Pittsburgh ENGINEER

SUMMER 2018

Quarterly Publication of the Engineers' Society of Western Pennsylvania

SPECIAL IBC CONFERENCE ISSUE

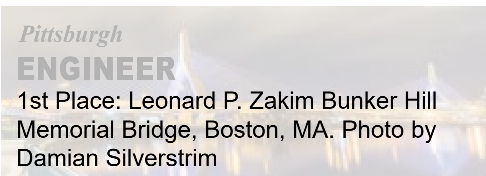
Pittsburgh
ENGINEER
Quarterly Publication of the Engineers' Society of Western Pennsylvania

In this Issue...

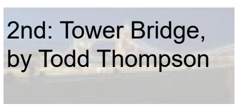
ON THE COVERS: 7th ANNUAL IBC PHOTO CONTEST

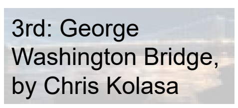
In keeping with the magazine's focus this year, our contest was dedicated to photographs of cable supported bridges. The world-wide response was overwhelming and the photographs on the covers (front & back) represent both newer structures as well as iconic veterans on several continents. This elite group include pedestrian, transit, and vehicular bridges or some combination thereof. The graceful but formidable nature of the cable supported bridge is most certainly demonstrated by these winning photographs - enjoy!

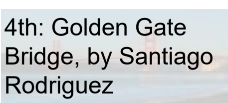
P.S. Our winners are pulling double-duty this year! In honor of our 35th Anniversary of the IBC, we are publishing a calendar featuring the top 13 photographs and providing it to all conference registrants as a commemorative anniversary gift!

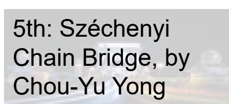


1st Place: Leonard P. Zakim Bunker Hill Memorial Bridge, Boston, MA. Photo by Damian Silverstrim


2nd: Tower Bridge, by Todd Thompson


3rd: George Washington Bridge, by Chris Kolasa


4th: Golden Gate Bridge, by Santiago Rodriguez


5th: Széchenyi Chain Bridge, by Chou-Yu Yong

ESWP 1880
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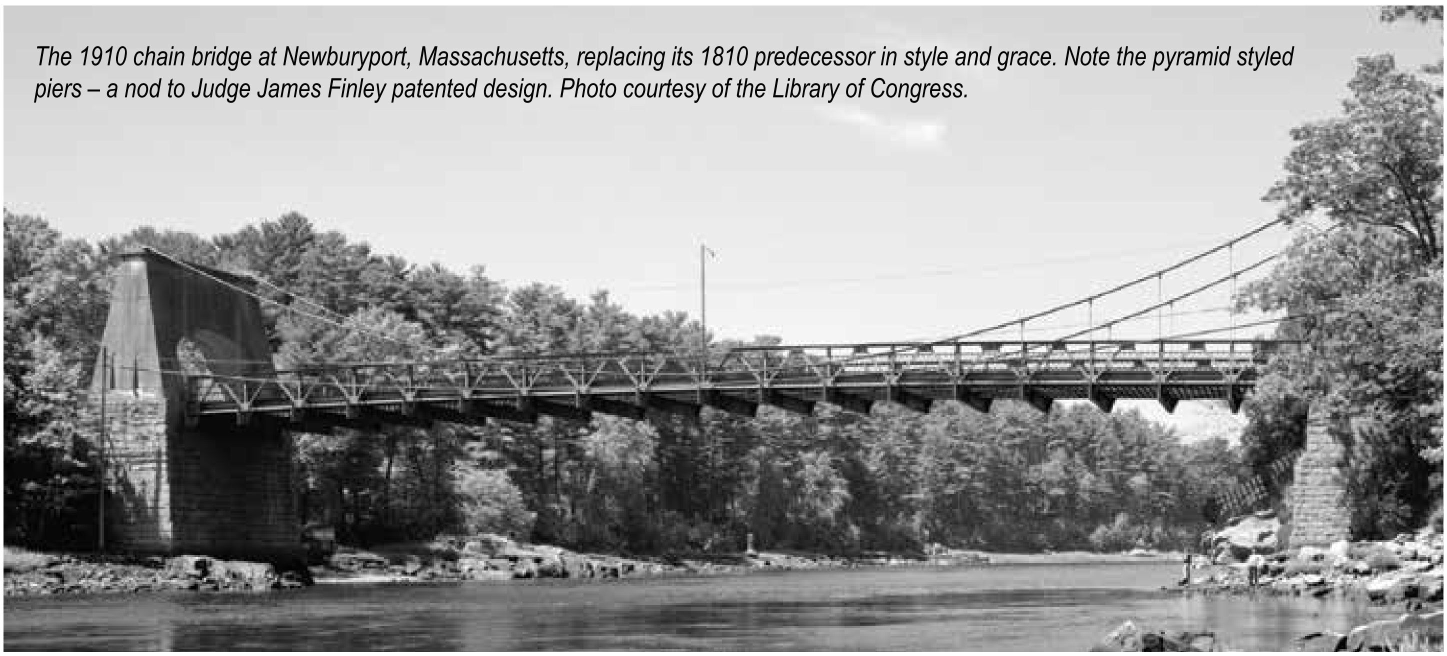
Answers to Bridge Quiz: 1-D, 2-C, 3-B, 4-A

Harmonious Rhythm – Bridges with Cables

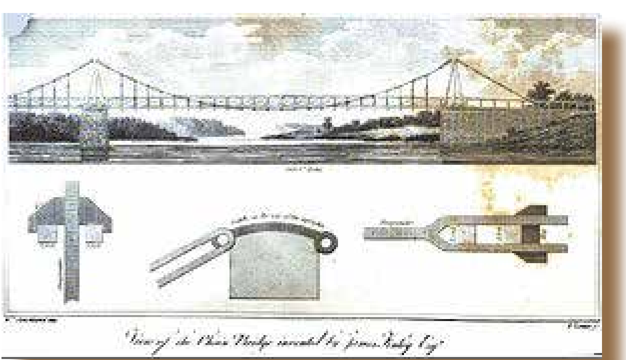
By: Tom Leech, George Horas, Jane Patton

"Eurythmy [or harmonious rhythm] is beauty and fitness in the adjustments of the members. This is found when the members of a work are of a height suited to their breadth, of a breadth suited to their length, and, in a word, when they all correspond symmetrically." (Marcus) Vitruvius (Pollio) – Book 1, Chapter 2, THE FUNDAMENTAL PRINCIPLES OF ARCHITECTURE (Vitruvius was a noted 1st Century BCE author, architect, civil and military engineer whose works were rediscovered in the Renaissance and influenced the works of da Vinci and Michelangelo.)



The 1910 chain bridge at Newburyport, Massachusetts, replacing its 1810 predecessor in style and grace. Note the pyramid styled piers – a nod to Judge James Finley patented design. Photo courtesy of the Library of Congress.

In 1801, not forty miles from Pittsburgh, from the vista of the banks of Jacob's Creek, Judge James Finley had a vision. His vision was the construction of a bridge over the small mountain stream, formed by a hanging chain, a chain whose "height [was] suited to [its] breadth, [and its] breadth suited to [its] length.…" Born in Ireland, he immigrated to the US, became the owner of a 287-acre farm in Fayette County, Pennsylvania, was elected a justice of the peace in 1784, then elected County Commissioner in 1789, then elected a member of the Pennsylvania House of Representatives and Senate, and finally from 1791 until his death, was an Associate Judge for Fayette County. His particular insight into mechanics and beauty took the form in the design, construction and patenting of the Jacob's Creek Bridge, a 70-foot span with the deck supported from a hanging chain, draped over pyramid styled piers. This modest but significant landmark, in engineering history, spanned a small stream immediately south of Mt. Pleasant, Pennsylvania – where the area adjacent to the site of the bridge still retains the name Iron Bridge in honor of Finley's accomplishment.



"View of the Chain Bridge invented by James Finley Esqr." (1810), wood engraving, William Strickland, delineator, The Port Folio [Magazine], June 1810. The 200-foot span shown in this image makes it almost certainly the Chain Bridge at Falls of Schuylkill.

With his patent in hand, Finley produced over forty chain suspension bridges, including one at nearby Dunlap's Creek (The National Road), the Chain Bridge at Falls of Schuylkill (see image, left), bridges over both the Potomac and Lehigh Rivers, and the Essex-Merrimac Bridge, also known as the Newburyport (Massachusetts) Chain Bridge. Although none of these original Finley chain suspension bridges remain, the Newburyport Chain Bridge was noted by Scientific American in 1896 as "the solitary specimen in New England of a style of suspension bridge that has served its intentions admirably, and may still be found preferable to the wire bridges under certain circumstances." In 1910, a "replica" of Finely's patented design was constructed over the Merrimac River at the original Newburyport bridge site, a present and lasting reminder of America's first suspension bridge.

The signature Millau Viaduct spanning the Tarn River Valley, in southern France, architecturally captures the essence of Vitruvius - harmonious rhythm of beauty and fitness. Photo courtesy of the editors.

In the US, the suspension form of harmonious rhythm of beauty and fitness was improved and perfected by engineers of note including Amman, Ellet, Roebling, Steinman, Straus and many others. Throughout the world, record breaking suspension spans have been achieved in Japan, China, Denmark, Turkey, South Korea, United Kingdom, Norway and the US.

Even before Judge Finley had his inspiration, support of bridges from inclined cables were imagined by the visionaries of the Renaissance. In 1595, inventor Fausto Veranzio published his imaginative solution for a cable supported bridge by inclined stay cables in his book, *Machinae Novae*. However, the underlying physical principles of support were not clearly understood until Robert Hooke published his observation in 1676, by means of Latin anagram, familiar to many college engineering students: "ut tensio, sic vis" – i.e. "as the extension, so the force" – a fundamental, yet essential, expression of the linear elastic behavior of an idealized material – and in the case of Hooke, a watch spring.

Cable-stayed bridge by the Renaissance polymath Fausto Veranzio, from 1595/1616

A little more than 15 years after Finley's patent, a small Scottish footbridge, connecting the villages of Dryburgh and St. Boswells, spanning the River Tweed (namesake to the style of clothing), was erected with support based on a stayed cable principle. The Dryburgh Abbey Bridge, as it was known, had a very short life, and with only minimal success of several cable stayed designs in the early 1800's, the structural form was abandoned for some time. Roebling, re-introduced the concept, in connection with his suspension bridge designs, employing stayed cables to some success with his rehabilitation of the Wheeling Suspension Bridge (which was damaged in in a wind event), his Niagara Falls Suspension Bridge and his signature and final structure, the Brooklyn Bridge.

With European pioneers like Dischinger, Morandi, de Miranda and Leonhardt, the modern cable-stayed bridge developed quickly in the post Second World War years. Starting with a single cable, or mono design, other and interesting forms of cable arrangements, with harmonious rhythm of beauty and fitness, including fanned, harped and star patterns, emerged.

This special Edition of the Pittsburgh Engineer is a tribute to Cable Supported Bridges – World Wide – a fitting tribute to bridges designed and constructed with 'harmonious rhythm of beauty and fitness'. Please enjoy our featured articles describing some unique cable supported bridge history, exciting new designs and words of interest and wisdom from the ones tasked to construct, maintain and preserve engineering legacies. China is the Featured Country of IBC 2018, and they have graciously contributed a culturally and technically significant feature article to this year's magazine. Take our bridge quiz and enjoy the results of our photo contest which has gained the interest of photographers world-wide. Seek out our 2019 anniversary calendar, which celebrates bridge engineering, cable supported bridges and the thirteen winners of our annual photo contest. In this 35th Anniversary of IBC, celebrate with us the global achievements of bridge engineering, in history and today.

The editors.

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

Welcome to the Conference!

By Ronnie Medlock

It is my honor and privilege to welcome you to the 35th annual International Bridge Conference (IBC) hosted by the Engineer's Society of Western Pennsylvania. Our conference has become one of the most recognized bridge engineering events in the United States and beyond; this is a testament to the excellent papers and programs that have been published and presented over the years, ever advancing the bridge state-of-the-art and keeping IBC attendees up to date on the most pertinent bridge topics of the day. This year is no exception, with sessions and papers ranging from bridge asset management and information modeling for bridges to innovative contracting and remarkable featured bridge projects.

Pondering these projects, I am awed by the work that the engineers in our community have accomplished over the years, designing and building structures that withstand the elements for decades, reliably connecting people to their work and play. The public is busy, and folks usually don't give bridges much thought, but this is okay: so often our work is in fact best when it goes unnoticed, crossed thousands of times a day by speeding loads of thousands of pounds. The resiliency of our structures reflects a quiet success, and this is just one more reason to come to the IBC: as we gather, not only will we learn from each other through presentations and dialogue, but also we will celebrate our accomplishments together, recognizing each other's work and acknowledging the most special achievements through awards for bridge projects and bridge engineers. On behalf of the ESWP, I welcome you to the conference, I look forward to celebrating your work, and I look forward to learning from the engineers who come to the IBC to share their thoughts and ideas and help us grow as an engineering community.

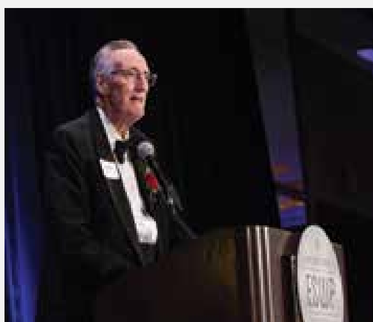
Ronnie Medlock

See you there!

Ronnie Medlock is Vice President, Technical Services, at High Steel Structures LLC in Lancaster, Pennsylvania and the General Chair of IBC, 2018.

