e-mosty

Issue 02 / June 2018

American Bridges

Front Cover: Governor Mario M. Cuomo Bridge, New York.
Photo Credit: New York State Thruway Authority
Back Cover: Anthony Wayne Bridge. Photo Credit: AECOM

International, interactive magazine about bridges
"e-mosty" (e-bridges).

It is published on www.e-mosty.cz. Open Access.

Released quarterly:

20 March, 20 June, 20 September and 20 December

Peer-reviewed.

Number: 2/2018, June.

Year: IV.

Chief Editor: Magdaléna Sobotková

Contact: info@professional-english.cz

The Publisher: PROF-ENG, s. r. o.
Velká Hraštice 112, 262 03
Czech Republic

VAT Id. Number: CZ02577933

E-MOSTY ISSN 2336-8179

Dear Reader

This Issue is dedicated to American Bridges.

First, we bring you an overview and description of design and construction of The Governor Mario M. Cuomo Bridge in New York. The presentation is accompanied with drawings and a rich photo and video gallery.

It is followed by an interview with Ms Jamey Barbas, Project Director of this Bridge, and her CV which provides an overview of the relevant projects she has been involved in.

Barry Colford of US AECOM wrote for us an article on Risk Based Inspection of Bridges in the USA.

Showcasing Canadian Steel Bridges from Coast to Coast is the name of another article which was written by Hellen Christodoulou. She is CISC – ICCA (The Canadian Institute of Steel Construction) Regional Manager in Quebec and in her article she focuses on bridges that have been awarded The Design Award.

The last article of this issue describes Bridges to Prosperity´s history and development in Latin America and the Caribbean and their three projects there: San Vicente Bridge in Nicaragua, Duraznal Bridge in Bolivia and a bridge in Banacito in Panama.

I would very much like to thank Derya Thompson for all her support, assistance, cooperation and patience with me during preparation of this issue. I believe we will get back to you with more articles and information on American Bridges in the future.

We are very happy to announce that our magazine has a new partner – the company ARUP. I would very much like to thank Mr Naeem Hussain for his support.

We agreed with Mr Marco Rosignoli on barter based mutual promotion so you can find in this issue information on his bridge tech forum and web.

This year, similarly to last year, we again cooperate with the company SELEM DMCC from Dubai, UAE, and become a medial partner to their conference on Cost, Procurement and Risk in Engineering Sector which will be held on 24 – 25 October in Dubai.

Next Issue of e-mosty: Vessels and Equipment for Bridge Construction will be released on September 20th. As it is almost full we have decided to prepare another specialized issue in September 2019.

e-mosty December 2018 focuses on Asian, Australian and New Zealand Bridges and in March 2019 on Multi-Span and Long-Span Bridges. Please see also our Editorial Plan for more details.

I kindly invite you to contribute to the issues mentioned above. Please contact me on my company e-mail (info@professional-english.cz) or LinkedIn and we will arrange the details of your presentation.

Magdaléna Sobotková

Chief Editor

e-mosty

The magazine **e-mosty** ("e-bridges") is an international, interactive, peer-reviewed magazine about bridges.

It is published on **www.e-mosty.cz** and can be read free of charge (open access) with possibility to subscribe.

It is published quarterly: 20 March, 20 June, 20 September and 20 December.

The magazines stay **available on-line** on our website.

It is also possible to download them as **pdf**.

The magazine **brings original articles about bridges and bridge engineers** from around the world. Its electronic form enables publishing of high-quality photos, videos, drawings, links etc.

We aim to include **all important and technical information** and show the grace and beauty of the structures.

Editorial Plan

We are happy to provide **media support** for important bridge conferences, educational activities, charitable projects, books etc.

Our **Editorial Board** comprises bridge engineers and experts from the UK, US and Australia.

The readers are mainly bridge engineers, designers, constructors and managers of construction companies, university lecturers and students, or people who just love bridges.

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ISSN: E-MOSTY 2336-8179

ISSN: E-MOSTY 2336-8179

ACKNOWLEDGEMENT

The Governor Mario M. Cuomo Bridge, New York

Jamey Barbas, Project Director

Khurram Saeed, Director of Communications, New York State Thruway Authority

Thank you for all information, valuable comments and for your time and assistance with preparation of the whole presentation.

Barry Colford, Vice President, AECOM

Thank you for your article and for cooperation, for your time and for the photos.

Hellen Christodoulou, Quebec Regional Director, CISC- ICCA Canadian Institute of Steel Construction

Thank you for your article featuring Canadian steel bridges, thank you for your time and cooperation.

Derya Thompson, Senior Vice President, Thornton Tomasetti

Thank you very much for all your assistance, cooperation, valuable comments, for your time and patience with me.

Governor Mario M. Cuomo Bridge

Magdaléna Sobotková

Figure 1: Rendering of the bridge at night. Credit: New York State Thruway Authority

Commencement of works: 2013

Opening of the bridge to traffic:

Eastbound span: late 2018

Westbound span: 26 August 2017

Cable-Stayed span: 2,230 feet (680m)

Main span: 1,200 feet (366m)

Total length: 3.1 miles, or 16,368 feet (almost 5km)

Bridge width: Westbound 96 feet (29.3m), Eastbound 87 feet (26.5m)

Overhead clearance: 139 feet (42.4m)

Height of bridge towers: 419 feet (128m)

Client: New York State Thruway Authority

Contractors: Tappan Zee Constructors, LLC (TZC)

The Consortium comprises Fluor, American Bridge, Granite, and Traylor Bros. along with design firms HDR, Buckland & Taylor, URS, GZA, and Wilkinson Eyre Architects.

It is design-build project.

I. INTRODUCTION TO THE PROJECT

The 3.1-mile twin-span bridge across the Hudson River between Rockland and Westchester counties is one of the largest single design-build contracts for a transportation project in the United States.

Located less than 20 miles north of New York City, the cable-stayed span crosses one of the widest parts of the river and will be the largest bridge in New York State history.

The Governor Malcolm Wilson Tappan Zee Bridge opened to traffic in 1955 and, until its retirement on October 6, 2017, was a vital artery for residents, commuters, travelers and commercial traffic.

Bridge traffic grew to about 140,000 vehicles per day in 2016, far more than the Tappan Zee was designed to support. Heavy traffic, narrow lanes and the lack of emergency shoulders had the potential to create unsafe driving conditions. As a result, the bridge had twice the average accident rate per mile as the rest of the 570-mile Thruway system.

Hundreds of millions of dollars were spent to maintain the structure in recent years, and the cost of maintaining it for the foreseeable future rivalled the cost of the new bridge, with no improvements to current traffic conditions.

Plans for a new bridge to replace the Tappan Zee were first discussed in 1999, and over the following decade, $88 million taxpayer dollars were spent, 430 meetings were held, and 150 concepts were considered – yet still, the project did not move forward.

