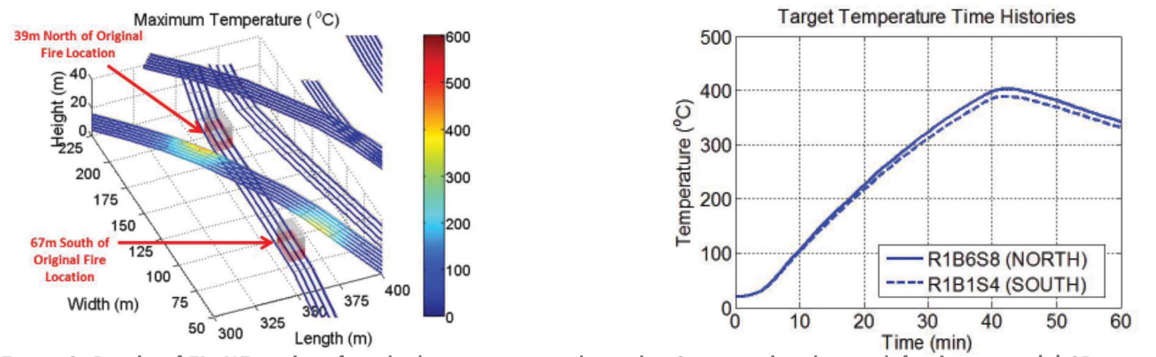


Figure 2: Results of FLaME analysis for a highway overpass subjected to 2 potential tanker truck fire locations: (a) 3D map of maximum temperatures in the steel girders and (b) time histories of the worst-case girders.

About the authors...Spencer E. Quiel, Ph.D., P.E., is with Lehigh University, Bethlehem, PA, and Kevin Mueller and Shalva Marjanishvili, Ph.D., P.E., are with Hinman Consulting Engineers, Inc., San Francisco, CA

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An Interview with Dr. David Lattanzi

Research Initiatives on the Forefront of Technology

The editors recently caught up with Dr. David Lattanzi. He brought us up to date on many of the advances that his research team at George Mason University has undertaken. His research is currently focused on future technologies with an eye towards practical solutions. David shared some interesting insight into unmanned aerial vehicles, virtual reality and artificial intelligence with applications in bridge technology. The high points of our interview follow.

Editors. We understand that you have an interest in the intersection of structural engineering and computer science. Tell us a little bit about yourself. How did this come about?

David. I grew up in Pittsburgh and eventually worked as a bridge engineer there. Living in a city known both for beautiful bridges and robotics had a definite influence on me. My wife also worked as a robotics engineer, which led to some interesting dinner conversations! Ultimately, I was fortunate to find Dr. Greg Miller at the University of Washington, who was willing to support my non-traditional research interests.

Ed. We understand that your current research includes use of unmanned aerial vehicles (UAVs) for bridge inspection. How do you foresee the future of bridge inspection with UAVs ?

The advances in UAV technology over the past 15 years are remarkable, and I believe UAVs will soon become a ubiquitous tool for practicing engineers across civil engineering. But we first need to develop protocols for using these systems safely and effectively, without endangering the general public. We also need to consider the end goals of a UAV inspection and build systems that support that goal. No one wants to spend hours reviewing UAV video footage, I promise you.

Ed. How do you logistically plan for a UAV flight? This seems pretty complicated.

Planning a UAV flight is a team effort. It is critical that the bridge inspectors, UAV pilots, and data analysts all work together from day one to meet the project goals. My philosophy is to take a "data-driven" approach. The design of the UAV itself, the sensor payload, and the flight plan all need to serve the desired end product. Our team recently used this approach during a UAV bridge inspection in Alaska, and I believe that is what made the mission so successful.

Ed. Tell us about this recent bridge inspection experience in Alaska? I believe that you called this project the Placer River Trail Bridge. Where was this project?

Yes. The Placer River Trail Bridge is located in the Chugach National Forest, about 60 miles south of Anchorage. It's a spectacularly scenic location within walking distance of the Spencer Glacier. But it is also a very remote location, only accessible via train in the summer, so it is almost impossible to get standard bridge inspection equipment, like a snooper truck, out to the site. That makes the bridge a perfect test case for a UAV inspection.

Ed. So, what do you start with to conduct this inspection? How does the UAV inspection work?

Well, we simply start with a 2D digital image of the bridge. The desired end product for the inspection was a highly precise 3D point cloud model of the bridge that could serve both as a "virtual" inspection environment and as a visual record of the bridge for future inspections.

Ed. Interesting. What were some of the challenges you faced?

David. Constructing this model meant developing a very complex photogrammetric process that leveraged imaging from on-board the UAV. That challenge, combined with the unpredictable weather in Alaska, required extensive planning and communication among the team members. It also required talented pilots! We were fortunate to be able to partner with the U.S. Forest Service and the University of Alaska, and the project would not have succeeded without such a strong team.

Drone in Action over the Placer River Trail Bridge (Photo courtesy of the USDA Forest Service)

Ed. Who are these talented pilots? What type of experience do you need to fly a drone successfully?

The drone pilots were from the University of Alaska-Fairbanks, and were ex-military predator drone pilots. They worked in tandem. One would operate the drone while the other actually observed the operator to make sure they weren't in danger (falling into the water, tripping hazards, etc). It turns out this is a common and major issue with robotics: a lack of situational awareness from the pilot.

Ed. If we wanted to become a drone pilot, where would we get this training?

Being a reliable and safe UAV pilot requires long hours of practice and training. Fortunately, there are a variety of UAV piloting schools that are popping up around the United States. The hope is that these schools will help standardize the training process, and potentially provide certifications for commercial pilots.

Ed. What other bridge research initiatives are you investigating on the forefront of technology?

We have made remarkable advances in how we collect information for bridge inspection and assessment. Take a look at the FHWA's RABIT, for example. Through these systems, we are now collecting massive amounts of data, and it can all be very difficult to work with. Figuring out how to represent, manipulate, and fuse these new data sources together are open research problems. I believe that the solution lies in using a combination of virtual reality and artificial intelligence to intuitively represent and automatically analyze this data, much like how the Google Self-Driving Car synthesizes data to navigate roadways. My research team, among several others, is currently exploring this idea.

Ed. David; thank you! This has been a most interesting interview.

Dr. David Lattanzi is an Assistant Professor in the Sid and Reva Dewberry Department of Civil, Environmental, and Infrastructure Engineering at George Mason University. Dr. Lattanzi's research focus is at the intersection of structural engineering and computer science. He studies how computer vision, robotics, and artificial intelligence can be adapted to improve civil infrastructure inspection and evaluation processes. His current research initiatives include the use of unmanned aerial vehicles for bridge inspection, the development of computer vision systems for post-disaster structural assessments, and the construction of artificial intelligence systems capable of aiding the engineering design process.

Wireless Infrastructure Monitoring
of the Cut River Bridge

By Ihab Darwish

EXECUTIVE SUMMARY

A pilot structural health monitoring (SHM) project has been initiated at the Cut River Bridge along U.S. Route 2 in Michigan's Upper Peninsula. The project is focused on developing the Michigan Department of Transportation's (MDOT) connected vehicle/technologies (CV) initiatives and meeting MDOT's core goals of safety, mobility, asset management, and planning. The structure is a three span, cantilevered deck truss and is a fracture critical structure. After the collapse of the I-35W Bridge over the Mississippi River, fracture critical structures have received additional scrutiny in an effort to prevent a similar catastrophic event from occurring. Installing a structural health monitoring system (SHMS) at the Cut River Bridge presented MDOT with a method of closely monitoring the fracture critical structure and working towards its CV initiatives and core goals. Additionally, the pilot project would provide valuable lessons learned for employing the SHMS technology at future bridge locations throughout Michigan.

The SHMS consists of fiber optic strain gauges, a weigh-in-motion (WIM) station, traffic sensors, environmental deck sensors, cameras, and a weather station. Due to the remote location of the bridge, the system utilizes wireless technology to transmit the data to MDOT through a series of radio towers installed at the bridge, the Mackinac Bridge, and the Mackinac Bridge Authority office in St. Ignace. From there, the collected data is available through MDOT's computer network. The system was designed to provide MDOT with real-time information from the structure that can be accessed from any MDOT location.

A three dimensional (3D) finite element model was developed using a finite element software and calibrated to more closely match the actual results from the bridge to aid in understanding the behavior of the entire structure. Sufficient data was collected to calibrate the 3D model.

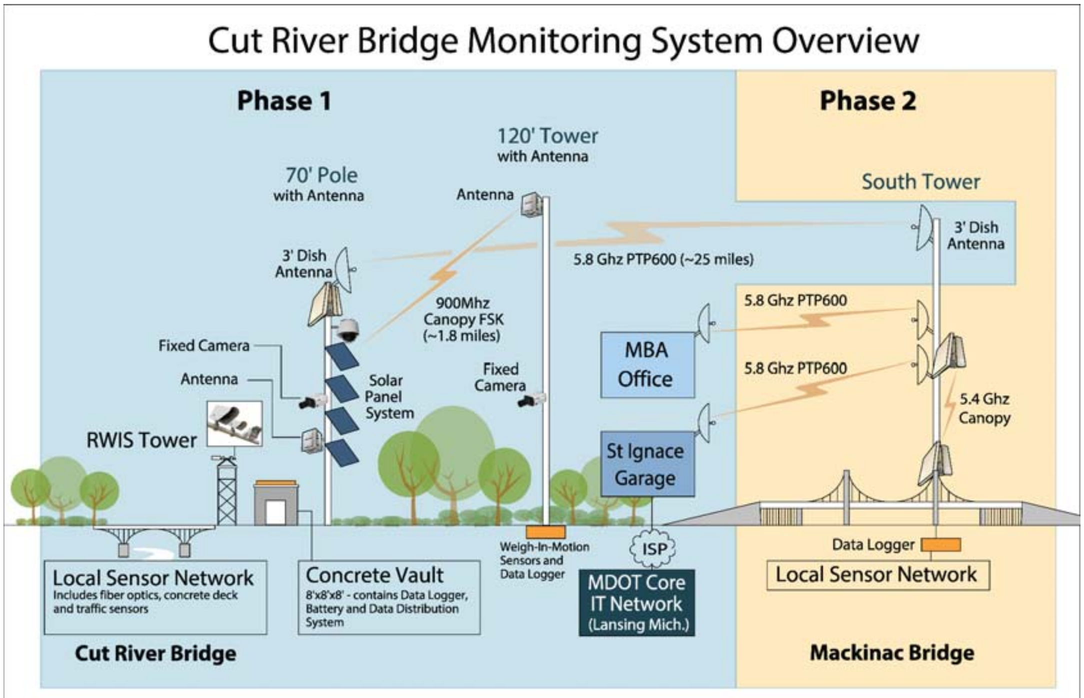
INTRODUCTION

The Michigan Department of Transportation (MDOT) has deployed a pilot project at the Cut River Bridge to investigate and develop a Structural Health Monitoring System (SHMS) that will aid in MDOT's Connected Vehicle (CV) Program. Connected vehicles aims to increase safety, mobility and reduce emissions by deploying vehicle to vehicle (V2V) communications and vehicle to infrastructure (V2I) technologies. The project utilizes a variety of sensors to monitor the structural behavior of the bridge and other conditions at the site. The SHMS will be able to report an overstressed critical member in the bridge, overweight trucks on the highway, weather, traffic conditions, and bridge deck environmental condition state. The goal of the project is to determine how the use of sensors installed on the bridge can be used to collect data to monitor structural behavior and to evaluate safety, mobility, asset management and planning applications with the remote sensors. The project also investigates and makes recommendations for a future SHMS deployment at other bridge locations in Michigan.