Fred Graham – 2018 ESWP William Metcalf Award Recipient

J. Fred Graham, Jr., an Honorary Member of IBC Board and a founding member of the International Bridge Conference® (IBC), having served on the first IBC Executive Committee 35 years ago, received the 2018 William Metcalf Award from the Engineers' Society of Western Pennsylvania (ESWP) at the Annual Banquet on February 15, 2018. Fred was a strong advocate for an international gathering of bridge practitioners and he approached the ESWP with a proposal for sponsoring such an annual international conference gathering. ESWP quickly accepted Fred's challenge and the International Bridge Conference was born.

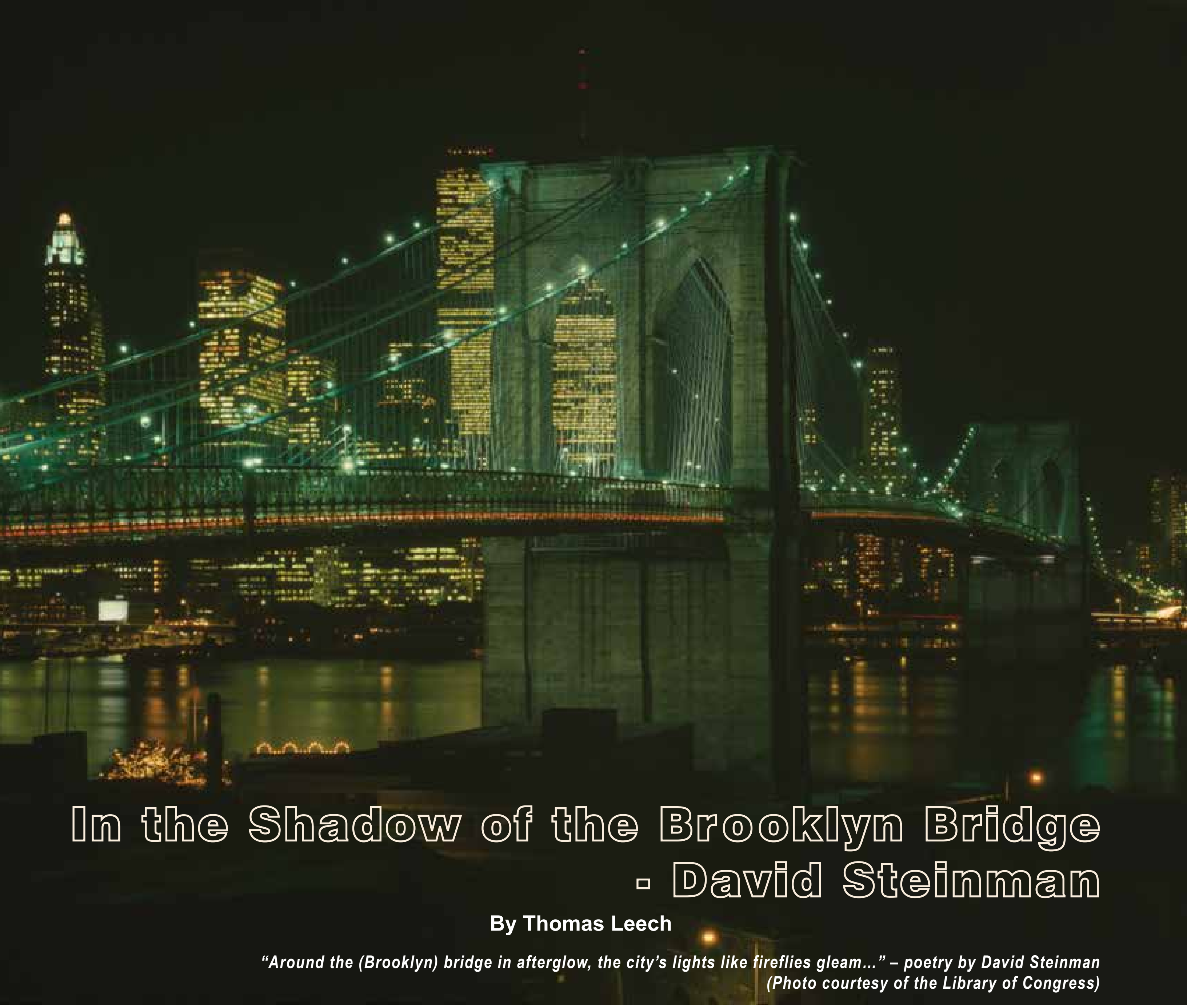


J. Fred Graham, Jr. at ESWP's 2018 Annual Engineering Awards Banquet

The William Metcalf Award is named in honor of the first President of the Engineers Society of Western Pennsylvania. The award, considered the most prestigious award granted by the Society, honors those who exceed expectations in multiple areas of leadership, trade and problem solving. It is bestowed upon a well- rounded, contemporary engineer who excels in all aspects of their work. Fred has exemplified these high ideals.

Fred served as Director of Engineering and Construction and Director of Capital Projects for Allegheny County and in various executive positions with the Pennsylvania Turnpike Commission and various private companies in Western Pennsylvania. He provided engineering consulting services up until his recent retirement in 2015. His engineering career spanned decades managing the design and construction of hundreds of bridges and 500 miles of roadway in Western Pennsylvania and throughout the Pennsylvania Commonwealth. Along the way, Fred has been a strong proponent of engineers serving in leadership positions in all branches of local, state and federal government as well as in business and industry. Additionally, Fred has been a long-time member of the ESWP, having served on the IBC Executive Committee, and serving as Conference Chair in 1985.

The International Bridge Conference owes a special debt of gratitude to Fred for not only serving actively for thirty-five years on the Executive Committee, but for also championing the annual Lichtenstein Award Medal, an award that recognizes a recent outstanding achievement in bridge engineering demonstrating artistic merit and innovation in the restoration and rehabilitation of bridges of historic or engineering significance.



In the Shadow of the Brooklyn Bridge - David Steinman

By Thomas Leech

"Around the (Brooklyn) bridge in afterglow, the city's lights like fireflies gleam..." – poetry by David Steinman (Photo courtesy of the Library of Congress)

Against the city's gleaming spires,
Above the ships that ply the stream,
A bridge of haunting beauty stands –
Fulfillment of an artist's dream.

The evocative twilight image of the Brooklyn Bridge and its – "haunting beauty" - came not from the heart of a poet but the soul of a Civil Engineer – David Steinman. Born in the late 1880's, and living in lower Manhattan as a youth, he literally grew up in the shadow of the Brooklyn Bridge. And by gazing at the silhouette of the Brooklyn Bridge and watching the construction of the nearby Williamsburg Bridge, he became, from a young age, captivated with bridges. This allure led to multiple degrees and teaching assignments in Civil Engineering.

From deep beneath the tidal flow
Two granite towers proudly rise
To hold the pendent span aloft –
A harp against the sunset skies.

As a young engineer, one can only hope to learn how to hold – "a pendent span aloft" - from the best. And Steinman did learn from the best, taking the role of special assistant to Gustav Lindenthal with the design of the Hell Gate Bridge, the iconic East River, New York City railroad crossing, with its expressive and powerful steel arched, through truss, linking Astoria and Wards Island. Steinman, along with Lindentahl and another of his protégés, Othmar Amman, became the trifecta of notable bridge forte in New York City in the early decades of the twentieth century.

Each pylon frames, between its shafts,
Twin Gothic portals pierced with blue,
And crowned with magic laced design
Of lines and curves that Euclid knew.

In the 1920's, Steinman joined forces with Holton Robinson and began a partnership in bridge design that lasted into the years of the Second World War. This venture emphasized economic designs over architecturally ornamented representations, yet never the less, produced some of America's most iconic suspension bridge designs – "of the lines and curves that Euclid knew" - including the Mount Hope Bridge spanning one of the narrowest gaps in the Narragansett Bay in Rhode Island, the St. John's Bridge spanning the Willamette River in Portland, Oregon,

Brooklyn Bridge, c. 1910 Photo Courtesy Library of Congress

the Waldo-Hancock Bridge spanning the Penobscot River below Bangor, Maine, and the Deer Isle Bridge spanning Eggemoggin Reach, allowing vehicular passage from the Maine mainland to Little Deer Isle.

The silver strands that form the net
Are beaded with the stars of night,
Lie jewelled dewdrops that adorn
A spiderweb in morning light.

One of Steinman's greatest legacies is his tour de force book entitled *A Practical Treatise on Suspension Bridges, Their Design, Construction and Erection*. As Steinman states in his introduction, this book "… has been planned to supply the needs of practicing engineers who may have problems in estimating, designing and constructing suspension bridges … a practical handbook … distinguished by simplicity of treatment and convenience of application …" This 1922, John Wiley Book, now available on-line as a Google Book, not only explains how to evaluate the - "spiderweb" - which is useful even in the day of high speed computation, but also provides a historical treasure trove which is readily available to the bridge engineering historian. This work contains photographs and detail drawings of many long-forgotten legacy suspension bridges of an earlier generation, including the 1877 iconic, iron chain, Point (Suspension) Bridge spanning the Monongahela River in Pittsburgh, Lindenthal's 1884 braced chain Seventh Street Bridge in Pittsburgh, and, as proposed in 1921, but never realized, Lindenthal's life-long dream bridge – the 16 lane wide, braced chain, 57th Street Hudson River Crossing, simply known as the proposed Hudson River Bridge, traversing the Hudson from New Jersey to Manhattan, New York.

Between the towers reaching high
A cradle for the stars is swung;
And from this soaring cable curve
A latticework of steel is hung.

In 1884, a store owner in the small town of St. Ignace, at the southern tip of the upper peninsula of Michigan, published a newspaper advertisement that included a reprint of an artist's conception of the Brooklyn Bridge with the caption "Proposed Bridge Across the Straits of Mackinac". Seventy-three years later, the upper and lower peninsulas of Michigan were connected by – "soaring cable curve(s)". Steinman's Mackinac Bridge, became known, in 1957 at its opening and still to this day, as the Western Hemisphere's longest suspension bridge (with two towers) between anchorages. As Steinman's most notable of designs, the bridge incorporated deep stiffening trusses – "a latticework of steel" – and an open-grid roadway to reduce wind resistance based on his 1943 published theoretical analysis of suspension-bridge stability problems, in response to the 1940 wind induced failure of the first Tacoma Narrows Bridge.

Around the bridge in afterglow,
The city's lights like fireflies' gleam.
And eyes look up to see the span –
A poem stretched across the stream.

from *BROOKLYN BRIDGE: NIGHTFALL*, by D. B. Steinman

From one who grew up in the shadow of the Brooklyn Bridge, the impression of the bridge, especially when night falls and the bridge lies in – "afterglow", always stayed with Steinman. In 1945, he published a fond retelling of the bridge's story in a book entitled *The Builders of the Bridge: The Story of John Roebling and His Son*; and in 1948, he was commissioned to conduct a major rehabilitation of his favorite bridge - the Brooklyn Bridge.

Thomas Leech, P.E., S.E. is the retired Chief Engineer, Bridges and Structures, of Gannett Fleming and currently instructor of Civil Engineering at Carnegie Mellon University. He is (co-)author of "Bridges…Pittsburgh at the Point…A Journey Through History" (with co-author Linda Kaplan, Word Association Publishers, 2016, and a 2018 IPPY Award Winner, non-fiction, Mid-Atlantic Region), editor and author of "Reflections of the Greatest Bridge Engineers and Architects of the 20th and 21st Centuries" (ESWP), a contributing author to "The Geology of Pittsburgh" (AEG) and author over 50 published articles in the history and technology of Civil Engineering and other related topics.

Take our annual Bridge Quiz – see next page – how well do you know Steinman's suspension bridges? - editors

BRIDGE QUIZ -

How Well Do You Know the Bridges of David Steinman?

"Of lines and curves that Euclid knew…"

David Steinman – bridge designer, author and poet

Take our Bridge Quiz – Match the four descriptions on the left with the four photos on the right. All photos are courtesy of the Library of Congress

Bridge 1: The 1931 St. Johns Bridge is a steel suspension bridge that spans the Willamette River in Portland Oregon, connecting the Cathedral Park neighborhood and the northwest industrial area. The bridge's two distinctive 408-foot-tall Gothic Towers gave the namesake to the adjacent park and neighborhood. On its June 13, 1931 dedication ceremony, David Steinman said: "… A challenge and an opportunity to create a structure of enduring beauty in the God-given wondrous background was offered us when were asked to design the bridge. It is the most beautiful bridge in the world we feel …" Is it Photo A, B, C or D?

Bridge 2: The 1931 Waldo–Hancock Bridge (connecting Waldo and Hancock Counties) was the first long-span suspension bridge erected in Maine, as well as the first permanent bridge across the Penobscot River. The iconic bridge, with a main span of 800 feet (243.8 m) was demolished in 2013. Technologically, the Waldo–Hancock Bridge represented a number of firsts. It was one of the first two bridges in the U.S. to employ Robinson and Steinman's prestressed twisted wire strand cables, and was also the first bridge to make use of the Vierendeel truss in its two towers, giving the structure an effect that Steinman called "artistic, emphasizing horizontal and vertical lines." Is it Photo A, B, C or D?

A

D

B

C

Bridge 3: The 1939 Deer Isle Bridge is a suspension bridge spanning Eggemoggin Reach in the state of Maine. The bridge, carrying State Route 15, is the only vehicular connection from the Maine mainland to Little Deer Island. With a main span of 1,088 feet, the bridge spanned the yachting area of the Eggemoggin Reach requiring a 200-foot wide channel at midspan with a minimum 85-foot underclearance, placing the roadway 100 feet above mean sea level, ultimately giving the structure a unique profile with steep (6.5%) approach grades and short (400 foot) vertical curve at mid-span. Is it Photo A, B, C, or D?