Under Governor Andrew M. Cuomo's leadership and with the support of President Barack Obama and the U.S. Department of Transportation, the project moved forward to construction. Since October 2011, new design-build legislation was enacted, a fast-tracked federal environmental review and concurrent procurement processes have been completed, a project labor agreement with construction unions was negotiated, and construction activities commenced – all with an unprecedented level of transparency and community involvement.

II. DESIGN

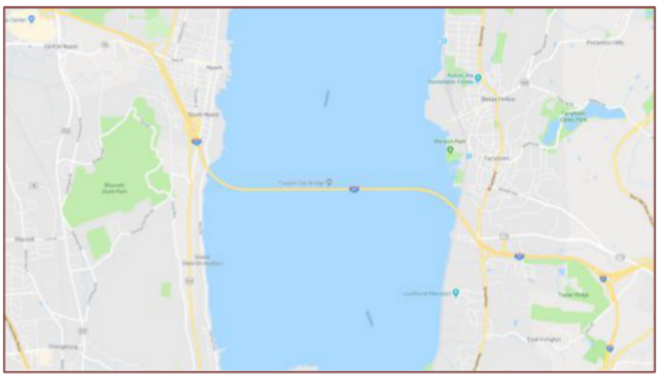
The Governor Mario M. Cuomo Bridge has eight general traffic lanes, breakdown/emergency lanes, and a state-of-the-art traffic monitoring system. The new crossing will be mass-transit ready, with space for Bus Rapid Transit as well as a design that can accommodate future heavy rail.

The cable-stayed main span is supported by eight 419-foot high chamfered towers. All towers stand at a 5-degree angle. The towers support the deck with 192 stay cables, which are made up of 4,900 miles of steel strands.

The westbound span will feature a 12-foot wide shared-use path for pedestrians and cyclists. Six overlooks—each with a unique theme, seating, and shade structure—will project out over the river.

The bridge's roadway will be illuminated at night with dark-sky compliant LED light fixtures to reduce light pollution. The state-of-the-art system will also accentuate the bridge's architectural features, including the iconic towers, stay cables, and piers, all while using an estimated 75 percent less energy than traditional lighting technology.

The bridge is designed so that major maintenance will not be necessary for at least 100 years.



Figures 2 + 3: Location of the bridge on the map
Source: maps google

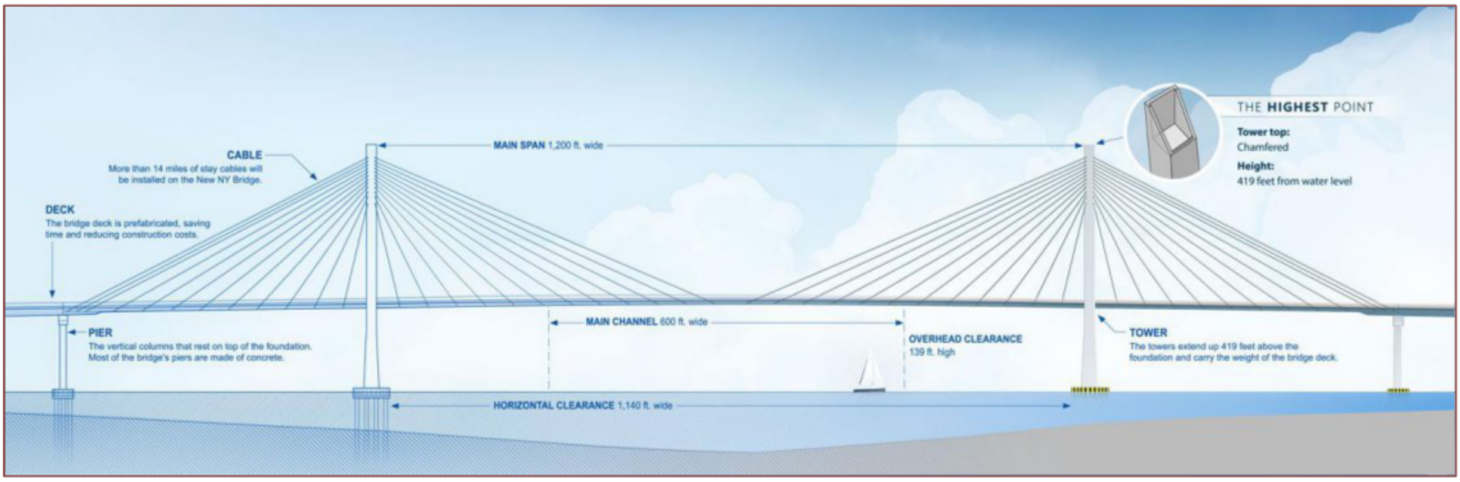


Figure 4: Elevation of the bridge

III. CONSTRUCTION

FOUNDATIONS

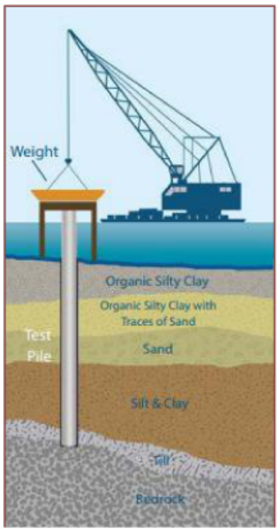
Designers developed the new bridge's foundation based on a series of geotechnical investigations and laboratory testing. Sonar technology was used to determine the layout of the riverbed and underlying layers of rock. These studies included more than 150 soil borings and probes, some up to 440 feet beneath the riverbed.

The investigations revealed the characteristics of varying layers of clay, silt, sand and glacial till covering the bedrock beneath the Hudson River.

With the development of an accurate river terrain map, foundation system featuring steel pipe piles up to six feet in diameter was determined. In order to verify the calculations, test piles were installed along the entire length of the new bridge.

The piles were tested to withstand up to 7 million pounds of weight. Every aspect of the process was monitored, verifying geotechnical conditions and load capacities.

Pile driving was carried out by powerful crane-borne hammers. A curtain of air bubbles was used to absorb the resulting sound waves, protecting aquatic life from the powerful underwater surge. Many piles rest on the hard bedrock found below the layers of clay and silt.



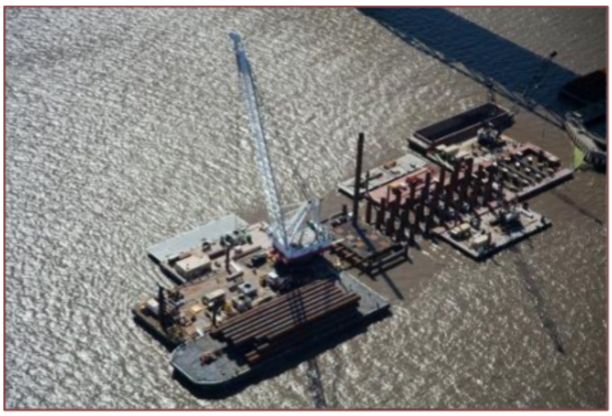


Figure 6: Aerial view of pile installation work

Figure 5: Installation of test piles

Other piles, in areas where bedrock is hundreds of feet farther down, are longer and supported by the friction between the piling walls and the soil.