The Cut River Bridge is located on U.S. Route 2 approximately twenty five miles west of St. Ignace in Michigan's Upper Peninsula between the towns of Epoufette and Brevort, in Henricks Township, Mackinac County. The structure is a three span, cantilevered deck truss that spans the Cut River Valley where it meets Lake Michigan. It carries two lanes of U.S. Route 2 traffic over the Cut River. The structure was constructed in 1947 and considered historic. U.S. Route 2 is one of the primary highways in the Upper Peninsula and is a vital transportation link for the region. Residents, logging trucks, campers, and tourists traveling through the Upper Peninsula cross the bridge daily. The ADT at the bridge is 4,100 vehicles. Roadside parks are located on both sides of the bridge.

Cut River Bridge Elevation

There are several types of sensors that have been installed at the bridge. The SHMS at the bridge is powered by batteries located in a concrete vault near the east abutment. Five solar panels situated on a tower adjacent to the bridge provide charge to the battery system. All the collected information is delivered from the tower wirelessly to MDOT. To perform the structural health monitoring (SHM), sixteen fiber optic strain gauges have been installed on several primary tension members in the deck truss. In addition, four temperature sensors were mounted adjacent to four of the fiber optic strain gauges. The temperature sensors aid in correcting for any "drift" of the strain gauges due to temperature effects. In order to understand the truck loads causing the observed strains, a weigh-in-motion (WIM) station was placed underneath the roadway approximately two miles east of the bridge. The WIM station provides axle weight and spacing for any truck traveling on the highway. Other types of equipment have been installed at the bridge. Two sets of traffic point detectors are located in the east approaches to the bridge to capture traffic speed, volume, and occupancy. There are two bridge deck environmental sensors that provide data on the bridge deck such as moisture content, deck temperature, chloride content, and icing conditions. There are closed-circuit television (CCTV) cameras at the bridge and at the WIM station to deliver visual verification and quality control of the data from the other sensors. An Environmental Sensor Station (ESS) was installed to capture weather data and correlate the data obtained from the other sensors at the site.



Cut River Bridge SHMS Overview

The research objectives include:

1. Analyzing the ability of data retrieval in a remote environment using an off-grid power supply.
2. Analyzing communication and data collection from several infrastructure sensors.
3. Analyzing the ability to collect, store, archive, and use infrastructure data collection for comparisons, correlations, asset management, and control purposes.
4. Analyzing the ability of vehicle probe data collection and dissemination.
5. Providing recommendations for integration with the DUAP project to automate the SHMS which includes threshold strain values to be used in an early warning system for the structure.

The scope of the project also included the development and calibration of a 3D finite element model. The finite element model assists in the assessment of the remaining structural members that are not equipped with fiber optic strain gauges, and is also used in the load rating of the structure. The model is calibrated using the data collected from the strain gauges and from the WIM station.

DATA COLLECTION

All data from the Cut River Bridge was able to be collected from any computer with internet access. The data was collected from a computer located at the Engineer's office. The objective of the data collection process was to be able to obtain data regarding weights and axle configurations of the trucks that cross the bridge as well as the strain in the bridge members caused by these trucks. After the data was collected, it was then processed to correlate the truck information with the strain information. This information is useful to make comparisons between actual loads experienced by the bridge to the design loads according to current AASHTO and MDOT standards. Data regarding traffic, pavement, and weather conditions was also collected throughout this process.

FINITE ELEMENT ANALYSIS

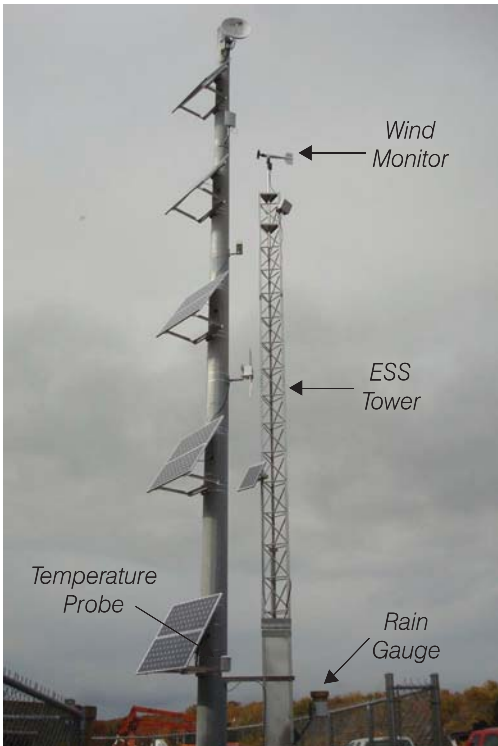
A three-dimensional finite element model (FEM) was created for the Cut River Bridge using LUSAS software. The FEM was initially used to analyze the bridge and determine the truss members that will be instrumented with strain gauges. The collected strain gauge data were then used to calibrate and validate the analytical model.

Finite element models can be a great asset in evaluating the structure performance of a bridge with the aid of the structure health monitoring sensors installed on the bridge. Both SHM and FEM can be used to examine trends or changes in the behavior of the bridge, and therefore maintain safety and ensure the proper planning for any future maintenance. Finite element models, calibrated with measured data, can also be used to validate the design and the load rating of the bridge. Data recorded from six trucks crossing the bridge was used to calibrate the finite element model. Configuration of each truck, including axle weight, axle spacing, speed, FHWA classification, gross weight, total length, and direction of travel were recorded at the WIM station. The strain gauge data of each of the six trucks were also collected. Using the geometric and material properties of the truss members, the maximum live load force in each of the instrumented truss member due to the passing truck on the bridge were then calculated. Collected strain gauge data for each truck include vehicular dynamic impact, which could not be separately measured. A method described by A.S. Nowak (Nowak, Kim, & Szerszen, 1999) is used to calculate the dynamic impact factor.

In general, the FEM forces for the top chord members are in agreement with the measured forces. However, computed forces in diagonal members vary by up to 49% from the measured forces. The variation between the computed and measured forces can be attributed to the accuracy of the FEM, variation between specified and actual material and geometrical properties of structural members, actual location of truck within the lane compared to assumed truck location in the FEM, actual vs. computed dynamic load factors, and arching or compressive membrane action in the reinforced concrete slab which can affect the live load distribution from the deck to the supporting beams.

RECOMMENDATIONS

The pilot project at the Cut River Bridge has provided useful lessons learned in deploying a SHM system. The experiences obtained at the Cut River Bridge will aid in



Towers at Bridge Site

developing future SHMS across the state of Michigan. The following recommendations are applicable to the Cut River Bridge SHM project and future projects.

- Build redundancy into the SHMS in as many aspects as feasibly possible. This will increase the reliability of the system. Perform a cost-benefit analysis to verify that any additional costs are indeed worthwhile.
- Provide backup forms of communication for any off-grid system. For the Cut River Bridge location, cellular modems or other forms of wireless communication can supplement the current radio transmission system. This will reduce the communication outages that have been experienced during the project.
- Provide multiple sources of power to the SHMS for any off-grid system. Wireless energy transfer technology or generators powered by propane or natural gas can complement the solar panels and keep the battery system adequately charged to operate the SHMS.
- Use temperature sensors at every fiber optic strain gauge location to compensate for any drift in strain gauge reading due to thermal effect. This will give the SHMS the ability to monitor changes of strain over a long period of time.
- Take additional precautions to ensure proper installation of all strain gauges and other equipment. Strict quality control and assurance measures will reduce the risk of equipment malfunctioning due to improper installation.
- Use equipment and corresponding software from fewer manufacturers to reduce coordination time and the possibility of incompatibilities within the system.
- Coordinate location of the SHM equipment to streamline the system, reduce overall cost, and reduce areas for potential maintenance.
- Perform load tests in calibrating the system to ensure accurate readings are being obtained from the equipment.
- Develop a maintenance team with adequate training, schedule, and budget to maintain the SHMS. The same maintenance team could be utilized across the State at multiple SHMS locations to minimize training and streamline maintenance efforts.
- At the Cut River Bridge, a predetermined threshold strain values should be established for each instrumented truss member to alert MDOT if the threshold is exceeded when a truck crossed the bridge.
- The use of FEM to examine trends or changes in the behavior of the bridge, in addition to the SHM should be evaluated based on the complexity of the bridge and whether it is feasible to calibrate the FEM with the measured data.

CONCLUSIONS

The pilot project at the Cut River Bridge has provided MDOT with a valuable means of meeting its core goals and a learning experience for future projects involving SHM. It is an effective tool to meet MDOT's core goals at the Cut River Bridge and other locations throughout Michigan. Any future SHM project in Michigan will be able to benefit from the lessons learned at the Cut River Bridge. There are improvements that would benefit the current system before full implementation with the DUAP project. Communication, power supply, and other improvements will increase the reliability of the SHMS. These same improvements can be incorporated into future SHM applications as well.

Once the SHMS at the Cut River Bridge is implemented with the DUAP project, the SHMS will be able to meet MDOT's core goals of safety, mobility, asset management, and planning. Safety will be achieved with a known safety factor of the loads acting on the bridge and a constant monitoring system in place. Mobility will be enhanced with real time weather and traffic conditions available to motorists. Asset management benefits from a better understanding the safety factor of the bridge and evaluating risks associated with the structure. Planning is improved with the real-time information stream from the bridge which can be used to observe maintenance or structure issues prior to or shortly after they occur.