Bridge 4: The 1957 Mackinac Bridge is the well-known suspension bridge spanning the Straits of Mackinac, connecting the Upper and Lower Peninsulas of Michigan. With an overall length of 26,372 feet, the "Mighty Mac" is the western hemisphere's longest suspension bridge between anchorages. At the time of construction, the bridge was noted for its deep stiffening deck truss and open grid deck with consideration of aerodynamic stability in an area noted for high winds. The bridge is also noted for its annual Labor Day Bridge Walk, where the bridge is closed to vehicular traffic and thousands of people, traditionally led by the Governor of Michigan, cross the five-mile span on foot from St. Ignace (upper or northern peninsula) to Mackinaw City (lower or southern peninsula). Is it photo A, B, C or D?

Answers can be found on Page 1

Notes on Good Practice in the Preservation of Long Span Suspension Bridges

By Barry Colford

As the stock of suspension bridges gets older, their maintenance requirements will naturally keep increasing with time and it will become more and more critical to ensure that adequate funding is provided to ensure that acceptable levels of safety and service are provided throughout the remaining life of the bridges.

Introduction:

The preservation of bridges provides different challenges than those faced when designing a new structure. These challenges are likely to be more numerous and increase in scale and complexity when dealing with long span suspension bridges. These long span bridges also tend to be vital links in a nation's infrastructure and any failure, either at the serviceability or ultimate limit state level is likely to cause significant disruption to the public.

There are approximately 147 major cable suspension bridges in the world. Up until the mid-1960s, the overwhelming number of long span suspension bridges were built in the US. Since that time the center of suspension bridge building has gone from Europe to Japan and is now in firmly in China as shown in Figure 1.

Figure 1 Distribution of Major Suspension Bridges by Country - spans greater than 300 meters

According to the latest National Bridge Inventory (NBI), there are approximately 36 major cable suspension bridges in the US, equating to nearly 25% of the major global suspension bridge inventory. Not only is it one of the largest inventories, but it is the oldest with an average age of 72 years. The older of these bridges includes Williamsburg (1903), Brooklyn (1883) and Roebling (1867), with Wheeling (1849) being the oldest at 168 years. The location of these bridges is shown in Figure 2.

The safety of the traveling public is of the highest priority and has to be assured. This is achieved by preserving the long term structural integrity of the bridge throughout its service life. However, in addition, the safety of the public and all personnel working on the bridge has also to be of the highest priority during any inspection, maintenance, preservation or rehabilitation works. This assurance has to apply also to operational works including setting out of traffic restrictions and controls; security patrols; winter maintenance and routine tasks such as gulley cleaning.

The aims of a preservation policy for a cable supported bridge should be to:

- maintain acceptable standards of safety and structural integrity.
- preserve the transport corridor with minimum disruption.
- provide sufficient and effective budget and resources.

Figure 2 Distribution of Long Span Suspension Bridges in N America

General Principles

It has been found to be very useful if all the information relating to the management, operation and maintenance of a large complex bridge be retained within a single document or 'Bridge Manual'.

A 'Bridge Manual' should contain all the information relating to the design and construction of the bridge. Ideally this should include design calculations, certification, contract documents and drawings, as-built drawings and resident engineers' reports. Material certification and all quality documentations should also be included, along with warranty information. Power, lighting and communications systems and other mechanical and electrical equipment (including signing and toll plaza infrastructure equipment) should be integrated into the manual.

In essence, all information relating to the bridge should be available through a single portal. Experience has shown that if this is not done then the complete retrieval of records and documents relating to the bridge can be very difficult to achieve and over time it becomes more difficult to locate all the information. The 'Bridge Manual' must be considered as a 'live' document and should be amended as changes are made over the service life of the structure.

All of this can be difficult to achieve and is very much dependent on staffing arrangements and funding. Ideally, the 'Bridge Manual' should also contain all operational procedures and requirements such as winter maintenance; managing traffic in high winds; security and etc.

The 'Bridge Manual' should ideally be in electronic format and in essence all information should be accessed through a single portal.

Procedures for replacement of important parts of the bridge that are expected to have a shorter service life than the bridge itself (pavement, expansion joints, bearings, and suspenders are all included in that category) are recommended to be established to ensure that disruption is minimized in the event of early or unexpected failure. Spare tooth/comb joint plates; springs and holding down bolts would be essential spares to hold and catalogue along with method statements and risk assessment within replacement procedures. Spare suspender rope is also useful to keep in store along with spare sockets.

Inspection and Monitoring

For large complex bridges, especially cable supported bridges, the use of risk-based inspection methods can be greatly beneficial. Risk based assessments of each bridge component (or group of components) can be carried out to determine the frequency of inspection based on the risk of failure. This approach not only reduces the risk of failure of critical components but also helps optimize resource management and can reduce risk to staff and users of the bridge.

The requirement of the FHWA to inspect fracture critical elements more frequently than other bridge elements is an example of risk based inspections. Internal cable inspections are now routinely carried out on many suspension bridges in addition to the routine inspections because there is a recognized and known risk of cable strength loss. A comprehensive risk based approach would include these requirements but also apply the same rationale to all the bridge elements in a methodical fashion.

With regard to existing structures, Structural Health Monitoring (SHM) has proven to be more effective at monitoring for specific and known problems on long span bridges. It would be possible to retrofit an existing long span bridge with a SHM system; however, it would be very expensive to install and maintain, and unless carefully planned and managed, the system could produce data which may never be used. Experience has shown that the management and suitability of the data and the robustness of the equipment are key issues that require more discussion.

Suspension Bridge Main Cables

Deterioration of suspension bridge main cables has been in evidence since the 1960s and 1970s but it was not until the late 1990s that work commenced on providing guidance on methods of inspecting and evaluating the loss of strength of deteriorated cables. We have somewhat belatedly come to understand that it is almost impossible to prevent water entering the main cables of suspension bridges. Typical sources of water in cables include entrapment during construction; intrusion from cracks in the external cable paint or wrapping system; gaps at cable bands or hood seals, and condensate from the variations in temperature and relative humidity inside the cables. If moisture is present then galvanizing will inevitably break down resulting in corrosion, wire cracks and breaks due to hydrogen embrittlement or stress corrosion and a subsequent loss of cable strength (Figure 3).

Figure 3 Cable Wire Breaks (Photo courtesy of AECOM)

Previous maintenance regimes involving continuing to paint and re-caulking at cable bands and saddles has not provided the protection required to prevent cable deterioration. Unfortunately, the other option of oiling the cable by introducing an internal lubricant is expensive and has largely fallen out of use. Wrapping cables with various materials to limit water ingress has been used on some bridges, but does not appear to have been successful in preventing water getting into the cables and there is a risk that the wrapping will simply trap water within the cables.

However, there is now strong evidence available to show that by retrofitting a system of cable dehumidification (Figure 4 and 5), further strength loss in cables, that have suffered deterioration through wire breaks, can be prevented (Figure 6).

Furthermore, the fitting of a dehumidification system to main cables now appears to be an industry standard for all new suspension bridges and is also being retrofitted on relatively new bridges even where inspection has shown little damage has occurred.

Figure 4 Cable Dehumidification Injection Sleeve location (AECOM)

The fitting of a dehumidification system does not mean that internal inspections need never be carried out again. Inspection remains the only effective method of determining cable condition. However, it is acknowledged that inspection frequencies may need to be reviewed and updated to take into account interventions such as dehumidification and the use of acoustic monitoring.

Figure 5 Photo of South 10th Street Bridge, Pittsburgh, PA by AECOM

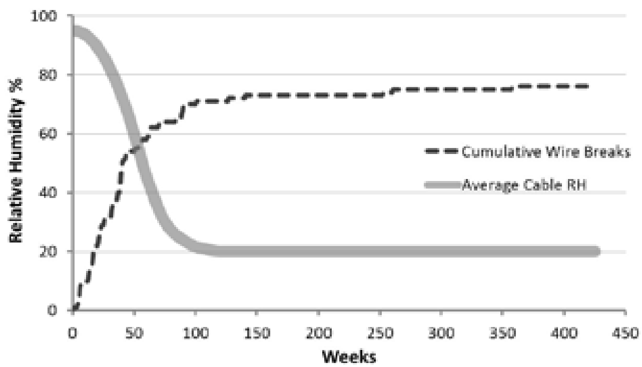


Figure 6 Graph showing reduction in cable wire breaks following dehumidification installation

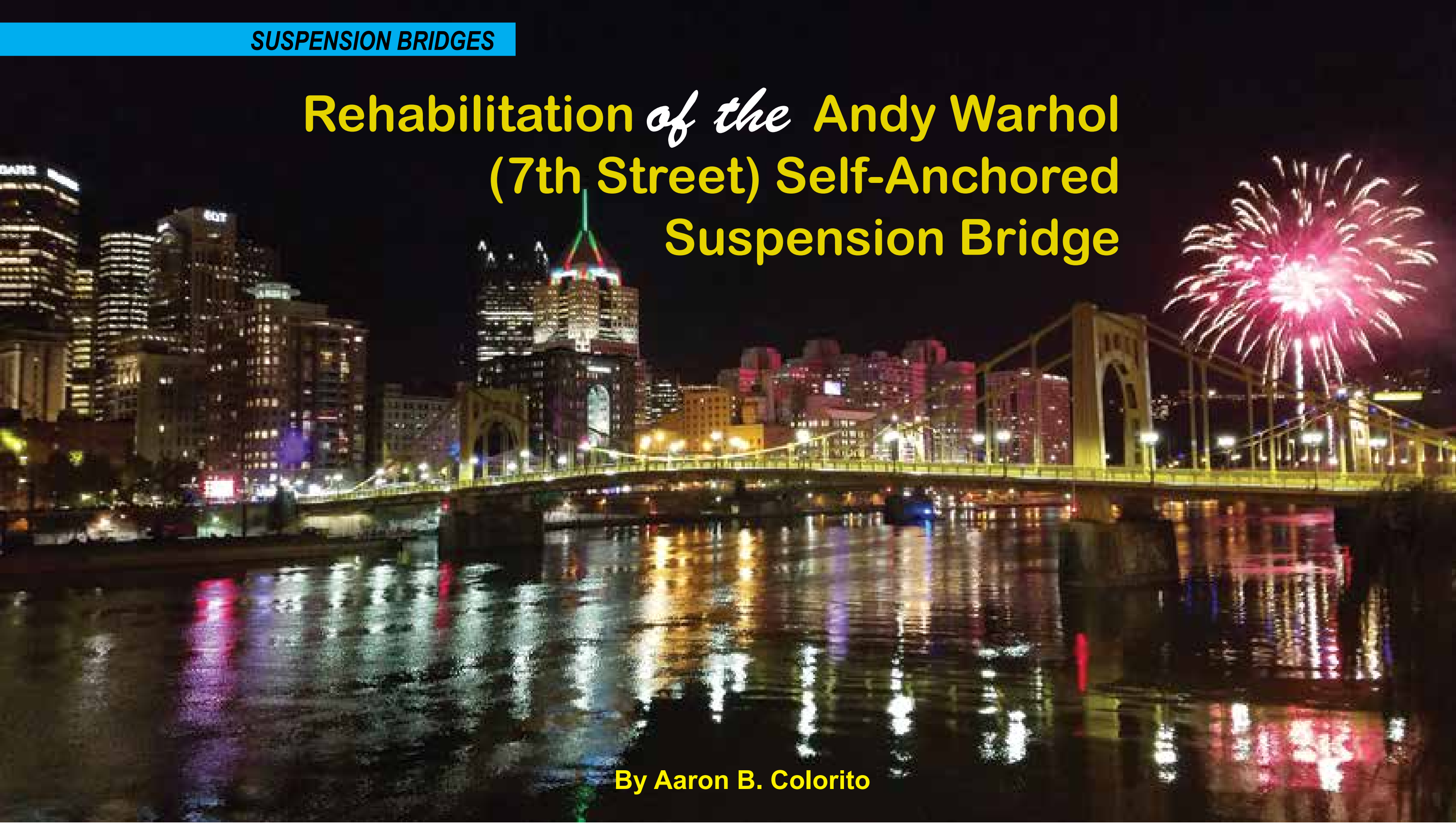
Conclusion:

This article highlights some of the issues that have affected suspension bridges over the last few years and offers guidance on good practice. The task of preserving the structural integrity of these bridges in order for them to be both reliable and used safely by the public for the remainder of their service life is difficult. Funding will always be a challenge because bridge maintenance usually only becomes a political issue when there is either a structural or operational failure. A sharing of knowledge between engineers, academics, contractors, owners and operators is an important part of keeping the public safe and the traffic moving. We must all keep pushing the case for adequate funding for these structures and ensure that there is a clear message on the risks involved if that funding is not made available.

About the author...
Barry Colford, PE CEng FICE, has led AECOM's Complex Bridge Preservation Practice in North America since 2015. In this capacity, he provides best practice advice to long span bridge owners, and participates in industry forums and workshops. He was formerly Chief Engineer and Bridgemaster of the Forth Road Bridge in the UK, a 3,300 ft main span suspension bridge. He has been closely involved in developing close ties with other long span bridge owners throughout the world and was the UK Committee Member of the International Cable Supported Bridge Owners Association.