Once in place, the piles were filled with steel-reinforced concrete.

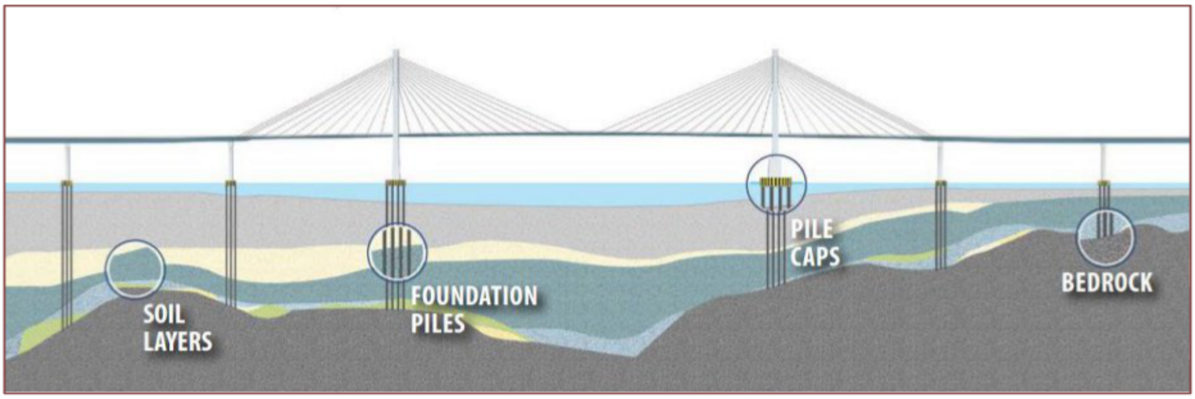


Figure 7: Bridge foundations

The Hudson River is more than 40 feet deep at the navigation channel, and subject to powerful currents. Pile caps distribute the weight of the bridge and act as platforms for the bridge piers and towers.

These foundation elements combine the strength of groups of piles into base-like structures. Pile caps have as many as 64 piles and are filled with steel-reinforced concrete, Figure 8 below:

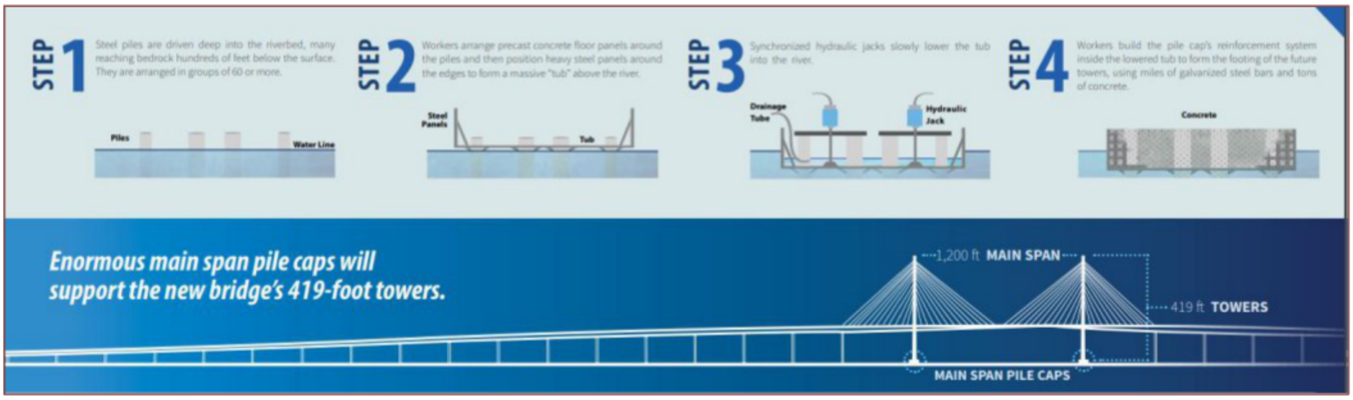
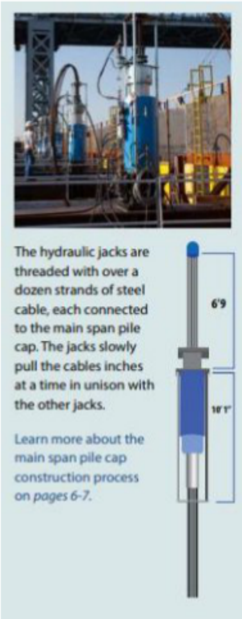


Figure 8: Main span pile caps construction process

Pile caps for the main span were lifted by *I Lift NY* floating crane and placed on steel foundation piles. They are 14 feet deep and filled with 12,000 cubic yards of concrete.

← Figure 9: One of the largest approach span pile caps on the project is carefully placed onto a group of foundation piles by the I Lift NY super crane

↑ Figure 10: One of the main span pile caps with its first layer of rebar installed



VSL engineers devised a system of 34 synchronized hydraulic jacks that could safely lower the tubs into the river.

Figure 11: Hydraulic jacks

Precast pile caps for the approach span weighing from 300 to 600 tons were produced at an off-site facility in Virginia and transported to the site. They were positioned over a group of piles with a barge-mounted crane. Holes in the bottom of the caps align with the piles.

Figure 12: Installing a pile cap tub for the project´s approach span

Concrete was then used to seal the caps to the exterior of the piles. Following rebar installation, 750 cubic yards of concrete was poured. Once the pile caps were completed, crew members began building pier columns.

Figure 13: Installing rebar in the pier and pile cap

SUPERSTRUCTURE

Various sections of a structure were fabricated and assembled in remote facilities, delivered to construction site and lifted and joined together. This modular construction process allows workers to perform more operations on the ground, rather than high above the river.

Figure 14: First steel girder assembly makes its way down the Hudson River

Formwork assembly for the concrete columns and rebar for piles and pile caps took place at Tomkins Cove in Rockland County. Precast concrete segments were formed in Schuylerville, N.Y., as well as at locations in Pennsylvania and Virginia and shipped to the construction site. Structural steel for the steel girders was preassembled at Port of Coeymans, 100 miles north - once fabricated, these two- to three-span girder sections were sent downriver.

Figure 15: Steel girders assembled at the Port of Coeymans in upstate New York and barged directly to the project site

The girders area fabricated with a protective zinc-rich primer, followed by up to three coats of high-quality paint, which shield the steel from the elements, including moisture and salt from the river´s brackish waters.

Figure 16: Steel girders

More than 100,000 tons of steel girders went into the project. With the distance between pier caps extending as far as 400 feet, individual girders were assembled into groups (typically of three) on land, floated down river via barge and lifted into place.