Both SHM and FEM can be used to examine trends or changes in the behavior of the bridge, and therefore maintain safety and ensure the proper planning for any future maintenance. Finite element models, calibrated with measured data, can also be used to validate the design and the load rating of the bridge. However, depending on the complexity of the structure, calibration of FEM with measured data can be a time consuming process and a reasonable agreement between the measured data and data computed by the FEM may not be achieved.

About the author...Ihab S. Darwish, Ph.D., P.E., S.E. is a Senior Project Manager for Alfred Benesch & Company. Mr. Darwish has more than 18 years of experience in developing plans and specifications for bridges varying from complete reconstruction and rehabilitation to the design of new bridges.

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Information Modeling for Bridge Engineering

By Brian Kozy

Technological progress always occurs in ways that we don't expect. When you consider the context of science fiction movies such as 2001: A Space Odyssey (1968), Terminator (1984), Matrix (1999), and so many others, it seems that our imaginations very often default to predicting that computers will exponentially grow more powerful and eventually take over. However, reality never seems to bring that to fruition. In fact, mankind is showing itself to have a deeper appetite for information and how to better exchange it and utilize it rather than abdicating control to computers. We now can't live without the smart phone and its ability to give us immediate news, traffic, stocks, medical advice, blogs, tracking, analytics, and more. But, at the root is a hunger for information and associated personal empowerment, more than the efficiencies gained. That is why "the information age" is such an appropriate name for this era.

How will bridge engineering be shaped by the information age? Engineering practitioners of the future, with the aid of ever-advancing computer technology, will be able to solve engineering problems of greater complexity, and produce designs/evaluations which are more optimized and all-encompassing than today. More alternatives can be explored. More criteria can be considered. More details can be communicated to stakeholders. Engineers can invest their efforts on activities that add greater value to the design beyond specification compliance checks and documentation of a design.

Information Modeling refers to an advanced modeling approach that is based on generalized definition of the "objects" that make up the facility. It is a holistic digital representation of physical and functional characteristics of the constructed facility, which provides a shared knowledge resource for information to support a reliable basis for decisions throughout its life-cycle. It is modeling with definitions that are more closely related to the physical conditions being simulated in a way more universally understood.

Unfortunately, the profession has not yet fully embraced the capabilities offered by this next generation of modeling. Many bridge engineers and owners appear to favor a general philosophy of keeping analyses as simple and consistent as possible to minimize errors or to remain true to the accepted, proven engineering practices, and consequently have avoided embracing regular use of advanced methods. Many fear that the more that is left to the computer is more that is hidden from the engineer, which provides greater opportunity for error.

INFORMATION MODELING EXPLAINED

The defining characteristic of Information models is that they are object based. That is, they digitally describe a bridge as a collection of objects such as the deck, traffic barriers, girders and cross-frames, bearings, piers, abutments, and anything else that has logical relationship to physical entity. Objects can be broken down into smaller objects like plates, bolts, reinforcing, materials, etc. depending on the level of detail desired. It is a much more powerful model than say a finite element model that is an approximate representation of the bridge discretized into nodes and elements for only one purpose (structural analysis).

Ideally, the object definitions use the minimum number of data parameters necessary to completely describe it for the intended purpose. A simple example is a rectangular concrete footing, where three variables – width, length, and thickness – are all that are needed to define the volumetric shape and visualize it. All subsequent footings for a bridge can use the same definition template by specifying width, length, and thickness values for each. All that is needed is to locate their position in the overall bridge by defining a reference point on the object, and its station, offset, orientation, and elevation along the alignment. Other engineering data can also be layered onto the object such as material type, reinforcement, date constructed, or anything else need to design, construct, and/or maintain it. All of these parameters form the template required to define the object.

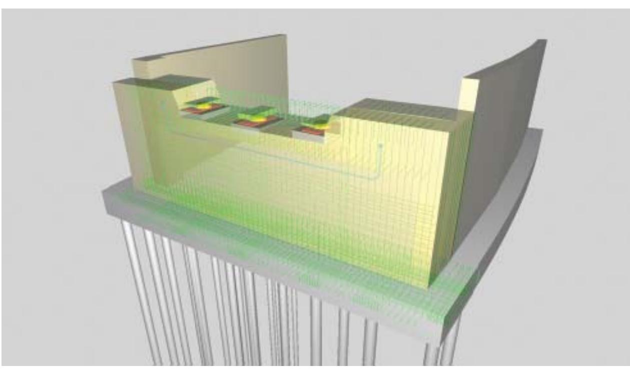
A complete bridge model is constructed by combining all of the individual objects into an integrated, connected assembly. Bridge objects in general are very repetitive and are often standardized by publications from AASHTO, industry organizations like PCI and NSBA, or by state standards. In most cases objects can be defined with a relatively small number of parameters. Once the object template is developed, it can be stored in a library and used again and again within the project, and on subsequent projects.

ENGINEERING IN HIGHER DIMENSIONS

Information models are by their very nature multi-dimensional. They describe the horizontal and vertical geometry using its true position in space and objects are given a "complete" definition that allows for fabrication and construction without assumptions. Additional dimensions can be added such as time (4D) and relationships and conditions (5D). Engineers in the future will certainly assemble models with a 3D graphical interface, driven by the natural desire to visualize, efficiencies gained, and business necessity to satisfy clients and remain competitive.

It is envisioned that modeling and analysis in the future will be done almost exclusively with the computer rather than pencil and paper. Engineers will "click and drag" standard objects from a library database and assemble them into a bridge model in the virtual environment. Details will be worked out with CAD and included in the model. This model will be placed within a digital terrain representation of the site so that the interface with geotechnical features and utilities and integration with roadway items can be fully considered. This will fundamentally transform the way that engineers think and solve problems.

Ideally, information models are made fully "parametric" with relationships and dependencies defined so that when one change is made, all necessary updates are automatically made. This allows for the analyst to easily study alternatives by "click and drag" to make changes such as abutment and pier placement and girder layout. Or, an entire bridge model made for a previous project can be copied and easily customized for the new site.



SUPPORTING REFINED ANALYSIS

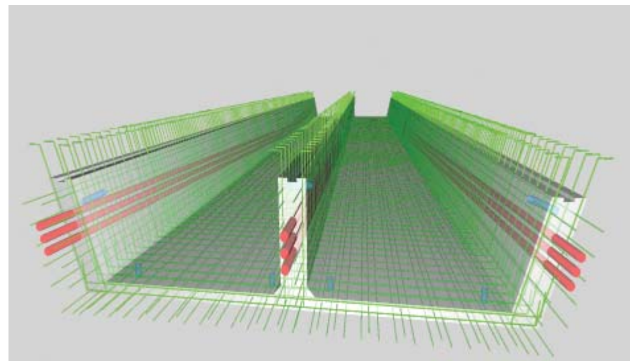
Engineers make models primarily for the purpose of performing analysis and developing a design. Fabricators need models to guide computer controlled material handling and processing. Owners need models for load rating and storage of management data. Information models make it possible to execute a "refined analysis" with essentially the same level of user effort as compared to a "simplified analysis." The generic term refined analysis is often used to describe a more detailed, sophisticated structural modeling approach, which can account for more variables or atypical conditions. Since the model is defined using information that fully describes the objects in the facility, no simplifying assumptions are made at the input phase and any type of analysis can be done. Ideally the software will filter and discretize the information to form a "model view" that can be used to perform specific calculations like structural analysis, specification checks, quantity takeoff, and plans development (if they are still required). However, these efforts will be done by the software and not the user.

DIGITAL DELIVERY

Today the bridge industry remains stuck in a paper delivery mode, operating as if the plans are the primary communication tool and not yet of the mindset that paper is only a simplified 2D representation of the data. The end result is that digital formats are typically provided for convenience only, and are often explicitly disclaimed to be relied upon as part of a contract. It can be argued that the cost of doing so exceeds the benefit, which is in reality, the absolute reverse of the desired state. It has always been the case that the data are what drive the production of the paper. For information models to replace paper, digital standards are necessary for bridge information modeling with process documentation that can be referenced in contracts, similar to how other reference standards are used today, such as ASTM. These data standards continue to be developed and tested and are moving towards industry consensus.

THE FUTURE

Our industry will see the full power of information modeling when there are widely



accepted national data exchange standards that accomplish what .CSV files accomplish for spreadsheet software users and what .PDF and .DXF files accomplish for word processing and CAD software users. With these standards, commercial bridge software applications will export and import; in a way that is vendor-supported but not vendor-specific. Project receipts and deliverables will become digital rather than paper-based. Visualization and 3D/4D based engineering and construction planning and scheduling are easily achieved. Digital files and protocols originating as bridge "birth certificates" support ongoing asset management activities (inspection, load rating, permitting and routing/network analysis, programming rehabilitation). Futuristic developments such as virtual reality, artificial intelligence, performance monitoring, and rapid post-event assessment become supportable.

Credible, robust, and adaptable standards that have the endorsement of the federal government and other governing bodies would provide the impetus needed. Using a standard model for representing bridge information in a digital format which can be rapidly defined, accepted, and exchanged by software tools with minimal ambiguity will offer the opportunity to use digital project delivery, 3D visualization, virtual assembly, automated machine control, fast routing and permitting, network-level study, smart inventory, and more, as a routine part of project development and asset management.

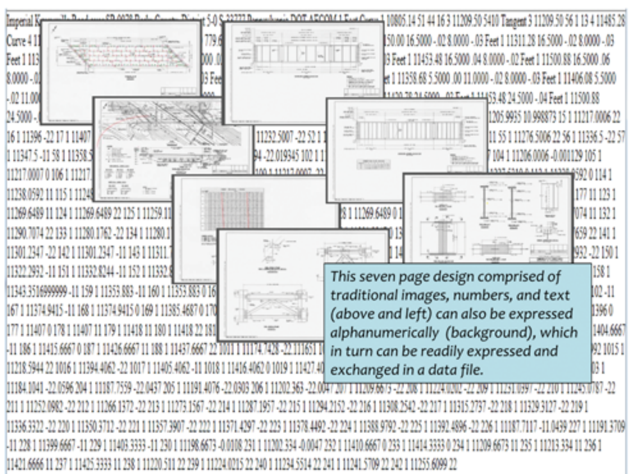
About the author...Brian M. Kozy, Ph. D., P.E., is the Principal Bridge Engineer, Federal Highway Administration.Dr. Kozy currently leads the Structural Engineering Team in the FHWA Office of Bridges and Structures, which aims to identify, advance, and deploy the latest engineering and construction technologies to improve infrastructure performance on a national level. Dr. Kozy strives to motivate his community both inside and outside the FHWA to engage in ongoing pursuit of innovation and technology advancement, and to act as pioneers and ambassadors for the profession. Dr. Kozy is a member of the International Bridge Conference Executive Committee.