Rehabilitation of the Andy Warhol (7th Street) Self-Anchored Suspension Bridge

By Aaron B. Colorito



Bridge elevation at night (photo by Dave Briskey, P.E., Hill International)

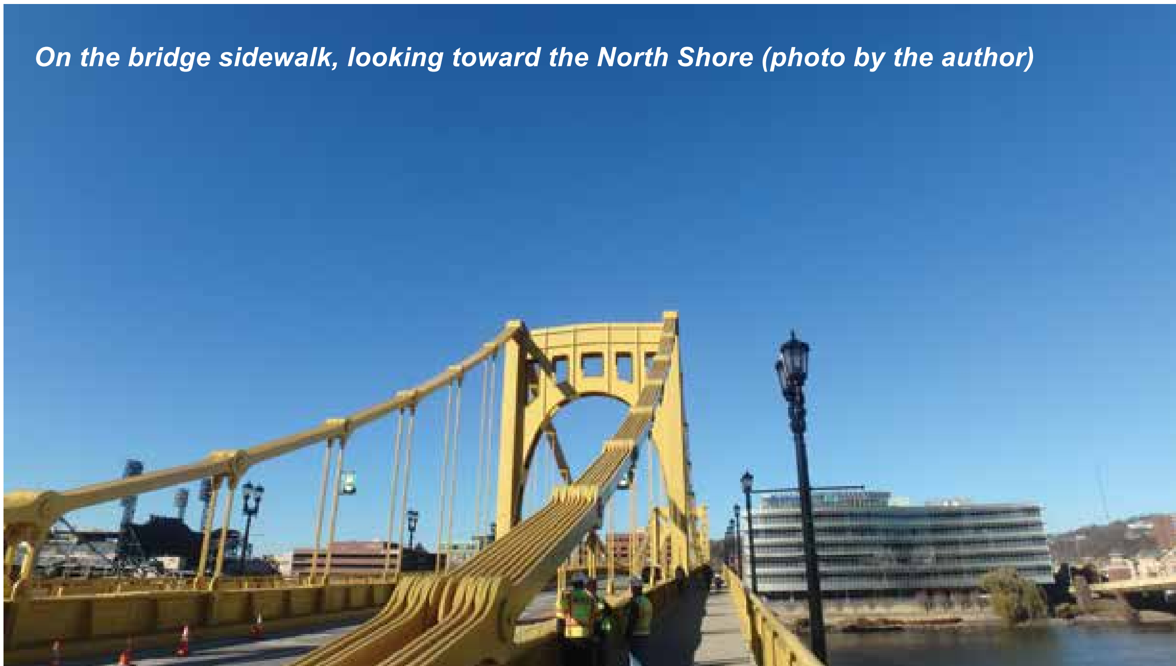
There are projects in every engineer's career that they can call "once-in-a-lifetime opportunities". My career is relatively short – only 7 years long – but I am proud to say that I've been lucky enough to work on one of those projects: the Andy Warhol Bridge rehabilitation. The Andy Warhol Bridge (formerly known as the 7th Street Bridge) crosses the Allegheny River in downtown Pittsburgh, Pennsylvania. The bridge connects Fort Duquesne Boulevard in downtown Pittsburgh to West General Robinson Street in the North Shore neighborhood near PNC Park.

The bridge was built from 1924 to 1926 by the American Bridge Company of Ambridge, PA. Ambridge was the company town of American Bridge for most of the twentieth century. Ambridge is my hometown, and my late paternal grandfather worked as a draftsman for American Bridge for most of his life, so bridges built by the American Bridge Company hold a special place in my life. To get the opportunity to perform a modern finite element analysis of the bridge and be a part of the design of the rehabilitated structure is truly special to me.

The Andy Warhol Bridge is the middle of the Three Sisters Bridges, a trio of nearly-identical, side-by-side self-anchored suspension bridges at 6th, 7th, and 9th Streets. The Three Sisters Bridges are comprised of the Roberto Clemente (6th Street) Bridge, the Andy Warhol Bridge (7th Street), and the Rachel Carson (9th Street) Bridge. Although all three bridges are visually identical, the Andy Warhol Bridge is slightly longer and narrower than the other two (which are completely identical). The bridges are eyebar-chain, self-anchored suspension bridges with steel buckle plate and noncomposite concrete floors, supported by a stringer-floorbeam floor system. The floorbeams frame into the stiffening girders, which are in turn hung from the suspension chains by eyebar hangers. The suspension chains are supported by two rocking towers, one expansion and one fixed, which rest on 24-inch diameter pins. The stiffening girder, floorsystem, towers, and hanger eyebars are made of open-hearth carbon steel. The suspension chain eyebars are composed of high-strength, heat-treated steel of American Bridge's design. The Three Sisters Bridges comprise the only trio of nearly identical, side-by-side bridges anywhere in the world, and hold the distinction of being the first self-anchored suspension bridges in the United States.

The last major rehabilitation of the Three Sisters Bridges occurred from 1991 to 1995, and by 2016 were exhibiting rapid deterioration of their structural steel, concrete decks, and paint systems. Michael Baker International was chosen by the Allegheny County Department of Public Works (the bridge owner) to perform analysis and design of the rehabilitations. During design, the bridge was analyzed for the first time using a full three-dimensional finite element analysis, to accurately determine the element forces after original construction and to include the effects of changing dead load due to the numerous previous rehabilitations. The bridge was then rated using the Load and Resistance Factor Design (LRFD) method for standard PennDOT design and rating trucks, as well as creating a series of unique pedestrian-only live load cases. The pedestrian-only live load cases were created to study the effects of large crowds of pedestrians on the structure. Because of their proximity to downtown Pittsburgh, Heinz Field, and PNC Park, the Three Sisters bridges are occasionally closed to vehicles and are used to allow pedestrian access, stage fireworks, or provide space for concerts and concessions. Based on the analysis and the amount of space available to pedestrians, the factored pedestrian loading can exceed the HL-93 design loading and thus was an important consideration for design.

To verify the finite element analysis, it was deemed necessary to have a method of independently verifying the results of the finite element model, particularly the element dead loads under self-weight. After a significant amount of research, the primary resource used for the verification was the paper *Simplified Theory of the Self-Anchored Suspension Bridge*, authored by Carl H. Gronquist in 1941, in fulfillment of his civil engineering degree at Rutgers University. Gronquist's Simplified Theory is an extensive treatment of the theory and calculations behind determining the el-



On the bridge sidewalk, looking toward the North Shore (photo by the author)

ement forces in a self-anchored suspension system due to applied loads. By using spreadsheets, hand calculations of the existing dead and live loads, and Gronquist's paper, the element forces for one suspension "line", including girder, hangers, and suspension chain, were calculated for dead and live load. The independent analysis gave results in relatively good agreement with the finite element analysis, both confirming the assumptions of the finite element model as well as giving the engineers extensive insight into the behavior of the bridge.

Construction activities included structural steel repairs, repairing sidewalk and utility support brackets, replacement of the roadway curb plates, substructure repairs, installation of scour protection, a complete repainting of the superstructure, and replacement of the concrete deck. It was determined after inspection and conversations with the County that the existing noncomposite deck should be replaced with a composite deck. The noncomposite concrete fill tends to "float" over the supporting stringers and buckle plates, resulting in the bottom of concrete deck being reduced to dust and gravel, requiring significant investment by the County to maintain a safe riding surface. The new reinforced concrete deck is fully structural and composite, relegating the buckle plates to serve as formwork rather than the structural portion of the deck. Converting the deck to composite also has benefit of increasing the load ratings of the existing stringers without requiring extensive structural steel repairs.

Originally scheduled for completion in November 2017, minor work remains to be completed upon the return of warmer weather in Spring 2018, including completion of utility relocation, concrete cleaning and sealing, and minor touchup of the paint system. The Andy Warhol Bridge – and the Three Sisters Bridges as a whole – represent an important achievement in the field of bridge engineering as well as an important historic resource for the City of Pittsburgh and Allegheny County. Being a part of the analysis, design, and construction of the rehabilitations of these landmarks has been a personal and professional pleasure.

On the bridge, looking towards Downtown Pittsburgh (photo by the author)

About the Author...
Aaron B. Colorito, P.E., is a structural engineer for Michael Baker International in Moon Township, PA. He specializes in bridge analysis and design, bridge rehabilitation, and bridge inspection. He is especially interested in the history of bridge engineering, historic methods of bridge design, and the analysis of historic bridges.

Setting World Records of Cable-Supported Bridges through Innovations

By M. Myint Lwin

Photo: Library of Congress

INTRODUCTION

Cable-supported bridges have been used for crossing natural and artificial obstacles for thousands of years. Ropes, chains and bars were used for earlier bridges. Wire ropes are commonly used for modern cable-supported bridges. Researchers and engineers are beginning to experiment with the use of CFRP wires, bars and strands for bridge construction. For this article, we will be focusing on the use of high-strength steel wires and strands for the support systems of long span cable-supported bridges – suspension and cable-stayed bridges

JOHN A. ROEBLING AND CABLE-SUPPORTED BRIDGES

John A. Roebling

John Augustus Roebling was born in Germany in 1806. His fascination with bridges started from his childhood years spent in Prussia. He carried this interest throughout his life. He studied engineering at the Royal Polytechnic School in Berlin. He and his brother migrated to the United States in 1831 and settled in Saxonburg, Butler County, Pennsylvania. He tried farming but soon realized that he did not have much of a green thumb. He left the farming to his mother, who was very successful in farming. Roebling went to Harrisburg, the State Capital, and found a job with the State as a surveyor. While performing survey, he observed the state-owned Portage Railroad using heavy but weak hemp ropes in towing canal boats on the inclines across the Allegheny Mountain. His creative mind led him to invent the wire ropes, which were stronger, lighter and more durable, to replace the hemp ropes. The demand for his new invention gained general acceptance and broad applications.

John A. Roebling developed the 7-strand wire ropes and began producing them in Saxonburg, Pennsylvania in 1841. Later he built a large industrial complex named “John A. Roebling’s Sons Company” in Trenton, New Jersey, for steel wire production. Roebling was involved in the design and construction of several cable-supported bridges for aqueducts, railroads, and highways. He earned a reputation for inventing a web truss system added to either side of the bridge roadway to stabilize and to prevent premature failure of suspension bridges at the time. Using this method, he successfully built the historic Niagara Falls Suspension Bridge, connecting Niagara Falls, Ontario to Niagara Falls, New York across the Niagara River Gorge. It was a double deck bridge, carrying carriage and pedestrians on the upper deck, and railway traffic on the lower deck. It was an engineering marvel at the time! Later, he was commissioned to design and build the Brooklyn Bridge to connect Manhattan and Brooklyn by spanning the East River.

The Brooklyn Bridge was the last bridge Roebling designed. But he did not live long enough to work on the construction of the bridge. In the final phase of the design, while he was standing at the edge of a dock surveying the final location of the bridge, the toes of one of his feet was crushed by an arriving ferry. His toes had to be amputated. He refused further medical care and treated the wound himself by “water therapy”. Unfortunately, the wound was infected, and Roebling died of tetanus just 24 days after the accident.

Roebling’s son, Washington Roebling, and Roebling’s daughter-in-law, Emily Warren Roebling, continued with the construction of the bridge. After 14 years, the famous Brooklyn Bridge was completed and opened to traffic on May 24, 1883. The Brooklyn Bridge is a hybrid suspension/cable-stayed bridge in New York City. It is one of the oldest cable-supported bridges in the United States. With a main span of 486.3m (1,595’), it was the largest cable-supported bridge in world at the time of completion and ranked as one of the greatest engineering achievements of the 19th. Century!

In recognition of Roebling’s outstanding achievements, IBC established the John A. Roebling Medal, awarded annually to honor a person with a lifetime achievement in bridge engineering in design, construction, research and/or education.

WORLD RECORDS OF CABLE-SUPPORTED BRIDGES

John A. Roebling sowed the seeds for technological advancement in the design and construction of cable-supported bridges. With a review of the top 10 suspension and cable-stayed bridges in the world, we can appreciate the efforts of bridge researchers and engineers in meeting the challenges in spanning large valleys, bays and rivers with creative innovations. A study of these bridges will provide valuable lessons in planning, building and preserving existing and future populations of cable-supported bridges. Tables 1 and 2 show the progress in main span lengths in a period of 10 years.

Table 1: Top 10 Suspension Bridge Main Spans

2007				2017			
No.	**Bridge Name**	**Span/Year**	**Country**	**No.**	**Bridge Name**	**Span/Year**	**Country**
1	Akashi	1991m/1998 (6,532’)	Japan	1	Holds Record		
2	Xihoumen	1650m/2009 (5,413’)	China	2	Holds Record		
3	Great belt	1624m/1998 (5,328’)	Denmark	3	Holds Record		
4	Runyang	1490m/2005 (4,888’)	China	4	Osman Gazi	1550m/2016 (5,085)	Turkey
5	Humber	1410m/1981 (4,626’)	England	5	Yi Sun-Sin	1545m/2012 (5,069’)	S. Korea
6	Jiangyin	1385m/1999 (4,544’)	China	6	Runyang	1490m/2005 (4,888’)	China
7	Tsingma	1377m/1997 (4,518’)	China	7	Nanjing 4th Bridge	1418m/2012 (4,652’)	China
8	Verrazano	1298m/1964 (4,260’)	USA	8	Humber	1410m/1981 (4,620’)	England
9	Golden Gate	1280m/1937 (4,200’)	USA	9	Bosphorus	1408m/2009 (4,619’)	Turkey
10	Yangluo	1280m/2007 (4,200’)	China	10	Jiangyin	1385m/1999 (4,544’)	China

Table 2: Top 10 Cable-Stayed Bridge Main Spans

2007				2017			
No.	**Bridge Name**	**Span/Year**	**Country**	**No.**	**Bridge Name**	**Span/Year**	**Country**
1	Tatara	890m/1999 (2,920’)	Japan	1	Russky	1104m/2012 (3,622’)	Russia
2	Normandie	856m/1995 (2,808’)	France	2	Sutong	1088m/2008 (3,570’)	China
3	3rd Nanking	648m/2005 (2,126’)	China	3	Stonecutters	1018m/2009 (3,340’)	China
4	2nd Nanjing	628m/2001 (2,060’)	China	4	Edong	926m/2010 (3,038’)	China
5	Baishazhou	618m/2000 (2,028’)	China	5	Tatara	890m/1999 (2,920’)	Japan
6	Qingzhou	605m/2001 (1,985’)	China	6	Normandie	856m/1995 (2,808’)	France
7	Yangpu	602m/1993 (1,975’)	China	7	Jiujiang	818m/2013 (2,684’)	China
8	Xupu	590m/1997 (1,936’)	China	8	Jingyue	816m/2010 (2,677’)	China
9	Meiko-chuo	590m/1998 (1,936’)	Japan	9	2nd. Wuhu	806m/2017 (2,644’)	China
10	Taoyaomen	580m/2003 (1,903’)	China	10	Incheon	800m/2009 (2,625’)	S. Korea
				10	Yachi Riv Br	800m/2016 (2,625’)	China