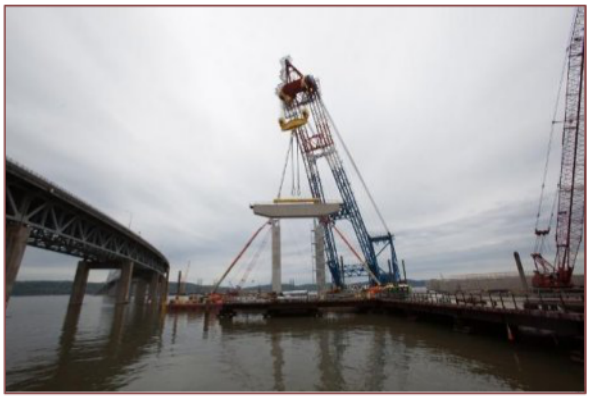


Figure 18: The I Lift NY super crane places the new bridge´s first pier cap with exact precision

The girder assemblies include infrastructure to carry communications, electrical power, water and compressed air to support bridge operations.

Larger girders and deck segments are lifted with the *I Lift NY* which is a floating crane with lifting capacity of up to 1,900 tons (the largest girder weighs 1,100 tons, largest approach pile cap 600 tons) and with 328-foot lift arm.

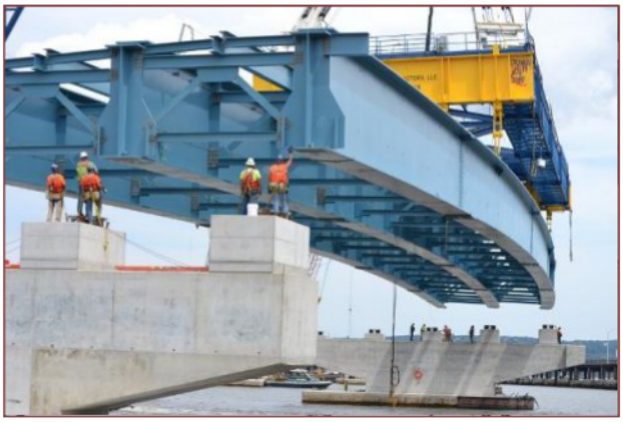


Figure 17: The project´s first steel girder assembly is slowly lowered to its final location atop a pair of concrete piers

Atop the girders deck panels were installed. They form a base for the driving surface.

Figure 20: Installation of concrete road deck panels

Building the bridge requires more than 300,000 cubic yards of concrete. TZC decided – in order to avoid using local roads – to utilize three floating concrete batch plants on the Hudson River, Figures 21 and 22.

Each floating batch plant is about 60 feet wide and 200 feet long and produces an average of 125 cubic yards of concrete per hour.

Crushed stone from a nearby quarry is delivered by barge. The materials are mixed in precise proportions by an on-board operator. The final concrete mixture is then pumped with a specialized hose to the various sections of the bridge.

← Figure 19: The I Lift NY super crane - moments before raising a pair of precast pile caps, each weighing 550 tons

Figure 21 and 22: Floating batch plant

THE MAIN SPAN TOWERS

The towers are constructed in successive segments with the assistance of mobile eight jump forms. They are used simultaneously – each tower requires 26 jumps in total, with each jump rising between 12 and 18 feet, see Figures 23 and 24.

The forms follow the slight outward angle of the towers as they continue upward. As they rise, the walls of the forms are narrowed to shape the decreasing perimeter of the towers.

Forming the horizontal bar of the H-shaped towers are crossbeams. They are securing the outward-angled towers and serve as the underpinning of the concrete road deck.

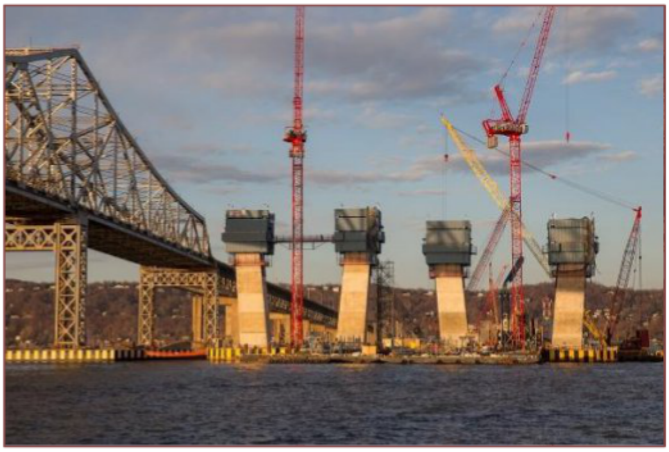


Figure23: Tower construction with the aid of the jump forms

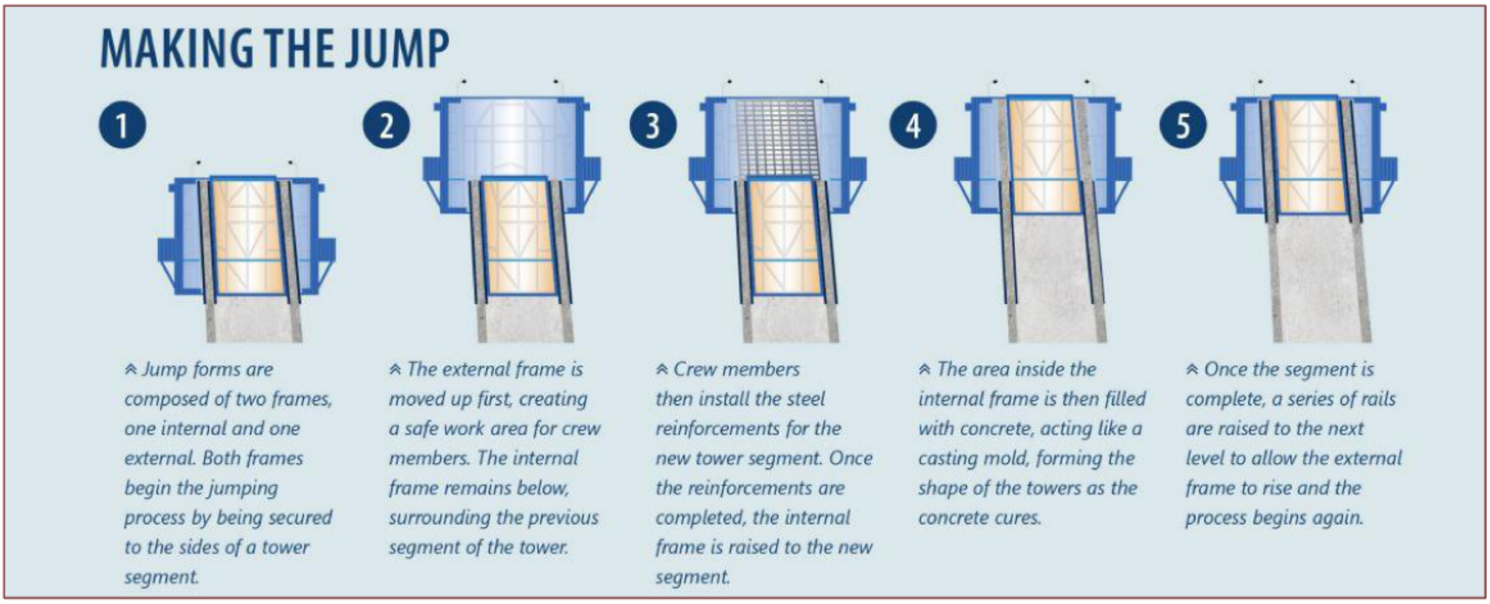


Figure 24: Jump Forms

↑ *Figure 25: The first tower crossbeam secured on the main span*

↗ *Figure 26: The I LIft NY installs a precast crossbeam between the main span tower legs*