Steel Bridges and the Data Express

By Ronnie Medlock

The exchange of data between the design and construction disciplines will have a profound impact on steel bridge construction. This revolutionary train is not quite ready to leave the station, but when it does pull out, be prepared to climb aboard and not look back.

The exchange of data between designer and fabricator is the next logical step in the evolution of computer use in building steel bridges. Software now helps every step of the way, from survey, design, and analysis up front to estimating, detailing, ordering, and numerically controlled fabrication in the shop. Notwithstanding the slide rulers we left behind, computers have brought wonderful improvements. We can take these improvements to the next level by getting the programs talking.



This seven page design comprised of traditional images, numbers, and text (above and left) can also be expressed alphanumerically (background), which in turn can be readily expressed and exchanged in a data file.

Already data is shared for some processes. For example, design software can import field measurements, and the data used to produce drawings can be used for CAD/CAM program and material purchasing. Solutions that provide an effective means of exchanging data among the disparate stakeholders in the life a bridge will be the next step. The drive to take this step is as compelling as it obvious: instead of recreating bridge data as bridge projects move from stakeholder to stakeholder, let's save time and improve accuracy by using the same data to build the bridge that is used to design the bridge.

The idea is simple, but two key barriers need to be hurtled. The first is a matter of custom: how do we avoid losing control of the engineer's work if we don't use a sealed piece of paper to convey the design? To address this, we simply need to adopt other means of maintaining control. As a start, data can be exchanged in parallel with a governing plan set. Taking this step will allow us to develop and gain confidence in the exchange processes and protocols. Later, we'll transition from drawings to exchange by information model. Yes, this will be a huge change, but take heart: the juice will be worth the squeeze.

The second challenge is more practical: how do we exchange data when we are using so many different and independent types of software for various tasks? How does a design file feed a CNC punch? Obviously, the solution is not to rewrite software into the same system. Rather, the practical solution is to exchange the data through an independent neutral file. If a neutral file format is defined and adopted by the community, any number of parties can readily use it to exchange data once they've learned how to read the neutral file format into their software and how to provide output in the neutral file format.

Work is already underway by the AASHTO/NSBA Steel Bridge Collaboration to develop and recommend a neutral file solution (or solutions) for the steel bridge community. There are a number of choices ranging from a comma delineated file to an XML file or a model. And the best solution might vary by bridge type. Though an XML file would work well for I-girders bridges, a 3D model may work better for a truss.

Generally, fabricator work flows for I-girder bridges are ready for design data. Fabricators use software to generate the geometric information needed to produce drawings and CAD/CAM files for the shop. Their software also goes further and automates much of the drawing and CAD/CAM file creation, improving both accuracy and efficiency. However, at the front end of the process, work is still done by hand: via a system of coordinated points, detailers convert the information on drawings into data that can be read into the fabricator's (or detailers) software. A neutral file containing of the geometric bridge information is all that the fabricator needs; the fabricator can write a routine that will read the neutral fill and pull in the information.

The neutral file work flow will offer numerous significant benefits. The fabricator's process for ordering main member material will become virtually instant: the detailing software will read the file, check the geometry, and, if the geometry is good, produce the bill of materials. The file will be used further upstream for estimating. Designers could also request a courtesy up-front check of their bridge geometry, improving the accuracy of bridge designs as-let, reducing RFIs and change orders, and saving time. Through exchange of the file, designers and fabricators could refine designs, improving constructability.

The train that represents data exchange is indeed revolutionary. Information models will replace drawings, fabricators will instantly understand designs and have the information they need to order material and run the shop; and designers will have feedback on the constructability of their designs. Accuracy will improve, confusion will go down, and lead times will shrink. The data exchange train has yet to leave the station but when it does, punch your ticket –it's an express.

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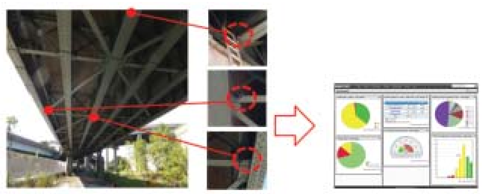
RAPID TECHNOLOGY ADVANCEMENTS ENABLE A

Brave New World

By Jeremy Shaffer

Many industries have been revolutionized or significantly disrupted by the rapid advancements in technology. In transportation, most of these innovations have been most visible on the consumer side. These include items such as navigation apps like Waze on our smartphones to new automated, self-driving cars. Technology has even enabled entirely new business models such as that of Uber and Lyft that have led to a near collapse of the traditional Taxi industry. While consumer uptake has been rapid, the pace of change may seem glacial for those who are designing, building, and managing our infrastructure. Although, in many ways this glacier is about to break free and produce a wave of change.

Academic research labs have been doing research on the application of proven technologies on infrastructure for several years. Now the natural progression to industry has begun. Companies are poised to move these concepts out of the domain of a handful of research projects and into repeatable and supported commercial endeavors. New innovations have the potential to dramatically improve the efficiency and reliability of our transportation network. Companies and practitioners should work to embrace these technologies in a useful manner and not simply resist them in favor of "we have always done it this way" approaches. Some key areas for consideration include:



Sensors provide continuous information on the bridge condition. By identifying key locations the right information can be readily available to all decision makers via interactive web interfaces.

3D AND 4D MODELS ACROSS THE LIFE CYCLE … FROM PLANNING TO DESIGN TO CONSTRUCTION TO MANAGEMENT:

A bridge simply doesn't just happen. It goes through a lifecycle that includes planning, design, construction, and ultimately on-going operations and management. Through this process a large amount of information is generated. Unfortunately, much of this data is simply "lost" during each phase of handoff between consultants, contractors, and owners. The typical project delivery and asset management process is still largely one that mimics a process based on 2D paper designs and standard paper forms. Technology can enable so much more.

On the most basic level, having a 3D model that passes through each stage and allows relevant data to be accessed is a simple first step. There is no reason that an inspector should not be able to go out into the field and access a model of a bridge on an iPad or other mobile device. By clicking on a joint, bearing, or other item, the inspector can see the exact information from the manufacturer and notes from construction. The inspector can even compare as-built photos to the current condition that is observed. The ability to visualize condition changes across time (4D) is also fully enabled. A manager can easily see how conditions are trending on specific elements and also track how maintenance or rehabilitation activities are affecting those elements.

BRIDGES THAT CAN TALK WITH INTERNAL AND EXTERNAL "SENSORS"

As a bridge is managed over its long life, the DOT and consultant personnel are the "Doctors" that must constantly evaluate their patient and attempt to keep it healthy. The challenge these bridge doctors face is that their patient doesn't talk to them and non-visible problems can be easily missed. However, we now have the ability to make the bridges "speak" to us. Sensor technology has progressed extensively over the past decade. From the domain of research labs or limited to only signature bridges, sensors have improved and can be utilized on a much wider variety of projects. These sensors can provide either a continuous stream of useful data to monitor trends or more discrete information. In addition to monitoring that is done physically in or on the bridge with sensors, we also now have exciting possibilities of using the vehicles that traverse the bridge to provide useful information. By having simple data connectors as part of connected vehicles, a variety of data points can be collected for decision makers. A DOT can obtain useful information on road and bridge conditions simply by having their fleet of vehicles record data from sensors as they drive around daily.

REAL TIME SCANS / DRONES

We have all read and seen the examples of drones being used in a variety of settings. Drones provide a platform to provide easy, cheap access to areas or views that might have been challenging in the past. For bridges, drones can be used as the platform on which to mount cameras or LIDAR scanners. During the construction, daily scans can be taken to track progress and provide a record/view of items that might never again be visible once concrete is poured or decks are placed. This information can serve useful later to inspectors or managers who need to make key safety and repair decisions.

During the operations phase of a bridge's life, portable LIDAR scanners can be used for a wide variety of purposes. Scans can be automatically compared using software tools and any changes can be instantly highlighted. For example, if an approach slab or pier is settling it can be quickly spotted and an exact difference calculated. Drones can also be used to take pictures/video of hard to reach places (both in the air and underwater). This can provide much greater detail than in the past and also prevent risk to an actual person. The videos/photos can also be used not in place of, but in support of a detailed inspection. By having a preliminary scan or video recording the inspector can better plan and focus their efforts on areas that need the most attention.

EMBRACE DON'T RESIST

Technology offers a variety of new tools to assist bridge and transportation professionals in doing their jobs. While all of the various technology tools offer much promise, they can be worthless if not used properly. Firms or agencies should carefully consider how best to effectively integrate tools that can provide real benefits. Our industry has evolved over time to be one that is relatively risk adverse and standards driven. These factors can often be used to stifle innovation. However, innovation should be embraced as a way to help proactively achieve the goals that all stakeholders, from the travelling public to the practitioners themselves, want to see realized.

About the author… Jeremy Shaffer earned a Ph.D. in Electrical and Computer Engineering at Carnegie Mellon University, during which time he co-founded InspectTech. InspectTech was focused on providing advanced solutions for bridge inspection and management, and Jeremy has written over 40 papers on this topic. The company was acquired in 2012 by Bentley Systems, where Jeremy now works as Senior Director of Transportation Asset Management. Jeremy also serves on multiple industry groups including the Transportation Research Board's Bridge Management and Structure Maintenance Committees and is a member of the IBC Executive Committee.

VDOT I-95 Bridge Restoration ABC Project in Richmond, VA

By Scott Fisher and Jorge Suarez

Gantry Cranes Moving PCU in Casting Yard

PCU Erection

PCU Erection

Demolition Removal

The I-95 Bridge Restoration project consisted of rehabilitating eleven existing dual bridge structures along the I-95 corridor just north of downtown Richmond, Virginia over a four year period. This project is used state-of-the-art accelerated bridge construction techniques. All of the bridge superstructure units are being constructed off site and delivered to the bridge locations with specialty transport trailers.

With a project of this magnitude, it was imperative to develop a public affairs campaign that would be sustainable over the life of the project. VDOT launched an extensive public affairs campaign prior to the beginning of construction by hiring the Richmond-based advertisement firm, Siddall. VDOT kept motorists informed of upcoming project events through a project-specific web page, social media outlets such as Facebook/Twitter/511, Richmond's Traffic Operations Center, billboards, overhead message signs, and local news media.