IN SEARCH OF SUPER LONG SPAN CABLE-SUPPORTED BRIDGES

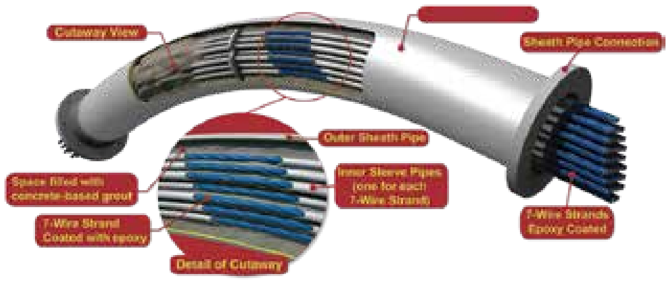
Bridge researchers and engineers continue to find safe, durable, efficient, economical and sustainable solutions to bridge wide and difficult terrains to meet the needs of public transportation. Cable-supported bridges have the highest potential to beat current records. South Korea’s Super Long-Span Bridge R&D Center has launched a research project to develop super long-span bridges with main span greater than 2000m (6,560’) for suspension bridges, and 1000m (3,280’) for cable-stayed bridges, and with longer design life, higher performance, more intelligent, lower maintenance and more economical. China has an ongoing research project on large main spans over 1000m (3,280’) for railway bridges. Dr. Man-Chung Tang, Chairman of the Board and the Technical Director of T.Y. Lin International, U.S.A., predicts that by 2050, a suspension bridge might reach a main span of 4000m (13,123’), and a cable-stayed bridge might reach a main span of 2500m (8,200)! There is excitement and challenge in the bridge community to stretch the span lengths of bridges to better serve the people!

CLOSING REMARKS

Cable-supported bridges – suspension and cable-stayed bridges – represent advancement in materials, creative design concepts and innovative construction techniques for spanning deep valleys, large bays and wide rivers. They are the pride of the communities, which have invested significant resources in the design and construction of these signature bridges! It is important that we commit adequate resources for diligent inspection and timely maintenance to assure efficient and effective performance throughout the service lives of these bridges. Inspection and maintenance of the cables of cable-support bridges are very complex but essential, because there are miles of cables and layers of wires, many of which are not readily visible or accessible. Designers are beginning to design a main cable system such that an individual strand of a cable can be removed for inspection and replacement if necessary. Couple of examples are: (1) the Penobscot Narrows Bridge – Cradle System, Maine, U.S.A., and (2) the Second Wuhu Yangtze River Bridge – U-Shaped System, Wuhu, Anhui, China.

The biggest problem in cable-supported bridges is corrosion of the wires in the main cables. Corrosion is caused by the presence of water or moisture in the interior of the cables. Water gets into the cable through damages in the wrapping, cover, duct or joint. Cracks in coating, sheathing or sealing allow water to enter the cable. Maintenance effort should be focused on repairing damages and sealing cracks to assure watertightness of the cable system. Moisture may be trapped in the voids of the cable during construction. Moist air condenses on the steel wires, causing corrosion. Condensation problem can best be solved by installing a dehumidification system, which introduces dry air into the cable to drive out the moist air. Regular inspection and timely maintenance are important for assuring structural integrity and watertightness of a cable system, and for preserving the safety, durability and efficiency of cable-supported bridges.

Second Wuhu Bridge – U-Shaped System



Penobscot Bridge – Cradle System

About the Author...
M. Myint Lwin is currently an independent Consulting with special interest and services in engineering education and training, QC/QA assessment, constructability and peer reviews of major projects to ensure compliance with the Owner's requirements, project provisions and Federal and State laws and regulations with emphasis on safety, durability, efficiency, sustainability, and economy. He is the former Director of the Office of Bridge Technology, Federal Highway Administration (FHWA). He was the State Bridge and Structures Engineer with the Washington State Department of Transportation.

He holds a BSCE degree from the University of Yangon, Myanmar, and holds an MSCE degree from the University of Washington, Seattle, WA. He is a registered Professional Engineer in Civil and Structural Engineering, the 2013 IBC John A. Roebling Medal recipient, and a Life Member of ASCE. He has authored numerous papers and books on bridge engineering.

Notable Cable Supported BRIDGES in China

By Xu Gongyi, Xu Rundong

INTRODUCTION

China has a vast territory with many rivers. Throughout history, thousands of bridges have been built and high prestige has been achieved, such as stone arch bridges and suspension footbridges. Since 1980, along with the opening and reform in China, economic development demands efficient transportation systems, which have resulted in large scale construction of many highway and railway long-span bridges. By the end of last year, China has more than 800,000 highway bridges and 200,000 railway bridges. Valuable technical experience and scientific research has brought many achievements in bridge engineering, such as design theory, calculation methods, construction technology, testing methods, application of new materials and supporting installations. This paper briefly presents an overview of the significant achievements in long-span suspension bridges and cable-stayed bridges in the last 20 years.

SHANTOU BAY BRIDGE (1)

In 1995, the Shantou Bay Bridge in Guangdong Province was completed as the first modern long-span suspension bridge in China. A prestressed concrete box girder serves as both the bridge roadway and the stiffening girder for the suspension system. The 452m main span in this bridge is the longest span of a suspension bridge with prestressed concrete stiffening girders in the world. The project was awarded with Gold Prize for National High-quality Project, 2nd Prize of National Award for Achievements of Promoting Science and Technology. Despite the frequently overloaded vehicles that the bridge experiences, the Shantou Bay Bridge has been in good condition since its completion, with a road surface replacement scheduled for 2017 and a suspender replacement planned for 2018.

A: Crossing Shantou Bay (本桥跨越汕头海湾)

B: Carrying dual direction six lanes (双向六车道)

C: Max span length is 1,483 feet (本桥主跨为452m)

D: Max pier height is 312 feet (塔高95.1m)

E: Span to sag ratio is:1/10 (主缆挠跨比为1/10)

XILING YANGTZE RIVER BRIDGE (2)

The 900m long Xiling Yangtze River Bridge was built in 1996 for the special highway loading of 78-ton trucks for construction and maintenance of the Three Gorges Dam. The all-welded orthotropic steel box girder was selected as the stiffening girder in a suspension bridge for the first time in China. The main span is 900m; total steel used is 17,900tonnes. With the longest span in China at the time of completion, it was ever honored as "The First Span in China". It has been awarded the Luban Prize for China Construction Project.

A: Crossing Yangtze River (本桥跨越长江)

B: Carrying dual direction four lanes (双向四车道)

C: Max span length is 2,953 feet (本桥主跨为900m)

D: Max pier height is 394 feet (塔高120m)

E: Span to sag ratio is:1/10 (主缆挠跨比为1/10)

TSINGMA BRIDGE AND JIANGYIN YANGTZE RIVER BRIDGE (3 & 4)

After the construction of the Xiling Yangtze River Bridge, two suspension bridges with main spans over 1000m were opened to traffic. In 1998, the Tsingma Bridge in Hong Kong was opened with a 1377m long main span, which is the longest double deck bridge for both highway and railway traffic in the world. One year later, in 1999, the Jiangyin Yangtze River Bridge with a 1385m main span over Yangtze River was opened to traffic. It was the longest bridge in China and the fourth longest bridge in the world at that time. Due to the serious rusting of the hanger ropes, the hanger ropes of the Jiangyin Bridge were replaced after ten years of operation. The bridge deck pavement was replaced lane by lane during the period of 2003 to 2015. The original deck pavement design concept of the Jiangyin Bridge is commonly used in Britain. However, China is now in the stage of economic development and infrastructure construction, where many overload vehicles traverse the structures, which places more demand on the design of the deck. This is also a common problem for Chinese engineers for long-span cable-stayed bridges and suspension bridges.

TSINGMA BRIDGE (3)

A: Crossing Mawan Strait (本桥跨越马湾海峡)
B: Carrying dual direction eight lanes + two light rail (双向八车道 + 两线轻轨)
C: Max span length is 4,518 feet (本桥主跨为1377m)
D: Max pier height is 430 feet (塔高 131m)
E: Span to sag ratio is:1/9 (主缆挠跨比为1/9)

JIANGYIN YANGTZE RIVER BRIDGE (4)

A: Crossing Yangtze River (桥跨越长江)
B: Carrying dual direction six lanes (双向六车道)
C: Max span length is 4,446 feet (本桥主跨为1385m)
D: Max pier height is 597 feet (塔高 182m)
E: Span to sag ratio is:1/10.5 (主缆挠跨比为1/10.5)

TAIZHOU AND MAANSHAN SUSPENSION BRIDGES (5 & 6)

China built two long-span suspension bridges with double main spans longer than 1000m in 2007. One of them is Jiangsu Taizhou Bridge across Yangtze River with the span arrangement of 390 + 2×1080 + 390m, and the other is the Anhui Maanshan Bridge over the Yangtze River spanned as 360 + 2×1080 + 360m. These two bridges are tied in the record as the longest double-span, three-pylon suspension bridge in the world. Two large main spans and three pylons were used to meet the requirements for complex river flow, hydrology and navigation at substantially less cost. Each of these bridges carries six traffic lanes, three in each direction, with a deck width of 33m. The central pylon of the Taizhou Bridge consists of two inverted-Y shaped towers in elevation view, constructed of steel and founded on caissons. Taizhou Bridge opened to traffic in 2012. The central pylon of the Maanshan Bridge is constructed of steel-concrete composite design and founded on a revolutionary foundation system called the “root foundation”. The “root foundation” technique was developed and used in the Maanshan Bridge to increase stability and bearing capacity at reduced cost. The Maanshan Bridge opened to traffic in 2013. The Taizhou Bridge won International Award of Merit in Structural Engineering (IABSE) on 2014, and the Maanshan Yangtze River Bridge, won the George S. Richardson Medal in the 33th International Bridge Conference (IBC), in 2016.

TAIZHOU YANGTZE RIVER BRIDGE (5):

A: Crossing Yangtze River (本桥跨越长江)
B: Carrying dual direction six lanes (双向六车道)
C: Max span length is 3,543 feet (本桥主跨为1080m)
D: Max pier height is 630 feet (塔高 192m)
E: Span to sag ratio is:1/9 (主缆挠跨比为1/9)

MAANSHAN YANGTZE RIVER BRIDGE (6):

A: Crossing Yangtze River (本桥跨越长江)
B: Carrying dual direction six lanes (双向六车道)
C: Max span length is 3,543 feet (本桥主跨为1080m)
D: Max pier height is 440 feet (塔高 134m)
E: Span to sag ratio is:1/9 (主缆挠跨比为1/9)

MACAU SAIWAN BRIDGE (7)

The Macau Saiwan Bridge is a cable-stayed bridge with the main span arrangement of 110+180+110m. It carries 6 lanes + 2 lanes for highway and 2 Tracks for LRT. The most special feature of the Saiwan Bridge is the fact that it adopts double deck design, a roadway on top and a roadway inside the PC box girder. The roadway inside the PC Box enables traffic to cross the strait under all weather conditions. It was opened to traffic in 2004. The project was awarded 2nd Prize of National Award for Achievements of Promoting Science and Technology.

A: Sea Crossing (跨海大桥)
B: Carrying 6 lanes + 2 lanes highway and 2 Tracks for LRT (双向六车道 + 两线轻轨 +2箱内车道)
C: Max span length is 590 feet (本桥主跨为180m)
D: Max pier height is 279 feet (塔高 85m)

WUHAN TIANXINGZHOU YANGTZE RIVER BRIDGE (8)

The Wuhan Tianxingzhou Yangtze River Bridge adopted the design of a “double-tower, tri-cable plane cable-stayed”. The bridge is 4657 meters in full length, with a main span 504 meters, with main towers 189 meters in height, and with other spans which distribute as follows: 98+196+504+196+98m. The upper deck is a dual six-lane highway, with designed speeds of 80 km/h, while the four-lane railway at lower deck is designed for 250 km/h HSR. It carries the Wuhan–Guangzhou High-Speed Railway across the river, and allows trains to cross the river at speeds up to 250 km/h. It won the George Richardson Medal, awarded by IBC in 2010.

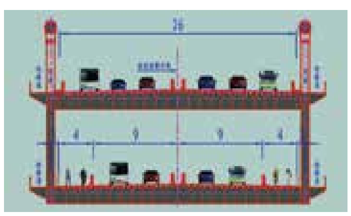
A: Crossing Yangtze River (本桥跨越长江)
B: Carrying dual-way six-lane highway+ four-track railway (双向六车道+四线铁路)
C: Max span length is 1,653.5 feet (本桥主跨为504m)

In recent years, many cable stayed bridges have been built in China both for high speed railway and highway. The following table lists the bridges with a main span larger than 500m, all of them are designed by BRDI.