At the highest levels, anchorages for the new bridge´s cables are installed. Formwork travellers are removed after the final segments of the towers are completed.

192 high-strand cables are individually anchored to the interior of the concrete towers and tensioned until they can support the weight of the main span roadway.

Each side of the main span requires 24 stay cables to support the deck. Cables length varies from 190 to 623 feet. Each of the stay cables are comprised of bundled metal strands that are tightly packed in a protective casing.

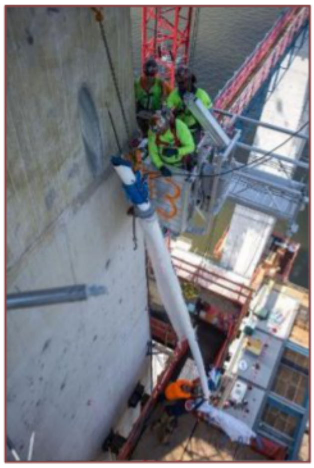


Figure 27: First stay cable is raised to its anchor point
Figure 28: Crews guide the first stay cable into an anchor point within a main span tower

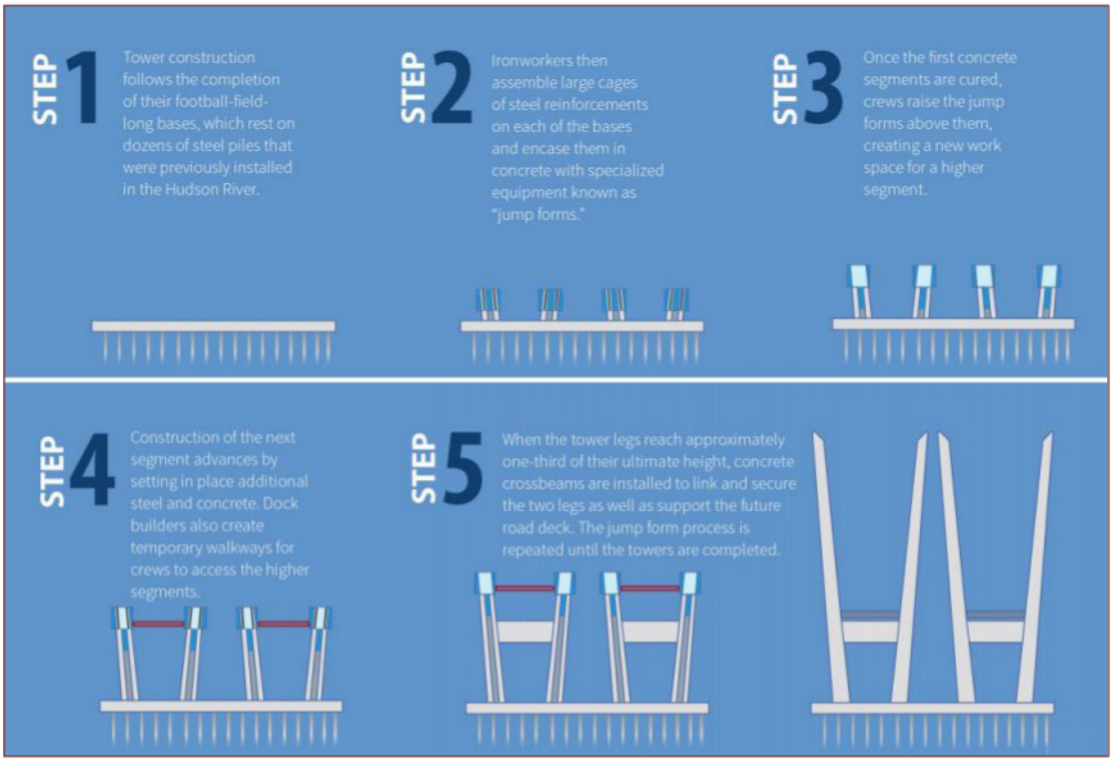


Figure 29: Erection of the Towers

IV. OPENING TO TRAFFIC

The westbound span was opened to traffic on 26 August 2017. Work on the eastbound span continues. In order to complete the second structure, the ends of the old bridge – which occupied the same alignment as the second span – have been removed so the second span can be connected to land. All traffic from the old bridge is now temporarily shifted onto the first new span, providing four lanes in each direction.

Figure 30: The old bridge´s main span prepared for dismantling

Many of the old bridge´s materials, including 135 deck units will be transferred to nearly a dozen state and local municipalities. Additionally, recycled materials from the Tappan Zee Bridge will be used to develop and expand five artificial reefs off the coast of Long Island, N.Y.