Shutting down this section of I-95 to construct these bridges was not an option as 150,000 vehicles per day travel through this corridor. VDOT along with their design consultants AECOM and Wilbur Smith developed an extensive MOT plan which reduced 3-lanes of traffic down to 1-lane of traffic in both directions while keeping an emergency lane clear during night-time operations between 8:00 P.M. and 6:00 A.M. A five-phase MOT plan was developed that included the use of crossovers and movable barrier system (aka 'zipper barrier'). This system was utilized mainly for its ability to be deployed in less than one hour; critical for the contractor's 10-hour nighttime window to replace the superstructure units.

Substructure repairs on the abutments and piers consisted of epoxy injection of cracks and surface repairs. Three of the bridges were widened, thus requiring over 50 permanent drilled shafts be installed. The average diameter of the shafts was 4' with an average depth of 50'. The Lombardy Bridge, a 730' long / 12-span

ESWP Member News

More than 75 firms are represented in the Corporate Member program of the Engineers' Society of Western Pennsylvania (ESWP). Memberships are available at 3 levels: Gold, Silver and Bronze. Gold members are entitled to 14 memberships that can be exchanged by employees; Silver, 9; and Bronze, 5 — annual dues are $2400, $1700, and $1000 respectively. In addition, ESWP Corporate Member Firms may add 2 additional individuals in our Under-35 age category at no additional cost. More information can be found at eswp.com. Please contact the ESWP Office (412-261-0710) for additional details.

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WYATT INCORPORATED Interior Construction bridge not only was widened on both the northbound and southbound sides, but five of the twelve total piers required removal and replacement of the pier caps. Temporary bent supports on either side of the piers that were to be removed, were jacked and carried the existing superstructure loads during demolition and replacement of the pier sections. Substructures on two of the bridges received electrochemical chloride extraction (ECE) treatment, a non-destructive process to extract chlorides from the concrete and protect the structure from corrosion related damage. All the substructures on the project also received a sacraficial cathodic protection (CP) system.

"VDOT found the accelerated bridge construction process to be an economic and efficient way to deliver quality construction projects quickly and reduce the impacts to the traveling public"

VDOT chose to replace the superstructure by utilizing an accelerated bridge construction (ABC) method of pre-fabricating complete modular concrete deck slab and girder superstructure elements off-site, delivering the units with specialized multi-axle transport trailers to the bridge locations, and then erected them after demolition and removal of the existing bridge superstructure. The units are then tied together either with post-tensioning bar tendons or with high-early strength concrete closure pours. Several benefits were realized with ABC construction including: minimizing traffic impacts to the public, safety of workers and public, quality of materials built off-site, environmental impacts, reduced construction time and weather-related delays.

All the I-95 bridge replacement pre-constructed composite units (PCUs) are comprised of fabricated steel girders with a minimum 9-inch thick lightweight concrete deck slab. The PCU units are generally two or three girder components in widths varying from approximately 14'-0" to 22'-6". PCUs are full span units, longitudinally. Eight of the total eleven bridges have transverse 1-1/4" diameter post-tensioning (PT) bar tendons to tie the prefabricated units together, generally spaced at approximately 4 foot centers. The remaining three bridges incorporate a cast-in-place concrete closure pour strip approximately 2'-6" wide to connect the PCUs together due to the excessive skew of these bridges.

All PCUs that utilize transverse PT bar tendons are match cast against each other in the casting yard and also incorporate formed 4 inch deep concrete shear keys between the segments. These longitudinal joints are covered with epoxy bonding compound prior to the PT operations which close the joint and provide approximately 300 psi compression across the joint prior to vehicle loading.

Both post-tensioned and cast-in-place closure pours bridges have threaded epoxy-coated reinforcement bars with a nut and plate assembly to provide continuity over piers for multi-span bridge locations. These continuity tendons are also grouted with standard PT grout for corrosion protection.

The casting yard was the critical path of the project. The strategic location of the yard was instrumental to the success of the project because the contractor needed a site that was large enough to accommodate all of the activities associated with producing and storing 234 PCUs and also close enough to the bridge locations to ensure that the 120-ton units could be hauled across existing structures en route to their final destination.

VDOT required the contractor to have two independent surveys to verify that the existing geometry of the substructures was exactly recreated in the casting yard. All PCUs are match-cast both transversely and longitudinally to ensure that the post-tensioning bars line up and the PCUs fit perfectly together in the field. The match cast PCUs were separated in the casting yard by jacking apart, then stored for future delivery to the bridge locations. The casting yard also allowed for safely building the bridge structures only five feet off the ground and reducing fall protection and increasing quality workmanship in a controlled environment without adjacent traffic next to the work zone.

In summary, VDOT found the accelerated bridge construction process to be an economic and efficient way to deliver quality construction projects quickly and reduce the impacts to the traveling public. Many challenges were successfully overcome by the efforts and teamwork of VDOT, the CEI firm (Michael Baker Jr, Inc.), the engineer of record (AECOM), and the contractor (Archer Western). Good communication and practical solutions have allowed the team to progress the work effectively. Innovative and malleable MOT schemes, proactive public involvement, quality off site casting yard production, unique hauling and erection equipment, and high level of worker commitment will provide the community with safe infrastructures for many decades to come.

The project was successfully and safely delivered four months early and $16 million under budget, a testament of excellent public involvement, quality products and partnering between VDOT, the engineers of record, the CEU team and the contractor.

About the authors... Scott J. Fisher, P.E. is an Area Construction Engineer with the Virginia Department of Transportation. Mr. Fisher was the Project Manager overseeing the construction of the I-95 Bridge Restoration Project.

Jorge M. Suarez, P.E. is a structural engineer and VP/Director of Bridge Services with Michael Baker International. Mr. Suarez was the Responsible Engineer in Charge for the construction of the I-95 Bridge Restoration Project.

Slide-in Bridge Construction at the Lardo Bridge

By Brian Byrne

Northern Elevation of Completed Lardo Bridge

With the increasing use of slide-in-bridge construction (SIBC) technology in the United States, the number of distinct means to perform the slide has also grown dramatically. Where site conditions allow, SIBC has taken off in popularity because it is less costly, simpler and last impactful on the superstructure than a heavy move using a self-propelled modular transporter. However, the use of proprietary products for SIBC and extensive falsework systems continues to drive higher-than-needed costs. Where project constraints allow, we need to continue to look at means and methods to further reduce costs and simplicity of SIBC methods.

One project for which SIBC was used with minimal costs and a straight-forward slide system was the Lardo Bridge Replacement in the resort town of McCall, Idaho. This was Idaho Transportation Department's (ITD's) first implementation of slide-in-bridge-construction technology for a permanent superstructure and was administered as their first federal aid design-build contract. The new single-span 155-foot precast concrete girder bridge replaces an existing 80-year old, 5-span bridge carrying State Highway 55 (SH-55) over the North Fork of the Payette River at the outlet of Payette Lake.

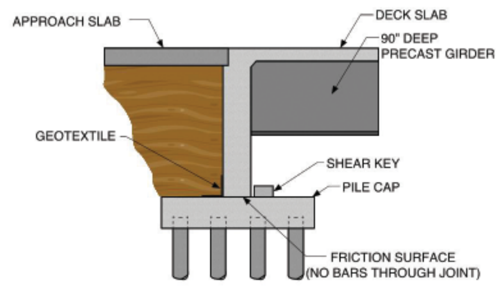
McCall's tourist season extends from Memorial Day through Labor Day and picks up again from Thanksgiving through New Year's for snowmobilers and skiers. With SH-55 as the main route along the base of the lake, ITD wanted the existing bridge to remain open during the summer to maintain connectivity between lodging, restaurants and recreation areas. The RFP for this design-build project required that both lanes on SH-55 be kept open until September 2nd, and re-opened again by December 23rd. Furthermore, A+B bidding was used with the "B" component assessed with a value of $7,700 per day for this roadway with a current ADT of 4,900 vehicles.

With only a 4-month window to detour traffic during the quieter fall season, and the incentive for better scoring during the RFP, all three short-listed design-build teams looked hard at accelerated bridge construction (ABC) methods. To successfully complete the bridge within project requirements, substantial work during the summer had to be completed while keeping SH-55 open, followed up by the completion of the bridge and roadway approaches prior to Christmas. However, the chosen ABC method had to be cost-effective for this design-build pursuit.

The constraints at the site were such that the Shore Lodge, the premier inn in McCall, was located in close proximity to the northwest quadrant of the bridge and there was a very tight right-of-way and overhead wires to the south of the bridge. Our design-build team ultimately elected to use SIBC by constructing both the superstructure and abutment stems to the north of the existing structure during the summer, and then sliding the structure (abutments and superstructure) into place on permanent footings in the fall.

The use of a simplified SIBC system at this project site was aided by good geometry, with the river flowing below the roadway by 15 feet and at a minimal skew. The team chose to build the abutments with the superstructure to the side, with the girders detailed to be integral with the abutment. Due to the 7'-6" deep precast girders and a 6-foot deep abutment stem, the top of the temporary falsework was at the high water mark and could be constructed without extensive cross frames and steel work. Simple coffer dams built with gravel-filled super sacks kept the construction area dry at the abutments.

Piles were driven and pile caps constructed in the four corners while the existing bridge remained in use. The new abutments were designed to span the 47'-6" between the pile cap centers, with the aid of longitudinal post-tensioning. In their permanent location, the abutments are held in location by the retained soil embankment and by shear keys on the exposed faces. There is no reinforcement that extends from the footing into the abutment stem. This detailing was chosen specifically to work with the slide-in, meeting long-term serviceability while avoiding the need to make a positive connection after the bridge was set in its permanent location.



Graphical Section through Abutment

The decision to construct the abutments with the superstructure and slide them together rested largely on the very limited vertical clearance beneath the existing bridge in spans 1 and 5. Riprap would have had to been removed and an expensive soil nail wall constructed to retain the existing abutments and the embankments. Furthermore, the RFP required a minimum hydraulic opening that positioned the new abutments immediately behind existing piers 1 and 4. In order to construct the new abutments in place, the bridge length would have had to been extended, increasing our bid costs. It was ultimately easier, and less costly, to build the new abutment stems out from under the existing bridge and slide them with the superstructure.

On the bottom of the abutment stems, four 12-inch high blockouts were detailed to allow vertical jacks to be placed and lift the bridge to set the structure on slide pads. The blockouts create five concrete "shoes" that were the primary points of contact for the bridge during the slide operation. The leading and trailing edges of the shoes are beveled to help ride up and onto the elastomeric slide pads. Stainless steel plates were cast into the bottom of the concrete shoes.