Bridge name	Main span	Bridge type	Carries	Open to traffic
Tianxingzhu	504m (1,657')	Cable-stayed	4R+6H	2010
Tongling	630m (2,073')	Cable-stayed	4R+6H	2014
Huanggang	567m (1,864')	Cable-stayed	2R+4H	2014
Anqing	580m (1,903')	Cable-stayed	4R+6H	2015
2nd Wuhu Railway Bridge	588m (1,929')	Cable-stayed	4R+6H	--
Hutong	1092m (3,582')	Cable-stayed	4R+6H	--

YANGSIGANG YANGTZE RIVER BRIDGE (9)

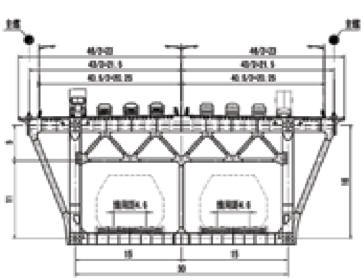
The Yangsigang Yangtze River Bridge is a double deck steel truss suspension bridge, with a main span of 1700 meters. The double deck can accommodate 12 lanes of highway at the same time. The bridge has 2 main cables, of diameter equal to Ø 109 cm, with a central spacing 28.0 m. Each cable consists of a number of ropes, each rope containing 91 parallel steel wires of Ø 6.22 mm, with a design tensile strength of 1960 MPa.



A: Crossing Yangtze River (本桥跨越长江)
B: Carrying 12 lanes of highway (双向12车道)
C: Max span length is 5,577 feet (本桥主跨为1700m)
D: Max pier height is 758 feet (塔高 231m)
E: Span to sag ratio is: 1/9.2 (主缆挠跨比为1/9.2)

WUFENGSHAN YANGTZE RIVER BRIDGE (10)

The Wufengshan Yangtze River Bridge is a suspension bridge with a steel truss stiffening girder and a main span of 1092 meters. The bridge will be the first rail-cum-road large span suspension bridge in China. The stiffening girder employs a double deck steel truss, the upper deck for 8 lanes highway and the lower deck for 4 tracks of high speed railway.



A: Crossing Yangtze River (本桥跨越长江)
B: Carrying 8 lanes highway+ 4 tracks of railway (双向八车道+四线铁路)
C: Max span length is 3,583 feet (本桥主跨为1092m)
D: Max pier height is 682 feet (塔高 208m)
E: Span to sag ratio is:1/10 (主缆挠跨比为1/10)

CLOSING REMARKS

During the infrastructure boom of the past two decades, bridge-building has proceeded at a rapid pace on a vast scale. Prior to the completion of the Wuhan Yangtze River Bridge in 1957, there were no bridges across the Yangtze River, China's longest. From Yibin to Shanghai, all overland roads and railways crossing this 2,884 km (1,792 mi.) reach of the river had to be ferried. There were only seven such bridges in 1992, but that number reached 113 by the end of 2017, including eight new openings in that year alone. These bridges have greatly promoted the development of China's economy and bridge technology.

All images are courtesy of China Railway Major Bridge Reconnaissance & Design Institute Co., (BRDI) Ltd., Hubei, China

Dr. Xu Gongyi is currently the Deputy Chief Engineer of BRDI. He has 35 years of experience in design, analysis and construction of bridges. He has been involved in the design and construction of over 70 major bridges worldwide, including 30 suspension bridges, 20 cable-stayed bridges, and other types of bridges. He has authored over 70 papers and 6 books in bridge engineering. Dr. Xu Gongyi holds a Ph.D. in Bridge and Tunnel Engineering from the Southwest Jiaotong University, Chengdu, China. He is the National Design Master, China, Fellow of the Institute of Civil Engineer, UK, and Charter Engineer in UK.

Dr. Xu Rundong is a Senior Engineer with BRDI. He has over 8 years experience in the design and construction of complex bridges. He has played major roles in the design and construction support of over 5 suspension and cable-stayed bridges. He led the construction engineering for the Erqi Yangtze River Bridge, the record holder as the longest main span (616m) cable-stayed bridge. Dr. Xu Rundong holds a Ph.D. in Bridge and Tunnel Engineering from the Southwest Jiaotong University, Chengdu, China.

Dr. Gongyi Xu was awarded the Roebling Medal at IBC 2018 in Washington, DC. This coveted award honors an individual for lifetime achievement in bridge engineering. For more information about Dr. Xu and his mark on Chinese bridge engineering, see the Awards Article - editors.

Composite Steel Cable-stayed Bridge Fabrication: CONSTRUCTABILITY CONSIDERATIONS

By Ronnie Medlock

Cable-stayed bridges are popular for long-span crossings, particularly over navigable waterways. Since 2000, High Steel has fabricated the steel superstructure for three cable-stay bridges (shown with opening date):

- Ravenel Bridge over Cooper River, Charleston SC, 2005
- Lewis and Clark Bridge over Ohio River, Louisville KY, 2016
- Kosciusko Bridge
  - ◊ Eastbound lane, over Newtown Creek, New York NY, 2017
  - ◊ Westbound lane – under fabrication

Many of the same fabrication principles that apply to traditional steel structures apply to composite steel cable-stayed bridges for achieving best fabrication constructability in the shop. However, there are a few key points to keep in mind that are particular to cable-stay bridges.

Workflow

Getting approved shop drawings into the shop is the key for fabrication to begin. Considering that cable-stayed bridges are often design/build projects, the best way to facilitate a good schedule is for the construction team to focus on design and completion of each of the following items in a sequential manner, rather than focusing too much on the entire project or moving on to the next item without fully completing the previous item:

- Geometry
- Tower information
- Pier table
- Floor beams
- Edge girders

If these steps are taken in the design process, then other parties can follow suit to accomplish detailing, fabrication, and erection; and drawings will be approved and issued to the shop in a much quicker and efficient manner.

It is particularly important to first establish the structure geometry, ensuring that all parties understand it and are in agreement with it, including a consideration and an understanding of the fit condition of the edge girders and cable anchorages, floor beams and ancillary structural components (for example, maintenance traveler rails). Most especially, camber must be established for detailing of the shop drawings to proceed. However, it is recognized that each of the key cable-stayed bridge elements, substructure, tower, and superstructure, is a function of and dependent upon the other, including the erection sequence. In bridge construction, erectors are often brought on board later in the project after construction and even fabrication are underway, but on a cable-stay bridge, all parties are best served if the erector is brought on early so that the erection sequence and camber can be established, and fabrication can proceed. Other trades can also impact detailing, especially the deck panel supplier because the layout of reinforcing and post tensioning for precast deck panels impacts shear stud placement on the edge girders and floor beams.

Use of a *working drawing* (sometimes called a *worksheet)* developed by the fabricator is a good way to get all parties on the same page. Through the *working drawing* the team can work through the basic structure geometry and make sure that all parties are interpreting the intent of the design correctly. Establishing the structure geometry will achieve the following:

1. **Confirmation that the computations used for determining the final elevations for edge girders at splices, bearings, and floor beam locations matches the design intent –** The geometry reflected in the *working drawing* will be a combination of the design drawings, which show a method for generating these elevations rather than numerical values, and clarifications that are established through RFIs. The *working drawing* will include stationing, offsets from the horizontal center line, profile grade and super-elevation used to generate deck elevations at relevant points, and also cross section definitions used to relate deck elevations to girder working chord elevations.
2. **Confirmation that the cross-sectional shape definition of the floor beams satisfies the design intent -** In particular, the *working drawing* will achieve acceptance of the proposed floor beam flange bend (or splice) locations that are not explicitly dimensioned on the design drawing. The *working drawing* will also reflect dimensions at the roadway crown and at the deck cross slope transitions.
3. **Confirmation that the top of deck overlay to top of steel dimensions are acceptable to all parties.**

Once the structure geometry is established and agreed upon with the design team, the *working drawing* can then serve as the basis for development of the balance of the design details, and all parties are able to refer back to it over the course of the project. Also, the exchange of data can help speed the process of establishing the geometry and also reduce the chance for errors.

Design Details

From a fabrication standpoint, cable-stayed bridge superstructures may be thought of as a sum of three parts: edge girders, floor beams, and cable anchor assemblies. Accomplishing the project is an effort of fabricating these elements individually and then combining them. One fundamental question is how to achieve integration of the anchor assemblies with the edge girder.

There are two basic approaches for integrating anchor assemblies with edge girders: either build them as two separate components and then attaching the anchor assembly to the girders, typically by bolting, or incorporate the anchorage into the girder itself as one element. Both approaches have been demonstrated to be effective. Separating the components and bolting them on provides greater flexibility in handling because the two smaller components are completed before they are brought together as one. Both anchor assemblies and edge girders are complex structural elements that will need to be rotated into welding position during fabrication. Smaller elements are lighter and less awkward to handle than larger elements, resulting in fabrication that is generally easier. However, it is important to ensure there is adequate access for bolt installation.


Cable anchor assembly in the shop


Cable anchor assembly attached to an edge girder in the shop


Edge girders and floor beams assembled in the yard

For bridges where the anchor assembly is incorporated into I-shaped edge girders, often called the "shark fin" approach, attaching the fin is a key consideration. Generally it is preferable to use a continuous girder web-to-anchor fin plate with optional shop splices for the web versus a fin that is welded to the web plate (see figure 1). The optional shop splice provides flexibility for ordering web plates; size availability varies, but generally 150" wide plates are available in typical web thicknesses. Also use a bolted attachment to accomplish the web-to-top flange connection because achieving the fit-up needed to weld these elements takes considerable effort.

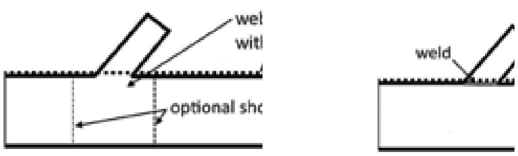


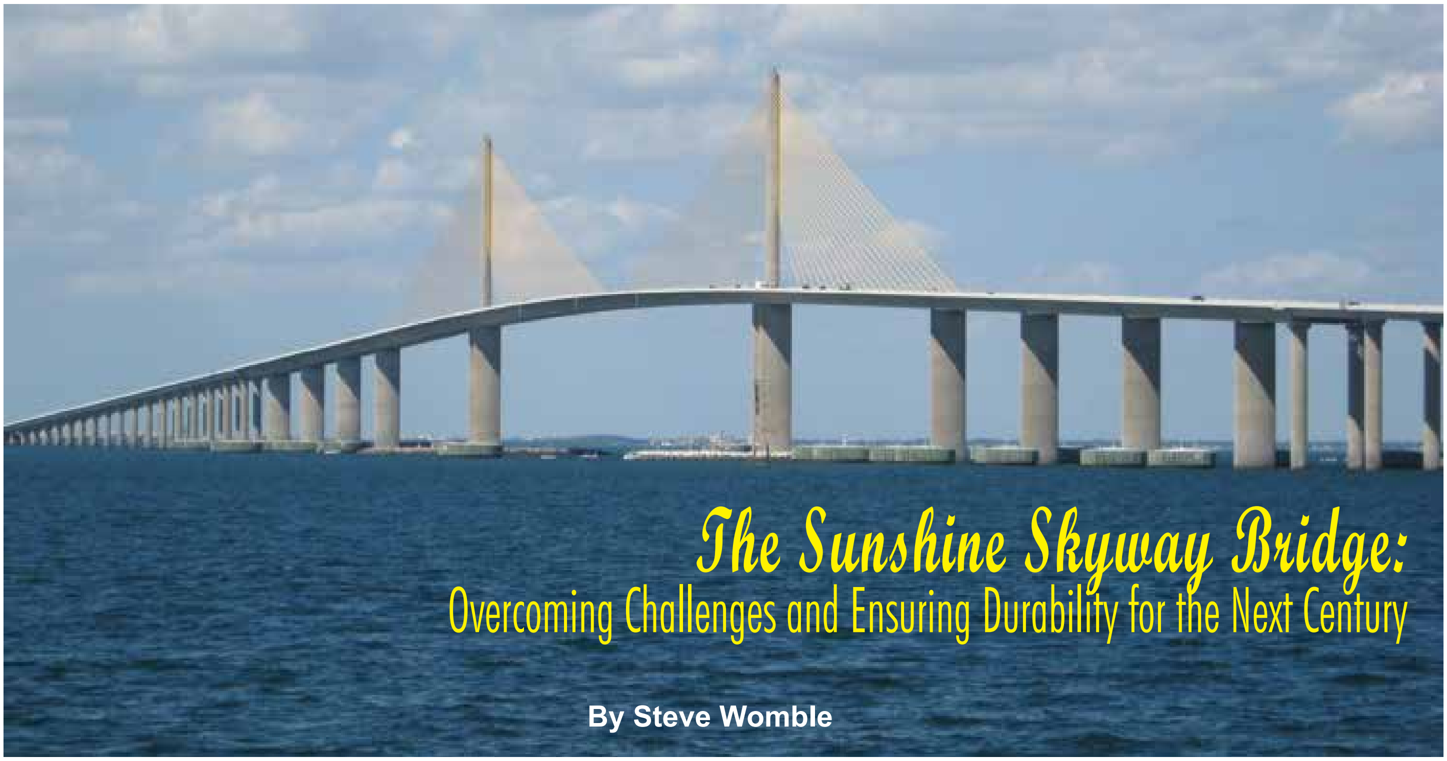
Figure 1 - Consider making the anchor fin continuous with the edge girder web (left) when incorporating the anchor assembly into the girder instead of attaching the fin with a weld (right)

In connections, it is important to avoid full penetration welds if possible. Full penetration welds are useful and can be accomplished, but compared to fillet welds they add effort for weld preparation, back-gouging, and non-destructive examination. Also, use of traditional shear studs and avoidance welded rebar should be considered for attachment to concrete elements. A traditional shear stud weld is much easier to accomplish than the circumferential fillet weld that is need to attach rebars.

Conclusion

Cable-stayed bridges are elegant structures that grace our nation's infrastructures with growing popularity. Comprised of three basic steel superstructure elements—edge girders, floor beams and cable anchorages--steel cable-stayed bridge superstructures can be readily accomplished and facilitate construction to address a variety of long span needs. Like other steel bridges, there are many ways to execute the design and accomplish the details; doing so with an understanding of a fabricator's workflow and shop floor practices can improve a project. While some high level thoughts are provided here, the prudent approach for an actual project is to engage contractors and fabricators to provide feedback as early as possible in project development.