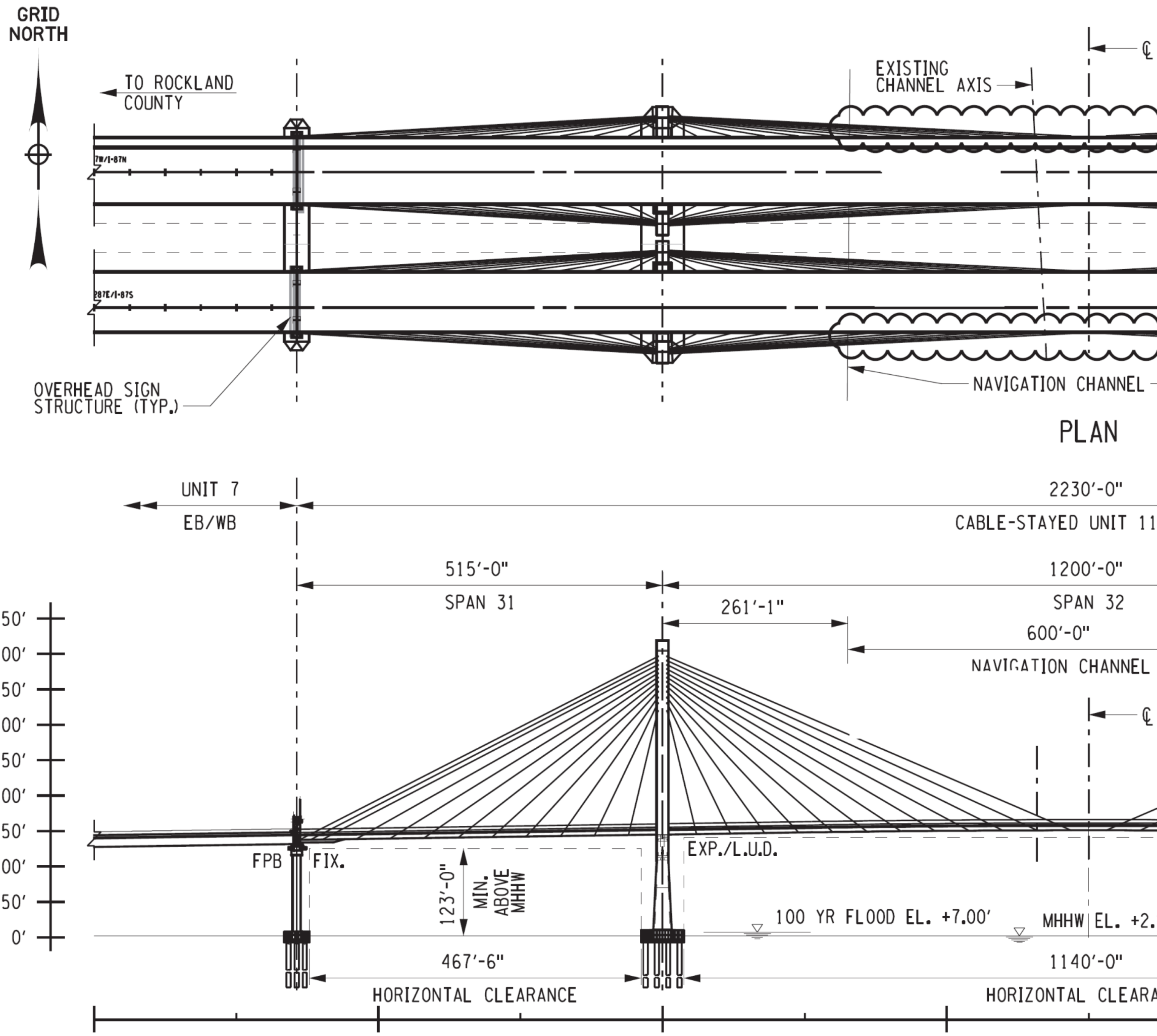
Intelligent Transportation Systems will improve safety and mobility on the crossing by monitoring roadway conditions and notifying Thruway Authority staff of any disruptions.
Motorists will also be informed of accidents and closed lanes through overhead electronic signage. These enhancements have been shown to minimize delays, allowing the public to get the most out of its investment.

The stream of data from the bridge's sensors will be tracked at the Thruway Authority's command center through an advanced Structural Health Monitoring System. The system will measure the twin-span crossing's structural behavior under traffic and weather conditions.

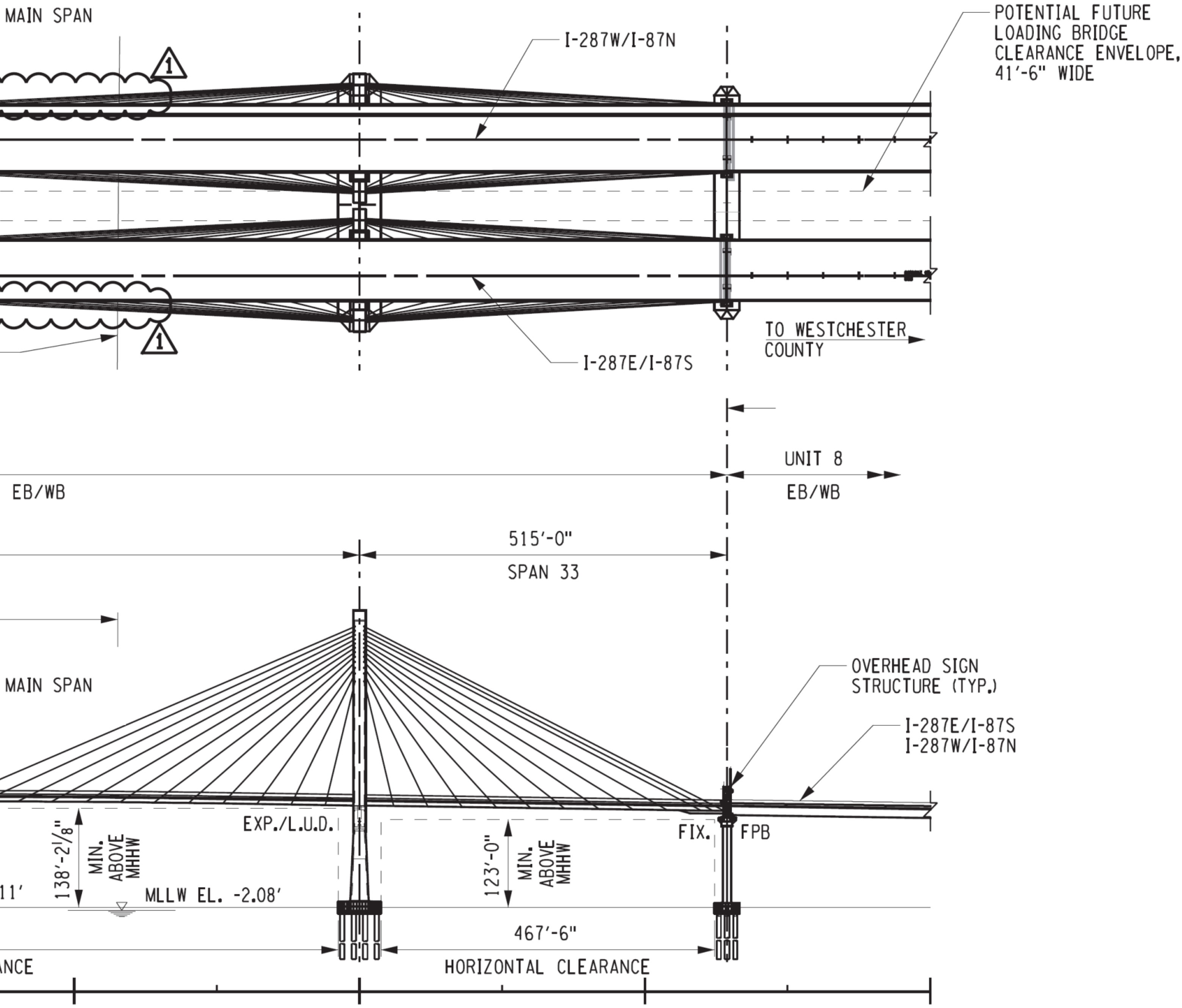
Routine and preventive maintenance work will also be efficiently scheduled with this state-of-the-art system. This vital communication network will make the bridge one of the most technologically advanced crossings in the United States when it fully opens to traffic in 2018.