Once the existing bridge was demolished, a 2-foot thick concrete "slide slab" was constructed as a temporary surface on which the structure could be slid from the north to the south pile cap. The permanent pile caps had concrete ledges which were designed to support the ends of the slide slab to minimize differential movement as the slide slabs are primarily supported by soil.

With the five concrete shoes per abutment, as noted above, the load distribution from the superstructure is less predictable given variations in support conditions as the structure is moved into place. One or two shoes could lose contact with the slide pads, requiring redistribution of the load from the superstructure into adjacent shoes. Anticipating this variation of support conditions, the abutments were designed to span the entire distance between the first and last shoes. However, it was felt that the use of five concrete shoes better distributed loads during the slide process and reduced settlement of the slide slab to near zero.


Abutment on Slide Slab after Bridge Move

As part of the design process, it was anticipated that if the slide slab had deflected under the second shoe, the leading edge of the first shoe may not have been high enough to fit over top of the slide pad. However, this risk was mitigated by the bevel and relatively tight spacing of slide pads. Calculations indicated that in order to have created a binding issue at the front shoe, a half inch to an inch of settlement would have had to occur. And while contingencies were put into place, the settlement of the slide slab was not a problem during the slide operation.

The bridge was slid into place with a jacking system designed to pull the 900 Ton structure assuming that a 10% static friction had to be overcome. High-strength 1-3/8" diameter threaded bars (threadbars) were placed on each abutment face with ends attached to steel anchor brackets. The brackets were temporarily bolted to the north pile caps to provide a reaction block to the jacking process. The other ends of the threadbars passed through fabricated steel push blocks. Center hole double acting jacks with a capacity of 75 Tons each were set up against the push blocks and pulled on the high strength bars to slide it into place in 7-inch strokes.

With a single manifold regulating each of the four jacks, a high degree of precision and ability to steer the bridge could be realized. A chalk line had been set to monitor the movement of the abutments and shifts were made to the alignment throughout the slide by engaging only the jacks at one abutment, effectively turning or steering the entire structure. The contractor was required to maintain a ½-inch tolerance in plan location. The chalk lines served as the only guide for the slide operation and there were no physical guides. This entirely prevented binding of the system, while still allowing for very accurate placement of the bridge.

The day before the slide, the bridge was moved about 10 feet onto the north pile caps. This allowed the contractor to test out the jacking system, before the press showed up the following day. The remainder of the slide, about 50 feet, occurred over the course of 4 hours. The move was slowed somewhat by the slide pads being pushed ahead of the concrete shoes, particularly when the slide pads were on the steel temporary falsework.

For the Lardo Bridge replacement, the slide system was chosen to allow geometric adjustments, while minimizing the number of physical constraints that could have slowed down the contractor. Using steel fabrications for the push block and purchased teflon slide pads, the increased costs of a proprietary system were avoided. The abutment detailing aided the slide system, reducing the temporary falsework, simplifying the final "connection" to the foundations and speeding construction.

About the author...Brian Byrne, P.E., P.Eng., is a Senior Structural Engineer and Associate Vice President with Lochner in East Hartford, Connecticut . Mr. Byrne has 23 years of structural engineering experience within the transportation industry and has managed the structural efforts on a dozen alternative delivery projects, including the Lardo Bridge Replacement project. This article has been taken in part from a paper written for the 2015 International Bridge Conference, IBC-15-82. Photos courtesy Ralph L. Wadsworth Construction

TECHNOLOGIES

for Condition Assessment and Performance Evaluation of Bridge Structures

–Their Past, Present, and Future –

By: Y. Edward Zhou

Technology has played an important role in assisting engineers in assessing the condition and performance of bridge structures. These applications can include:

1. Nondestructive evaluation (NDE) technologies for the detection of embedded defects or deteriorations that are not visible to the human eye, e.g., ultrasonic testing (UT) and X-ray for steel members, and infrared thermography (IR), impact echo (IE), and ground penetrating radar (GPR) for concrete members;
2. Sensing technologies such as strain gages, accelerometers, and displacement transducers for the measurement of structural responses to loads; and
3. Monitoring technologies such as acoustic emission (AE) for the detection of fatigue cracking or wire breaks, tiltmeters for the measurement of inclinational movements, crackmeters for the opening or closing movements of existing cracks or joints, and sonar for the assessment of foundation conditions for scour concerns.

Various combinations of the technologies mentioned above, and beyond, have been used to perform NDE and structural health monitoring (SHM) of bridges in different scales and for a variety of reasons.

The RABITTM – a robotic system for condition assessment of concrete bridge decks, in operation on the Arlington Memorial Bridge in Washington, DC (Photo courtesy of Dr. Nenad Gucunski, Rutgers University)

Many NDE and sensing technologies have advanced in the past decades in terms of their accuracy, reliability, and user interfaces, and will continue to do so in the coming future. A closer examination of these advancements may suggest that many of the improvements came in data processing and presentation thanks to progressive breakthroughs in computer technologies while the fundamental sensing mechanisms have remained essentially the same.

The basic mechanism of most NDE technologies is to identify existing defects or damages through the collection and analysis of the responding signals to a controlled energy source, such as ultrasonic waves in UT, electromagnetic waves in GPR, and stress waves in IE. It is important to understand that the collected NDE signals also include interference or noise, which is the response to other factors besides the defect or damage that is being investigated. In concrete members, such factors can include the reinforcing steel, interfaces between dissimilar materials, voids, and secondary cracks. The interference may be difficult to distinguish and quantify from the target signals, as they vary not only with the physical composition and mechanical and geometrical properties of the material, such as density and porosity, but also environmental conditions such as moisture and temperature at the time of test.

Although all technologies will continue to advance with time, bridge engineers must understand that each technology has its own limitations. When possible, it is prudent, if not necessary, to physically calibrate a technology for a specific application especially when important decisions are to be made based on the results. A most direct method for verifying an NDE technology is to take small representative samples from the structural component being examined, and compare the NDE results with the observed internal conditions. Another way for assuring consistent and reliable NDE results is to establish a baseline when the condition of the structure is known. A good time for establishing the condition baseline is when the structure is relatively new and the condition is known to be good. Future NDE results using the same technology are then compared with the baseline for the identification of condition changes or deteriorations. This same approach applies to SHM technologies. No matter how advanced technologies may become in the future, bridge engineers should always physically verify the sensors they employ on components that have known responses in known environmental conditions.

One important matter that must not be overlooked is the ever-advancing imaging technologies, including high definition (HD) digital photography/video, LiDAR (Light Detection And Ranging), and the associated imaging processing techniques for digital photos/videos and 3D point clouds (a point cloud is a set of data points in some coordinate system, created by LiDAR or laser scanners, to represent the external surfaces of an object).

Condition ratings of bridge components in the Federal Highway Administration's (FHWA) Structure Inventory and Appraisal (SI&A) database are determined by bridge inspectors in the field for bridge decks, superstructures, and substructures. This information has been used to assist bridge owners in making decisions on bridge maintenance, rehabilitation, and replacement. However, the determination of bridge condition ratings based on visual inspections can be subjective depending on individual inspectors' knowledge and experience, as well as varying field conditions. For the identification and documentation of concrete deterioration (cracks, spalls, delamination, efflorescence, etc.) and how these elements change over time, the current practice of visual inspections can be lacking in accuracy and completeness. It's also time consuming and costly if road closure and access equipment are required for the inspection.

Recent advancements in imaging technologies have made their applications possible to make bridge inspections more objective, more consistent, more scientific, and more efficient. Technology can minimize the shortcomings of human subjectivity and complement, but not replace, the manual inspections by certified personnel. HD photography/video can capture and record complete surface defects such as cracks and spalls; LiDAR can efficiently generate 3D point cloud images for actual structural geometries at various important times as needed; and simultaneous IR contours can reveal possible subsurface defects such as delamination due to rebar corrosion to provide warnings for potential spalls. These technologies can be implemented at fixed locations or through mobile carriers such as the inspectors, vehicles, boats, or drones with minimal or no interferences to traffic.

Looking into the future, NDE and SHM technologies are expected to gain increased applications in bridge condition assessment and performance evaluation. This may particularly be the case for integrated systems that encompass multiple technologies. One example is a robotic NDE system named RABITTM, which is equipped with GPR, IE, ER (electrical resistivity), USW (ultrasonic surface waves), HRI (high-resolution imaging), and GPS (global positioning system) for exact position coordinates along the scanning path. A unique advantage of RABIT is to allow correlations and/or comparisons among simultaneous results from multiple NDE technologies to increase reliability and reduce uncertainties.

Another future trend should be increased adoption of imaging technologies in bridge management. The combination of HD photography/video, IR and LiDAR imaging data provides complete information on the surface, subsurface and geometric conditions of bridge structures. Periodic collection of such data will allow consistent documentation and accurate identification of structural condition changes over time. Effective incorporation of this information into the Bridge Management Systems (BMS) will provide complete and objective information to aid bridge owners in making more intelligent, data-driven decisions for bridge preservation and management.

About the author...Dr. Ed Zhou is the National Practice Leader for Bridge Instrumentation and Evaluation at AECOM. Dr. Zhou specializes in bridge evaluation, retrofit, and preservation through visual inspections, finite element analyses, and structural testing/monitoring using various nondestructive field instrumentation technologies. Over the past 22 years with AECOM/URS, he has instrumented and evaluated over 80 bridges of various structural types across the U.S. Ed serves on several national technical committees and teaches the graduate course Bridge Design and Evaluation at Johns Hopkins University.

Highest Bridge Repaired with a Stronghold Solution

The Müngsten Bridge is the highest steel rail bridge in Germany. When this 116 year old steel girder bridge was renovated in 2013, a critical task was replacing the bridge bearings and connecting new bearing plates to the steel structure.

To complete the repair, MM1018 was specified. **MM1018 is a 100% load-bearing gap compensation material with a long track record in repair and new construction**. It has been used in more than 1000 applications worldwide. Originally developed for steel and steel composite bridges, it is also used in power plant construction, offshore platform repair and waterway maintenance.

MM1018 was used to attach filler plates to the Müngsten bridge base. After gap compensation was complete, the plates formed the bearing surface for the new bridge bearings. The process enabled 100% gap filling without machining.

MM1018 is a polymeric resin providing 100% gap compensation. It has high shear strength, and high compressive strength, even under extreme vibration and temperature conditions. It provides long term corrosion resistance, and is electrically non-conductive. It is highly resistant to weathering, aging, gasoline, oils, coolants, salt and acids. It cures in 24 hours, and allows all repair work to be completed on-site.