Ronnie Medlock is Vice President, Technical Services, at High Steel Structures LLC in Lancaster, PA. Ronnie worked for TxDOT from 1988 until joining High Steel in 2006. As a member of the ESWP Executive Committee since 2006, Ronnie is the General Chair of the 2018 IBC Conference. Ronnie acknowledges contributions to this article from Brad Dillman, also of High Steel, and Gino Pezzente, CandraftVSI.



The Sunshine Skyway Bridge:
Overcoming Challenges and Ensuring Durability for the Next Century

By Steve Womble

The current **Skyway Bridge** is a replacement structure for the former twin steel thru-truss structures built in the mid-20th century. On May 9, 1980, tragedy struck the newer of the two, when the freighter **Summit Venture** collided with one of the main piers of the southbound bridge, taking out two of the three continuous truss spans, and sending 35 people to their deaths.

The Florida Department of Transportation (FDOT) was then faced with a significant decision; whether to replace the destroyed truss span, or update the entire bridge passage over the bay. Both steel trusses required regular major maintenance due to the highly corrosive environment, and the old bridges did not have shoulder lanes, among other "out of date" conditions. Therefore, much thought was given to the options, and the final decision was made to replace both bridges with a new, state-of-the-art structure that would meet all current safety standards, and be designed using the best concepts, methods and materials available. The concept chosen was a cable-stayed structure that would incorporate as much prestressed and post-tensioned concrete as possible, primarily due to the highly corrosive environment. The new bridge design also included many additional safety features, such as a much higher and longer main span over the ship channel, main piers with wide overhanging footer cap extensions for greater impact protection, a large elliptical "rock island" consisting of huge granite boulders surrounding each tower pier, and thirty-six ship-impact-resistant dolphins forming a "horse shoe" shaped protective shield around all of the main and high-level approach piers.

Since opening, a wide variety of problems have occurred requiring maintenance. One series of rehabilitation projects involved the full replacement of the vertical post-tensioning in all of the high-level approach columns. This was done in a series due to cost, and required by-passing the existing 7-wire strands encased in PE (polyethylene) ducts filled with grout. The grouting process failed, which resulted in the development of serious corrosion near the top of many of these elements, and the decision was made to replace them using current PE materials, very strict grout specs, and solid Dywidag bars. All of the modular expansion joints in the main and high level approach spans have been replaced using similar joint systems, and there have been major repairs on the bearings at the transition piers where the segmental sections change from a dual twin-bridge cross-section to the main span single segment cross-section. Other repairs include repainting the stay cables, strengthening selected AASHTO beams using carbon fiber reinforced polymer (CFRP) materials, and a wide variety of more routine repairs.

"Many cable stayed bridges have had problems with stay cable bouncing, or dancing, sometimes to extreme levels due to wind and rain"

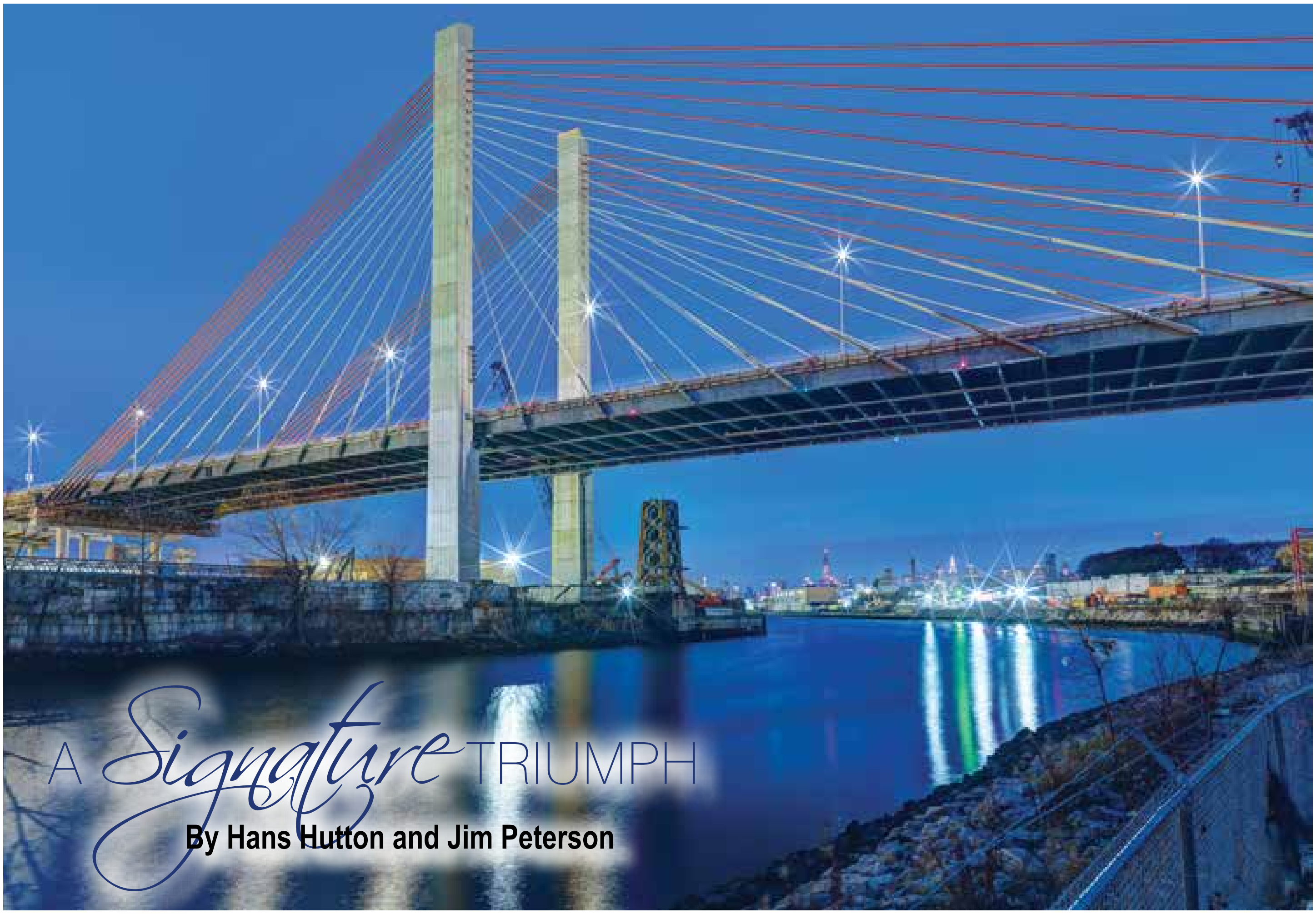
The new Skyway Bridge, designed by Figg & Muller, was one of the earlier cable stayed bridges in the United States. Muller had recently completed a similar bridge in France, called the Pont de Brotonne, since dubbed the sister bridge to the Skyway, and many improvements were incorporated into the Skyway design based on the Brotonne Bridge design and construction. The same stay cable design was used in both bridges, which consists of 7-wire strands surrounded by grout inside of steel pipes continuous thru the towers. This design soon fell out of use due to the steel pipes being an obstruction to internal inspection, and the multiple strands being in contact with each other in the curved section of the continuous cables as they pass through the towers, which raised concerns about the possibility of fretting stress in the stay cable strands. While there are no significant indications of a problem with the Skyway cables, the FDOT maintenance office has scheduled further assessment of the possibility of fretting stress occurring.

Many cable stayed bridges have had problems with stay cable bouncing, or dancing, sometimes to extreme levels due to wind and rain, and thanks to the design, the Skyway has not had this problem. The cable stay design included the installation of a stay damper system that has served well. During a dry wind condition reaching nearly 70 mph, one of the longer cables was observed to be bouncing a few inches in first mode, which is not considered significant. A highly respected engineering professor, Dr. Nick Jones, once described the Skyway, with regards to stay bouncing, as "a bridge that works." The damper system consists of two struts attached to the stay cables near the lower end that, while allowing movement of the cables, restrains the amount and frequency of movement with hydraulic shock absorbers which continue to work well, after over 30 years of service.

"A highly respected engineering professor...once described the Skyway, with regards to stay bouncing, as 'a bridge that works' "

The bridge remains in overall good condition based on the regular biennial inspections, and occasional special inspections of various components. The most recent biennial inspection was done in late 2016 which resulted in the following **National Bridge Inspection (NBI)** ratings for the deck, superstructure, and substructure. On a scale from "0" to "9" the ratings were **7, 7, and 7**, with a "Health Index" of 86.7. A significant contribution to the overall good health of the bridge goes back to the decision of the District Structures Maintenance Engineer, in overall charge of the bridge in 1999, to establish a "**Skyway Preservation Committee**" whose task it is to meet regularly and assess any significant issues about the bridge, and come up with recommendations for corrective action, when needed. That Committee consists of engineers from the local **District** Structures **Maintenance** Office, the **District** Structures **Design** Office, the **State Materials** Office, and the State **Structures Design Office**, and continues to meet approximately two times per year. They are well aware that the most challenging issue in the years ahead will be corrosion, and have taken proactive steps to address this threat by all means available. Based on the overall condition of the bridge at 30+ years, and input from the Skyway Committee, FDOT is optimistic that the bridge will achieve its anticipated 100 years of service life, and beyond.

Steve Womble, CBI, PE is the Skyway Bridge Resident Maintenance Engineer for Florida's District Seven Structures Maintenance Office. Steve started with FDOT (then the SRD – State Road Department) in January of 1963, retiring in 1994 with 31 years of service. He returned to FDOT in 1999 and will soon have another 19 years of service with the Department for a total of 55+ years of experience. He has served as Chairman of the "Skyway Preservation Committee" since its formation in 1999.



A Signature TRIUMPH

By Hans Hutton and Jim Peterson

The Kosciuszko Bridge, opened in April 2017, is the first cable-stayed bridge ever built in New York City
Photo courtesy of Andy Ryan, HNTB

New York City's original Kosciuszko Bridge, a through-truss structure built in 1939, was designed to carry 10,000 vehicles per day. It became part of the Interstate Highway System in the 1960s and, by the early 2000s, was carrying 160,000 vehicles daily on I-278 between Brooklyn and Queens on its six, shoulder-less lanes. In 2015, that figure increased to 180,000 vehicles. Perpetual congestion reigned on the bridge, which The New York Times called "perhaps the city's most notorious, hated and feared by drivers," and in the surrounding neighborhood.

An inspection of city bridges in 2008 identified numerous issues on the Kosciuszko Bridge and determined that the roadway's underlying support steel that was first installed in the 1960s, was structurally deficient.

In 2009, the New York State Department of Transportation (NYSDOT) decided to replace the deteriorating structure with twin spans built in two phases. Besides adding capacity, replacing the outdated bridge allowed the agency to address other deficiencies, including a steep roadway grade, narrow lane widths and a lack of shoulders.

A Signature Bridge

Though New York City is dotted with more than 2,000 bridges, it had been out of the bridge-building business for 50 years. As NYSDOT stepped back into that role, it focused on a delivering a signature bridge, selecting a cable-stayed design.

The project's $555 million first phase represents the largest single contract NYSDOT has ever awarded. Under that agreement, the Department selected Skanska-Kiewit-ECCO III Joint Venture (SKE) with HNTB as designer to deliver the Kosciuszko Bridge's Queens-bound span.

The new K-Bridge – as it is commonly called – has the distinction not only of being the city's first cable-stayed vehicular bridge, but also the first new span of any kind built in New York City since the Verrazano-Narrows Bridge opened in 1964. Built adjacent to the original bridge and opened in April 2017 with five standard-width lanes and two full-width shoulders, the massive new beauty will carry both eastbound and westbound traffic until the Brooklyn-bound span is built under phase 2. The project's first phase concluded with the demolition of the old K-Bridge in October 2017.

Addressing Design Challenges

Among the project's key challenges was the aggressive schedule, which mandated that the new construction and demolition be complete by the end of 2017 – just 43 months from notice to proceed – to accommodate the planned start of phase 2 construction in summer 2017.

Cable-stayed is among the most complex, computationally intensive bridges to design. To meet the exacting schedule and achieve high accuracy, there was a focus on simplification in both design and pre-design work.

Within just seven months, necessary analysis and design tasks had been performed, including:

- Wind engineering and wind tunnel testing, conducted in conjunction with RWDI Consulting Engineers and Scientists very early in the process to provide data to support construction of the bridge foundations.

- A nonlinear time-history analysis of the 1,001-foot-long, cable-stayed unit, which proved that any one of the structure's 56 cables could break suddenly without the bridge sustaining damage.
- A nonlinear time-history analysis which demonstrated that any damage to the bridge due to a 2,500-year seismic event would be limited to repairable.
- An evaluation of the bridge's aeroelastic stability and potential wind-induced vibrations. The span would not have met the industry-established vibration criteria if the wind turbulence levels at the site had been low. HNTB and RWDI determined that if the bridge experienced wind turbulence of 13 percent or higher, it would meet the vibration criteria. The team installed an ultrasonic anemometer to monitor turbulence, which demonstrated that turbulence at the site exceeded 13 percent.
- Identification of security measures that would be implemented to mitigate intentional damage to the K-Bridge.

Simplified Design

The design also was simplified. Through design evolution and analysis, and by taking the foundation elements 160 feet below ground, the team eliminated the struts between the bridge's two pylon legs. This approach not only helped achieve a clean, streamlined look for the complex structure, but also reduced NYSDOT's cost.