The opening of the eastbound span will also allow the project to complete the new Shared-Use Path, which will be built on the westbound span.

Figure 31: Aesthetic lighting illuminatign the piers and towers



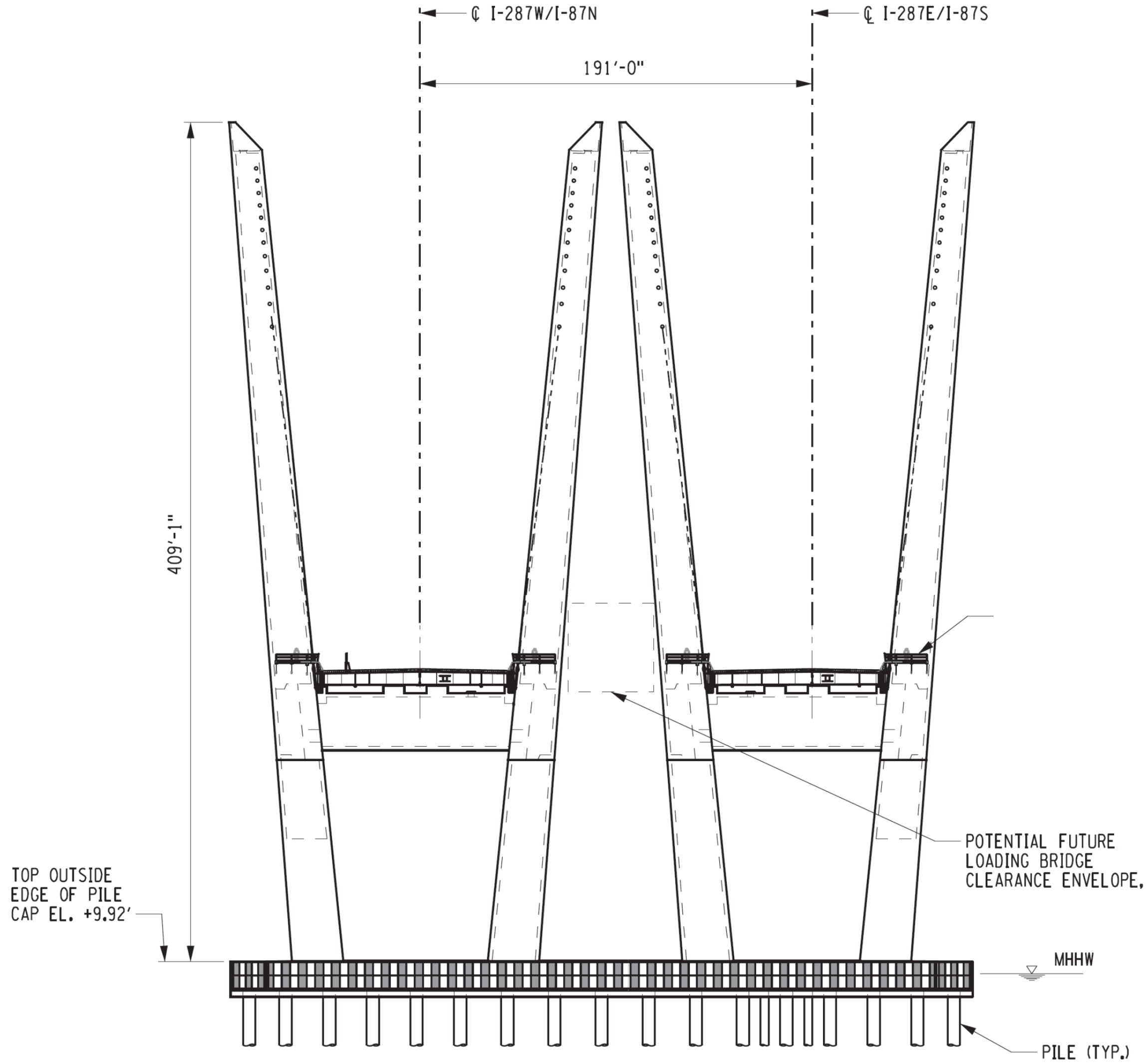
GRID NORTH
TO ROCKLAND COUNTY
EXISTING CHANNEL AXIS
OVERHEAD SIGN STRUCTURE (TYP.)
NAVIGATION CHANNEL
PLAN
UNIT 7
EB/WB
2230'-0"
CABLE-STAYED UNIT 11
515'-0"
SPAN 31
1200'-0"
SPAN 32
261'-1"
600'-0"
NAVIGATION CHANNEL
450'
400'
350'
300'
250'
200'
150'
100'
50'
0'
FPB
FIX.
EXP./L.U.D.
123'-0"
MIN. ABOVE MHHW
100 YR FLOOD EL. +7.00'
MHHW
467'-6"
HORIZONTAL CLEARANCE
1140'-0"