M1018 was also used in the Nuttlar Viaduct, scheduled for commissioning in 2016. In this case, MM1018 connects the bridge bearings to the steel box girders of the bridge. A 1.96” (5 cm) surface-milled steel plate supports the bearing, and is welded to the underside of the steel super structure.

The gap between the steel support and superstructure is filled with MM1018. For this reason, the weld has breaks into which the injection and deaeration packer is inserted. This construction has 12 injection and deaeration connections. The injection process saves time and expense, and precludes the need for costly filler plates.

In applications throughout Europe, **MM1018 has proved to be the ultimate answer for 100% force-fit connections between bearings and construction**. It is now available throughout North America, exclusively from Stronghold, a veteran-owned company, *now in our 25th year*.

Nuttlar Viaduct on Germany’s A46 motorway, was built using MM1018 resin.

100% force-fitting gap compensation is provided by MM1018.

Large gaps between steel structures are compensated with MM1018.

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Contact Larry Grimenstein
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Franklin, OH 45005

513-808-1695
Email: Strongholdone@cs.com

1st Place: Smith Avenue High Bridge over the Mississippi River, Saint Paul, MN
Photographer: Greg Lundgren
Judges' comments: "*Wonderful reflected image in still waters...beautiful...good compositional elements…great photo!*"

When the Smith Avenue High Bridge opened in 1987, it was considered one of the seven engineering wonders of Minnesota, and remains the highest bridge in Saint Paul, towering 160 feet above the river. Approximately, 2800 feet long (with a 520 foot long main span) and 54 feet wide, the bridge is the gateway from downtown Saint Paul to the city's West Side, and carries an estimated 14,000 vehicles per day with a single lane of traffic in each direction.

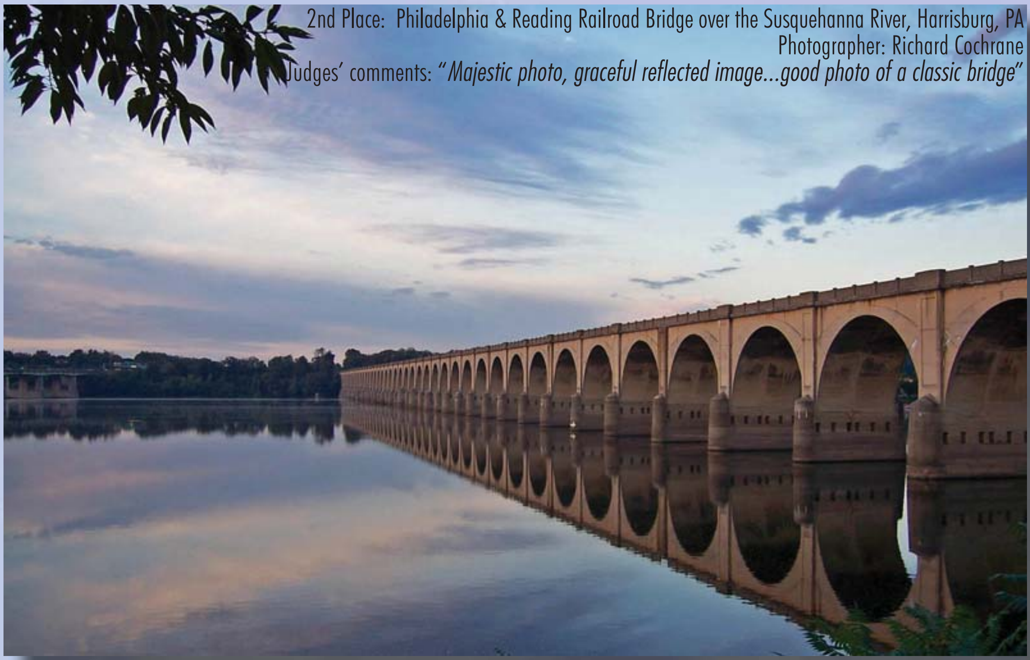
IBCPHOTOCONTEST

Our 5th Annual

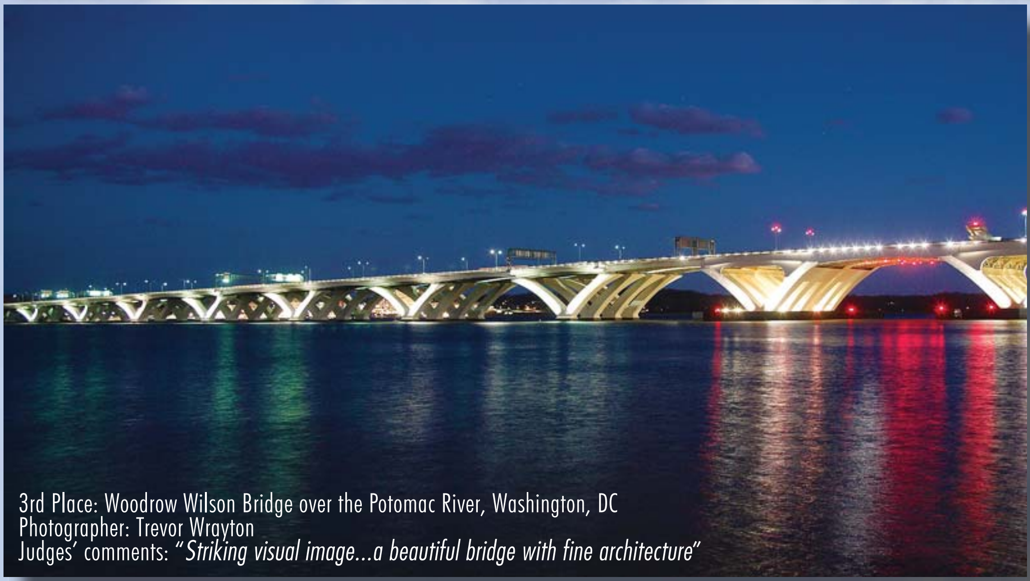
Government seats…financial and cultural hubs…historical settlements…. geographic centers of states - capital cities can be any or all of these as well as…home to beautiful bridges! With the IBC's move to Washington, D.C. this year, it only seemed appropriate that this year's photo contest features bridges of capital cities around the world. Leading global cities to America's small towns are well represented on the next few pages…

As luck would have it and with all the fabulous entries this year, we had a tie for 7th place with photos of the same bridge…..enjoy the top eleven photographs!!

IBC Executive Committee



2nd Place: Philadelphia & Reading Railroad Bridge over the Susquehanna River, Harrisburg, PA
Photographer: Richard Cochrane
Judges' comments: "*Majestic photo, graceful reflected image...good photo of a classic bridge*"



3rd Place: Woodrow Wilson Bridge over the Potomac River, Washington, DC
Photographer: Trevor Wrayton
Judges' comments: "*Striking visual image...a beautiful bridge with fine architecture*"

4th Place: 25 de Abril Bridge, over Rio Tejo (Tagus River), Lisbon, Portugal
Photographer: Adam Marolf
Judges' comments: "*Striking entrance to a global city...simple, elegant*"

5th Place: Hungerford & Jubilee Bridges over River Thames, London, England
Photographer: Richard Cochrane
Judges' comments: "*Visually interesting composition…beautiful picture*"

6th Place: United States Naval Academy Bridge over the Severn River, Annapolis, MD
Photographer: Kristopher Weidner
Judges' comments: "*Good color...good compositional elements*"

7th Place "A": Greiner Bridge over the James River, Richmond, Virginia
Photographer: Trevor Wrayton
Judges' comments: "*Excellent composition of a classical architectural form…great photo*"

7th Place "B": Greiner Bridge over the James River, Richmond, Virginia
Photographer: Jack Beilhart
Judges' comments: "*Good photo…like the sun reflecting off the underside of the arch*"

8th Place: Reina Victoria Bridge over the Manzanares River, Madrid, Spain
Photographer: Santiago Rodriguez
Judges' comments: "*Elegant, orderly, and charming...great architectural beauty*"

9th Place: Lt. Cmdr. John Waldron Memorial Bridge over the Missouri River, Pierre, South Dakota
Photographer: Todd Thompson
Judges' comments: "*Excellent capture of light and shadows...great colors and angle*"

10th Place: US 54 over the Missouri River, Jefferson City, Missouri
Photographer: Cathy Morrison
Judges' comments: "*Great cityscape...bold, handsome, rugged*"

IBC 2016 AWARDS PROGRAM

By M. Myint Lwin

Roebling Winner: *"…quietly confident in the application of his research but graciously patient for those of us still learning…a professor with a rare and outstanding combination of practical, academic and research experience that contributes significantly to the field of modern bridge engineering"*

George S. Richardson Winner: *"…an exemplary achievement…over the main channel, the world's longest suspension bridge with three pylons…over the back channel, a most unique arched pylon cable-stayed bridge, reminiscent of a rainbow…the bridge creates a magnificent view with the river and the sky"*

Gustav Lindenthal Winner: *"…a very impressive structure…appearing as six tall sails…standing bravely against the winds, waves…and a tidal bore!"*

Eugene C. Figg, Jr. Winner: *"…grace over a mighty river…the community leaders say:'…[the bridge] is crucial to the future of the Allegheny Valley, not just Oakmont … it's going to make a huge difference in the lives of the people of the Allegheny Valley '…"*

Arthur C. Hayden Winner: *"…a unique landmark representing a long line of innovations and achievements through eight generations of progressive improvements from 1820-2015…the community loves the new bridge and remarks:'…the fishing from the bridge is great, so is the ride on the bridge!… ' "*

Abba G. Lichtenstein Winner: *"…preserving a legacy…we were very impressed by the ability of the small local township to find sponsors to preserve their iconic bridge and town history…also, hats off to their congressman who sought the funding...Ithiel Town would be proud…"*

These are some of the many comments of the International Bridge Conference Awards Committee as they viewed, voted and selected this year's winners as well as the words of the public who strongly support local bridge projects.

The International Bridge Conference® in conjunction with Roads and Bridges Magazine, Bridge design and engineering Magazine and the Bayer Corporation, annually awards six medals and one student award to recognize individuals and projects of distinction. The medals are named in honor of the distinguished engineers who have significantly impacted the bridge engineering profession worldwide. Interest in the IBC awards program is quite robust nationwide and internationally. This year the Awards Committee reviewed more than forty nominations for the various bridge medal categories alone, half of which were projects nominated beyond the borders of the United States. After lengthy deliberations, the following individuals and projects were deemed worthy of this year's awards.

JOHN A. ROEBLING MEDAL

Dr. Dennis Mertz, P.E.