The bridge deck was designed to stand 90 feet above mean high water – 35 feet lower than the old span's deck – to eliminate steep approach roadways. The reduction of dozens of feet in height makes it easier for vehicles to maintain consistent speeds over a reasonable grade.

Because of the highly urban environment in which the new Queens-bound K-Bridge was being built, the design had to adhere to a small, prescribed footprint. Piers could be placed only in certain locations, and pylon heights were restricted because of nearby LaGuardia Airport.

The location's constraints also demanded an asymmetrical design. Unlike most cable-stayed bridges, which are somewhat balanced, the new structure is a single-tower bridge with two asymmetric spans. The back span is 377 feet and the main span is 624 feet, a configuration required to avoid the railroad right-of-way and environmentally sensitive areas below.

The shorter, lighter back span may be subjected to some uplift, and the tower height – at 303 feet, nearly as tall as the Statue of Liberty – made the cable angles flatter than desired. The design team added a 9,000-kip concrete counter weight to the back span to balance both spans of the bridge and used larger cables to accommodate the high force created by their flat angles. The team also analyzed each step of the bridge erection process to ensure the necessary balanced loading during construction of the bridge superstructure and cables.

The old Brooklyn approach viaduct and the new Brooklyn connector had the same alignment on the same elevation – an additional design challenge, because traffic still needed to access the bridge while the old viaduct was being replaced. A "replace-in-place" concept was designed, allowing the viaduct to be rebuilt one lane at a time, while traffic continued to flow on the other open lanes.

Taking Advantage of Current Trends

In addition to its security provisions, the new Queens-bound K-Bridge represents numerous other design trends, including:

- Making use of very compact steel anchor boxes inside the pylons.
- Use of metalized exposed steel surfaces, which are becoming the preferred corrosion protection in marine/coastal environments.
- Protecting the bridge deck with a polyester polymer overlay, which is less sensitive than other materials are to the environment.

When phase 1 of the K Bridge was completed – on budget and ahead of schedule – very few changes had been made to the base design, reflecting the project's efficient design and the extensive, effective collaboration between NYSDOT, SKE, HNTB, subcontractors and other stakeholders.

About the authors...

Hans Hutton, PE, SE, is a vice president and chief engineer for HNTB's bridge practice. He served as the engineer of record and technical lead on the replacement of the Kosciuszko Bridge.

Jim Peterson, PE, is a vice president and director in HNTB's Design-Build division. He served as project director for the Kosciuszko Bridge replacement.

IBC 2018 Awards Program

By M. Myint Lwin

Roebling Award Recipient

"An engineer, dedicated to innovative and quality bridge design and construction...his successful philosophy is: 'Build bridges for long-life performance through safety, durability, economy, functionality and sustainability' "

Award of Distinction Recipient

"A unique multi-purpose moveable bridge…with a creative configuration of double decked approaches…with a modern flair for style…and, with subtle aesthetic features"

Gustav Lindenthal Medal Co-Recipients

"A pair of creative and beautiful cable stayed bridges…spanning incredible chasms….what a complement to the natural environment"

Arthur C. Hayden Medal Recipient

"A pellucid solution connecting culture and nature…vision and innovation with transparency…to cross it is a thrill…to gaze down to the valley below through its see-through deck is both daring and exhilarating"

George S. Richardson Medal Recipient:

"An icon for Wuhu spanning the Yangtze River…an engineering marvel…radiating grace, creativity, sensitivity & bravery…it will be an inspiration for aspiring engineers"

Eugene C. Figg Medal Recipient

"A collaborative effort to construct an Iconic Gateway to Vermont that connects Vermont's history and nature with a majestic structure…there is harmony with the environment…reflecting an intimate relationship with the bridge and the local communities"

Abba G. Lichtenstein Medal Recipient

"Diligent engineering…to replace a suspension bridge superstructure without disrupting traffic is an extraordinary feat"

These are some of the many comments of the International Bridge Conference Award's Committee who 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, Bridge design and engineering Magazine, Roads and Bridges Magazine, Covestro and TranSystems, annually awards six medals plus other special awards 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 metal categories alone, many of which were projects nominated beyond the borders of the United States. After lengthy deliberations, the following individuals and projects were chosen for this year's awards.

John A. Roebling Medal

The John A. Roebling Medal honors an individual for lifetime achievement in bridge engineering. The International Bridge Conference is pleased to recognize Dr. Gongyi Xu as the 2018 recipient. Dr. Xu is Deputy Chief Engineer, China Railway Major Bridge Reconnaissance & Design Institute (BRDI). Dr. Xu is recognized as the National Design Master – one of the highest honors in China and had been involved in the design and construction of over 70 major bridges worldwide, including 30 suspension bridges and 20 cable-stayed bridges. He has designed many world-record suspension and cable-stayed bridges, two of which, the Yangsigang and the Wufengshan Yangtze River Bridges, are currently under construction. The former will have the longest main span of 5,600 feet in China and second longest in the world. The latter, with a main span of 3,580 feet, will be the first suspension bridge with double decks constructed for dual-use by highway vehicles and high-speed trains. Dr. Xu was the lead designer of the Shantou Bay Suspension Bridge – the first modern suspension bridge in China with precast box girders and a main span of 1,480 feet, holding the world's record for longest main span of this type of bridge. Dr. Xu was one of the lead chief design engineers for the Taizhou Yangtze River Bridge – the first suspension bridge with three pylons in the world. He is author/co-author of more than 80 papers, reports, book chapters and books in bridge engineering. The three books widely used in China are: "Suspension Bridge Design", "The Essential Data Manual of Bridge Design", and "Suspension Bridge with Plate Stiffening Girders". Dr. Xu is the Research Group Leader of an ongoing research project on large spans over 3,200 feet for railway bridges, and is the developer of an award-winning bridge design software. Dr. Xu has received 20 domestic and international awards/recognitions for his contributions and achievements in engineering. Three of his most recent awards are: the National Best Engineering Quality Award China in 2016, the Outstanding Achievement Award, ICE-SH, in 2015 and the Chinese National Outstanding Engineer Award in 2014.

Dr. Gongyi Xu

George S. Richardson Medal

The George S. Richardson Medal, recognizing a single, recent outstanding achievement in bridge engineering, is presented to the Anhui Transportation Holding Group Co. Ltd., the owner of the Second Wuhu Yangtze River Bridge. With an overall length exceeding one mile, with a main span of 2,644 feet and with towers 861 tall, this magnificent bridge is an icon for the City of Wuhu and an engineering marvel. As an improvement to the regional highway network, as an enhancement of public welfare, and as a promotion of social sustainability, the bridge is of note-worthy significance. For the very first time, a U-shape anchoring system was adopted for the cable stays, solving the problems of safety and durability caused by premature cracking in the cable-anchoring zone. Extensive research was conducted to verify the constructability and suitability of innovative technologies. The research included full scale testing of anchorage components, demonstration of the clamping performance of the saddles, fatigue and fretting cable performance testing and verification of the accuracy of the BIM-based automatic positioning method. The bridge is an outstanding accomplishment, combining modern bridge engineering with creative technical innovations, advanced technology in engineering and computer science, community involvement and sustainability approach to enhance the mobility of the traveling public, and economic growth of the region, while preserving the beauty and harmony of the environment.

The Second Wuhu Yangtze River Bridge

Gustav Lindenthal Medal

The Gustav Lindentahl Medal, recognizing an outstanding structure that is also aesthetically and environmental pleasing, is presented, as co-winners, to the both the Guizhou Highway Engineering Group Co., Ltd and the Road & Bridge International Co. Ltd., the respective owners of the Beipanjiang First Bridge and the Yachi River Mega Bridge. These twin bridges, spanning deep gorges in the Guizhou Province of southwestern China, are engineering marvels. The difficult site conditions led to a solution of a single long main span supported by a steel truss and cables with relatively short back spans supported by alternately steel trusses and prestressed concrete box girders. The bridges are located in a remote mountainous area with difficult site access, difficult terrain and karstic landforms. In view of the topographical challenges, the construction of the main span of each of these bridges, ingenious erection methods were employed. Weather also played a crucial role with periods of sustained 40 mph wind and with adverse weather (including fog, rain and high winds) for nearly 60% of the time of construction. As completed, the creative and beautiful twin steel truss-concrete girder, hybrid cable-stayed bridges, which cross over deep and wide canyons, provides not only an efficient transportation means, but dual signature complements to the natural environment.

Beipanjiang First Bridge

Yachi River Mega Bridge

Eugene C. Figg, Jr. Medal

Brattleboro Bridge

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 Vermont Agency of Transportation, the owner of the - *A Bridge to Nature*. The 1,036-foot-long bridge carries I-91 over the West River and West River Trail in southern Vermont. It is the largest bridge in Vermont history and the state's first concrete segmental bridge. The structure features landmark context-sensitive aesthetics with a 515-foot main span. The overall project provides an elegant solution to a complex set of needs and a visual gateway to the region. The design-build team engaged the owner and the public in project development, selecting a design theme of *A Bridge to Nature*. Its long-span, quad-wall-pier, segmental design allowed work to be performed without temporary falsework, maximizing mobility on the road, river and trail as well as protecting the environment by avoiding work in the river. A local Visual Quality Aesthetic Advisory Team worked with the Design-Build team. They guided development of the postcard worthy bridge features, including viewing platforms for pedestrians, hikers and visitors at the base of each pier overlooking the West River and mountainous valley. Every detail of the uniquely shaped bridge complements the natural Vermont landscape.

Arthur C. Hayden Medal

Zhangjiajie Grand Canyon Glass Bridge

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 Zhangjiajie East-line Tour Development Company, the owner of the Zhangjiajie Grand Canyon Glass Bridge. With a main span of 1,411 feet, this graceful pedestrian suspension bridge, with its translucent deck, spans the 950 foot deep gorge in China's First National Forest Park in Central China. Zhangjiajie Park, with its unique beauty, is said to have inspired the scenery for the alien world in the sci-fi movie Avatar. The bridge's skeleton is a steel frame supporting more than 120 glass panels. The frame is supported from cables with outwardly inclined suspenders. Each of the deck panels is triple layered and includes a 2-inch-thick slab of tempered glass. For recreation, there are three swings attached to the underside of the bridge plus a provision for making an 886-foot bungee-jump, considered to be highest such jump in the world. The structure provides access and vantage points to the parks graceful waters & marvelous mountains and has attracted visitors from all over the world. The bridge connects the east and west canyons giving the impression that one is floating on air. The span provides a unique vantage point, incorporating the surrounding landscape into an extraordinary experience.

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 Halifax Harbour Bridges, the owner of the Angus L. Macdonald Bridge. The 2,500 foot long suspended spans were replaced in a segment-by-segment approach, without interruption to traffic. The Angus L. Macdonald Suspension Bridge, completed in 1955, is a historically-significant bridge that plays a critical role in connecting Dartmouth and Halifax, Nova Scotia, Canada. The Macdonald Bridge was named after former Nova Scotia Premier Mr. Angus Lewis Macdonald, who oversaw the creation of an effective Canadian Navy and Allied Convoy Service during World War II. Renovating such a large bridge in this way is rarely undertaken, which made the erection sequence engineering an essential part for project success. A 57-step procedure was developed for the replacement of each 30-foot segment. During each of these stages and steps of erection, due consideration was given for all internal states of stress for each unique removal and replacement segment. Only weekend closures were permitted.

Angus L. Macdonald Bridge

Award of Distinction

The Award of Distinction, recognizing a recent outstanding achievement in bridge engineering for special use, lift structures, is jointly presented to the New Hampshire Department of Transportation and the Maine Department of Transportation, co-owners of the Sarah Mildred Long Bridge - Three Bridge in One - Lift Bridge. The bridge accommodates three modes of transport, including highway traffic from the upper deck, rail traffic from the lower deck, and major shipping when the bridge is in its lifted position. The structure connects Kittery, Maine and Portsmouth, New Hampshire, carrying the US Route 1 Bypass on the upper deck and heavy rail on the lower deck, with a 300-foot vertical lift span. The towers are constructed using hollow precast concrete enclosures that encapsulate and enhance the protection for lift bridge counterweights and ropes. The enclosed tower concept was developed through a Community selection process. The operator's rooms plus electrical and mechanical rooms were located at the base of the towers to provide ease of routine and long-term maintenance operations with enhanced visibility of the tenders during lift operations. Artistic features include uniquely shaped lift span towers and exposed working sheaves at the top along with a sleek box girder lift span that developed through interactions with the community.

The IBC Awards Committee includes Lisle Williams, Bill Wilson, Helena Russel, Myint Lwin, Gary Runco, John Dietrick, Ken Wright, Jay Rohleder, Matthew Bunner, Tom Vena, Rachael Stiffler, Shane Baebes, Pat Kane, Brian Kozy, Stephen Shanley, Ray Hartle, Al Ahmed and Tom Leech.

M. Myint Lwin is a long time IBC Executive Committee Member, former IBC General Chair, long time member of the Awards Committee, the 2013 IBC John A. Roebling Medal recipient, author and a valuable contributor to the IBC Magazine. He is currently an independent Consultant. - Editor

2018 Photo Contest Winners - continued from front cover

6th: Indian River Inlet Bridge, by Jason Hastings

7th: General Carrera Bridge, by Chris Kolasa

8th: Arthur Ravenal Bridge, by John Martell

9th: The Second Wuhu Yangtze River Bridge, by Xiuqin Duan

10th: Jökulsárlón Lake Bridge, by Todd Thompson

11th: Verrazano-Narrows Bridge, by Chris Kolasa

12th: Pearl Harbor Memorial Bridge (Q Bridge), by Damian Silverstrim

13th: Sundial Bridge, by Santiago Rodriguez

Congratulations to all of our Photo Contest Winners! Each of these award winning photos are featured in our special commemorative 2018-19 calendar, presented to all attendees of the 35th Annual International Bridge Conference®!