The John A. Roebling Medal honors an individual for lifetime achievement in bridge engineering. The International Bridge Conference is pleased to recognize Dr. Dennis Mertz as the 2016 recipient. Dr. Mertz is the Professor of Civil Engineering and Director of the Center for Innovative Bridge Engineering, at the University of Delaware. He has the rare and outstanding combination of practical, academic and research experience that contributes significantly to the field of modern bridge engineering - through supporting and advancing the AASHTO LRFD Bridge Design and Construction Specifications. Dr. Mertz has been the principal or co-principal investigator for many NCHRP Projects focused towards understanding the behavior of bridges, has authored many research reports on bridge behavior and has been a major contributor to the AASHTO LRFD Specifications, the AASHTO Movable Bridge Design Specifications, the AASHTO Guide Specifications for Bridges Vulnerable to Coastal Storms, the Steel Bridge Design Handbook and the Structural Steel Designer's Handbook 4th Edition. He has been the recipient of many awards including (most recently) the American Society of Civil Engineers (ASCE) Charles Pankow Award for Innovation: Honoring Innovation and Collaboration in the Design and Construction Industry, the Leslie D. Martin Award of Merit of the Prestressed/Precast Concrete Institute, Steel Bridge Forum Award , the Richard S. Fountain Bridge Task Force Award of the American Iron and Steel Institute, the American Society of Civil Engineers Richard R. Torrens Award, the Structural Engineering Institute of the American Society of Civil Engineers Certificate of Appreciation, the Inaugural American Association of State Highway and Transportation Officials Bridge Subcommittee Chairman's Lecture Series Award, the American Institute of Steel Construction Special Achievement Award, and the American Iron and Steel Institute Innovation in Steel Bridge Award. Dr. Mertz also is active with the American Society of Civil Engineers, the Precast/Prestressed Concrete Institute, the Transportation Research Board and the Executive Committee of the International Bridge Conference.

JAMES D. COOPER STUDENT AWARD

The James D. Cooper Student Award recognizes undergraduate and graduate students who demonstrate an interest and passion for bridge engineering. The 2016 Award is presented to Mr. Zhao Cheng and Mr. Robert Peggar, master's degree candidates at the Department of Civil, Construction and Environmental Engineering, Iowa State University, Ames, Iowa, for their paper entitled: "Integral Connections for Precast-Prestressed Concrete Girders in Seismic Regions". This paper presents an experimental campaign investigating the use of construction technologies able to provide positive moment continuity at the connection of precast bridge girders, specifically for improving the resistance to seismic excitation. The paper illustrates the performance of four alternative connection concepts, consisting of specific connections details between the girder and the bridge cap. The paper reports outcomes of the testing in which the connections have been progressively damaged, and the paper comments on the use of these technologies. The paper notes that while Precast-prestressed concrete girders are the most common prefabricated elements that have been used widely in the bridge industry in non-seismic regions throughout the United States and the world, the practice has been limited in moderate-to-high seismic regions due to inadequate seismic performance of connections between precast elements. The paper concludes, that based on laboratory testing of four specific positive moment connection types which utilize extended girder strands, continuity diaphragms, and dowel bars, satisfactorily performance is demonstrated when the girder systems are subjected to positive moments resulting from seismic excitation.

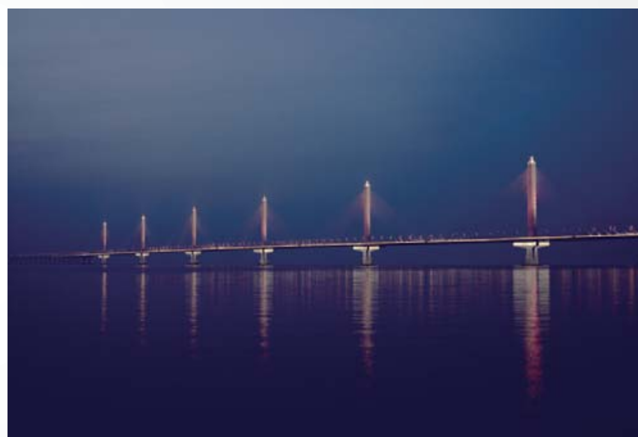
GEORGE S. RICHARDSON MEDAL

The George S. Richardson Medal, recognizing a single, recent outstanding achievement in bridge engineering, is presented to the owners of the Ma-an-Shan Yangtze River Bridge Project, Ma-an-Shan Province, China. The project is exemplary of the vision and the innovation of the engineering team in achieving an outstanding project. Over the main river channel, the bridge is formed by the world's longest suspension bridge with three pylons with its two main spans exceeding one thousand meters each. Over the river's back channel, the bridge is formed by most unique cable-stayed bridge featuring three arch shaped pylons. The design and construction of the Ma-An-Shan Yangtze River Bridges overcame challenges with innovative design, customized equipment, and special construction methods for improving safety, durability, efficiency, sustainability and cost savings in bridge engineering. Some unique features of design and construction include an innovative root pile foundation system employed for river construction, a composite section made of steel and concrete for the middle pylon of the suspended spans to increase overall structure rigidity, the development and construction of the most powerful tower crane in the world named D5200-240, which included a rotary horizontal arm with a torque capacity of 5,200 tonne-meters, and employment of innovative construction techniques including double wrapping belts, anti-twist pulling, circumferential incision and gradient maintenance construction methods

Ma-an-shan Yangtze River Bridge

GUSTAV LINDENTHAL MEDAL

The Gustav Lindentahl Medal, recognizing an outstanding structure that is also aesthetically and environmental pleasing, is presented to the owners of the Jia Shao Bridge, an impressive tidal crossing of the Qiantang River crossing in Zhejiang Province, China. The bridge is the world's largest cable-stayed bridge, consisting of six pylons. The main structure features five main spans of 428m each, two side spans of 200m each, and a bridge width of 55.6 meters to accommodate 8 lanes of traffic, with twin superstructures, each supporting four lanes of traffic. A double support and hinge system was provided at each tower to accommodate thermal expansion. A most unusual natural phenomenon, a tidal bore, occurs at the site. This twice daily tidal phenomenon is characterized by an incoming wave at the leading edge of the tide which at this location can reach a height of 9 meters (30 feet) in height and a velocity of 40 kilometers per hour (25 mph). The phenomenon is observed with special interest by the public, who come to witness this remarkable occurrence. Considered the largest bore in the world, the wave front brings intense turbidity and turbulent mixing with entrained air bubbles in the bore and a low frequency rumble audible for long distances. Special design considerations where addressed in the substructure design to sustain the associated hydrodynamic forces.



JiaShao Bridge

EUGENE C. FIGG, JR. MEDAL

The Eugene C. Figg, Jr. Medal for Signature Bridges, recognizing a single recent outstanding achievement for bridge engineering, which is considered an icon to the community for which it is designed, is presented to the owners of the Hulton Bridge over the Allegheny River, in Oakmont, Pennsylvania. The 1,600 foot river crossing includes a 500 foot main span over the navigational channel. The 1,200 ton, 285 foot closure section was erected by strand jacking techniques, the first ever in the Commonwealth of Pennsylvania. The Hulton Bridge is the symbolic entrance point to the community and the citizenry expressed its interest in public participation in the early feasibility study stages for bridge replacement and was sought as an active partner in a synergistic design effort. Final aesthetic details resulted in unique features integrated into the structure's overall form and character. Some of these features, such as the graceful parabolic curvature of the girders and detailing of bridge piers will invite the public to view the bridge with an appreciation of structure form from the waterways and nearby docks. Other features of the structure, such as the distinctive overlooks and ornamental railing elements will invite the community to walk upon the structure, pause and gaze at the scenic river environment.

Hulton Bridge

ARTHUR C. HAYDEN MEDAL

The Arthur C. Hayden Medal, recognizing a single recent outstanding achievement in bridge engineering demonstrating vision and innovation in special use bridges, is presented to the owners of the Brookfield Floating Bridge, spanning Sunset Lake in Brookfield, Vermont. The bridge, which is the only floating bridge east of the Mississippi River, was initially built in 1820 by Luther Adams and his neighbors. The latest design, unique for its type, represents innovations and achievements through eight separate generations of progressive improvements from 1820-2015. The community raised the funds and challenged the bridge engineers to build a new floating bridge that would be stronger and last longer than the past seven generations of floating bridges in the same location. The engineers responded with a superstructure made from Fiber Reinforced Polymer (FRP), producing a combination of strength and light weight. The bridge carries pedestrians and one lane of light vehicular traffic, and is the center of the community's recreational fishing.

Brookfield Floating Bridge

ABBA G. LICHTENSTEIN MEDAL

The Abba G. Lichtenstein Medal, recognizing a recent outstanding achievement in bridge engineering demonstrating artistic merit and innovation in the restoration and rehabilitation of bridges of historic or engineering significance is presented to the owners of the Martin's Mill Covered Bridge. The rehabilitated bridge spans Conocoheague Creek, in Antrim, Township, Franklin County, Pennsylvania. This 205 foot Town – or lattice – truss bridge was constructed in 1849 by Jacob Shirk. The bridge suffered severe flood damage during Hurricane Agnes and was rebuilt and strengthened in 1973. With wooden support members dating back to the original 1849 construction, insect infestation and rot placed the structure in jeopardy. As one of the few remaining and the largest lattice truss bridge in Pennsylvania, the Martin's Mill Bridge is listed on the National Register of Historic Places. The preservation, conducted within strict, Section 106 guidelines, included removal and replacement of all cladding and roofing elements with fire retardant materials, and included replacement of many key truss structural support members with southern white pine to restore to the original intent of the 1849 construction. During rehabilitation, the severely sagging structure was incrementally realigned and then strengthened with steel and Teflon elements. With a deed of dedication, signed in December of 2003, the local township took ownership of the bridge and then secured FHWA National Historic Covered Bridge Preservation Program funding to accomplish the 2015 preservation.

Martin's Mill Covered Bridge

The IBC Awards Committee includes Carl Angeloff, Lisle Williams, Jim Dwyer, Herb Mandel, Fred Graham, Richard Connors, Gary Runco, Myint Lwin, John Dietrick, Ken Wright, Jay Rohleder, Matthew Bunner, Ray Hartle, Helena Russell, Bill Wilson, and Tom Leech. The IBC Student Paper Awards Committee is led by Dr. Matteo Pozzi, of Carnegie Mellon University.

M. Myint Lwin, P.E., S.E. (retired - FHWA) is a past Roebling Award winner and for many years has faithfully served on the IBC as past General Chairman, Awards Committee member and International Reception Co-chair. Myint, with his many overseas' contacts, has been influential in broadening the appeal of the International Bridge Conference to many corners of the world. – Editor

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