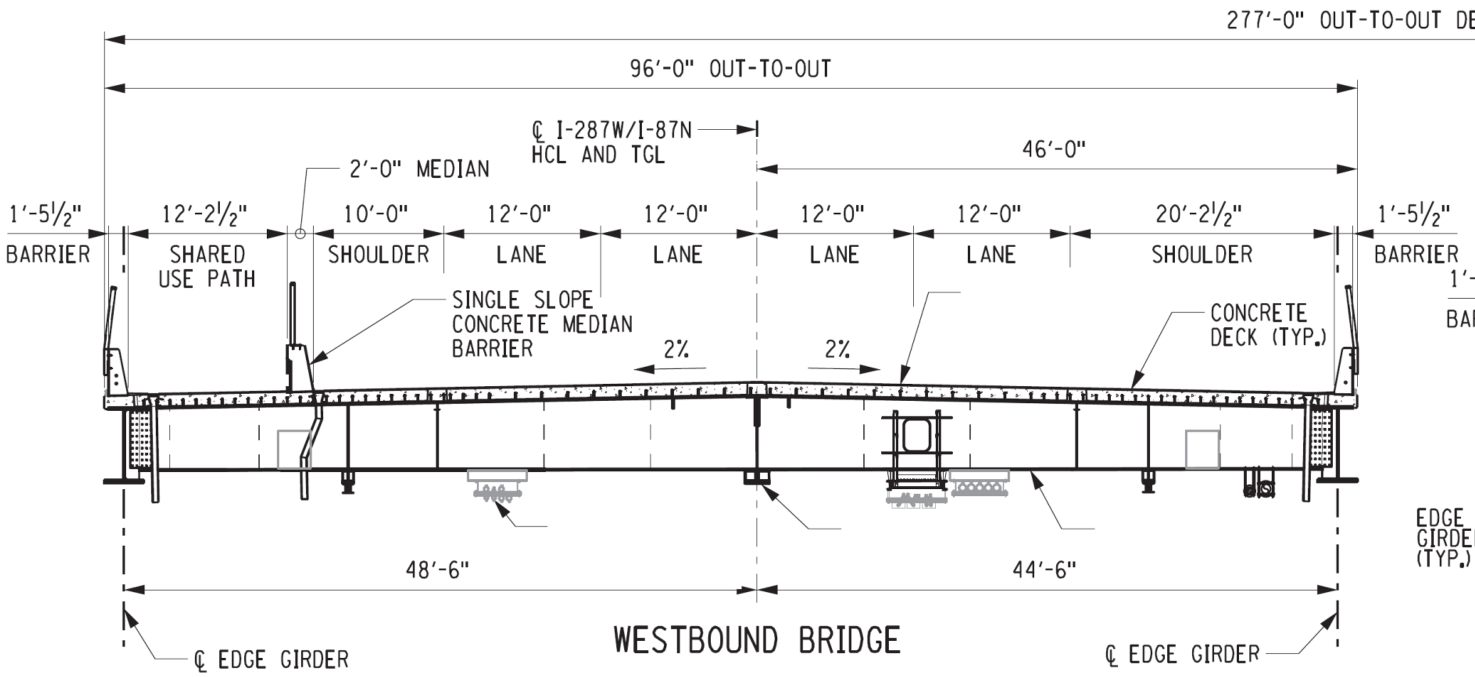


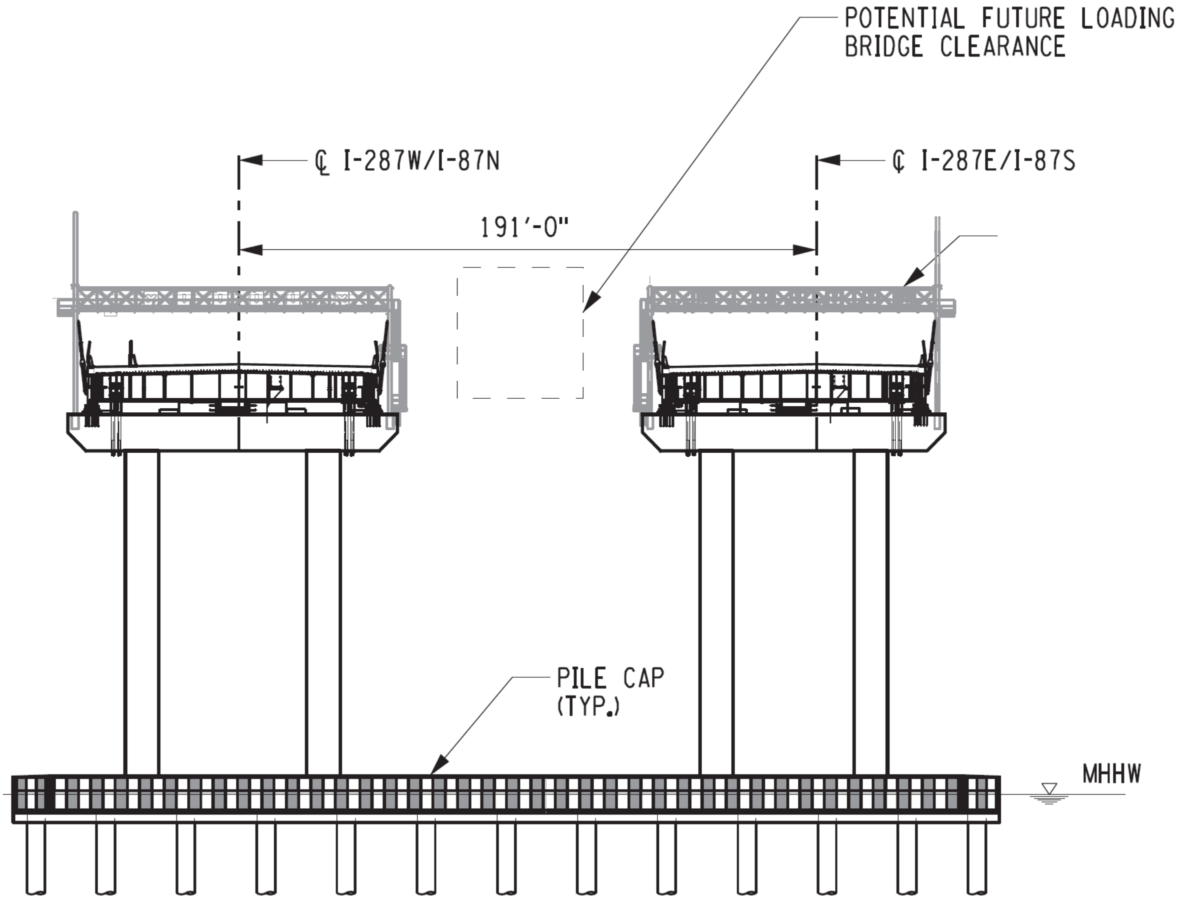
NEW YORK STATE THRUWAY AUTHORITY
DEPARTMENT OF ENGINEERING
200 SOUTHERN BLVD., ALBANY, N.Y. 12209

TAPPAN ZEE CONSTRUCTORS, LLC

TITLE OF PROJECT: THE NEW NY BRIDGE	CONTRACT NUMBER: D214134
LOCATION OF PROJECT: MILEPOST 14.67 +/− IN ROCKLAND AND WESTCHESTER COUNTIES	DATE: 04/25/2014
TITLE OF DRAWING: UNIT 11 – GENERAL GENERAL ARRANGEMENT	DRAWING NUMBER:


℄ I-287W/I-87N
℄ I-287E/I-87S
191'-0"
409'-1"
TOP OUTSIDE EDGE OF PILE CAP EL. +9.92'
POTENTIAL FUTURE LOADING BRIDGE CLEARANCE ENVELOPE.
MHHW
PILE (TYP.)


277'-0" OUT-TO-OUT DE
96'-0" OUT-TO-OUT
℄ I-287W/I-87N HCL AND TGL
46'-0"
2'-0" MEDIAN
1'-5½" BARRIER
12'-2½" SHARED USE PATH
10'-0" SHOULDER
12'-0" LANE
12'-0" LANE
12'-0" LANE
12'-0" LANE
20'-2½" SHOULDER
1'-5½" BARRIER
1'-
BA
SINGLE SLOPE CONCRETE MEDIAN BARRIER
CONCRETE DECK (TYP.)
2%
2%
EDGE GIRDE (TYP.)
48'-6"
44'-6"
℄ EDGE GIRDER
WESTBOUND BRIDGE
℄ EDGE GIRDER



POTENTIAL FUTURE LOADING BRIDGE CLEARANCE
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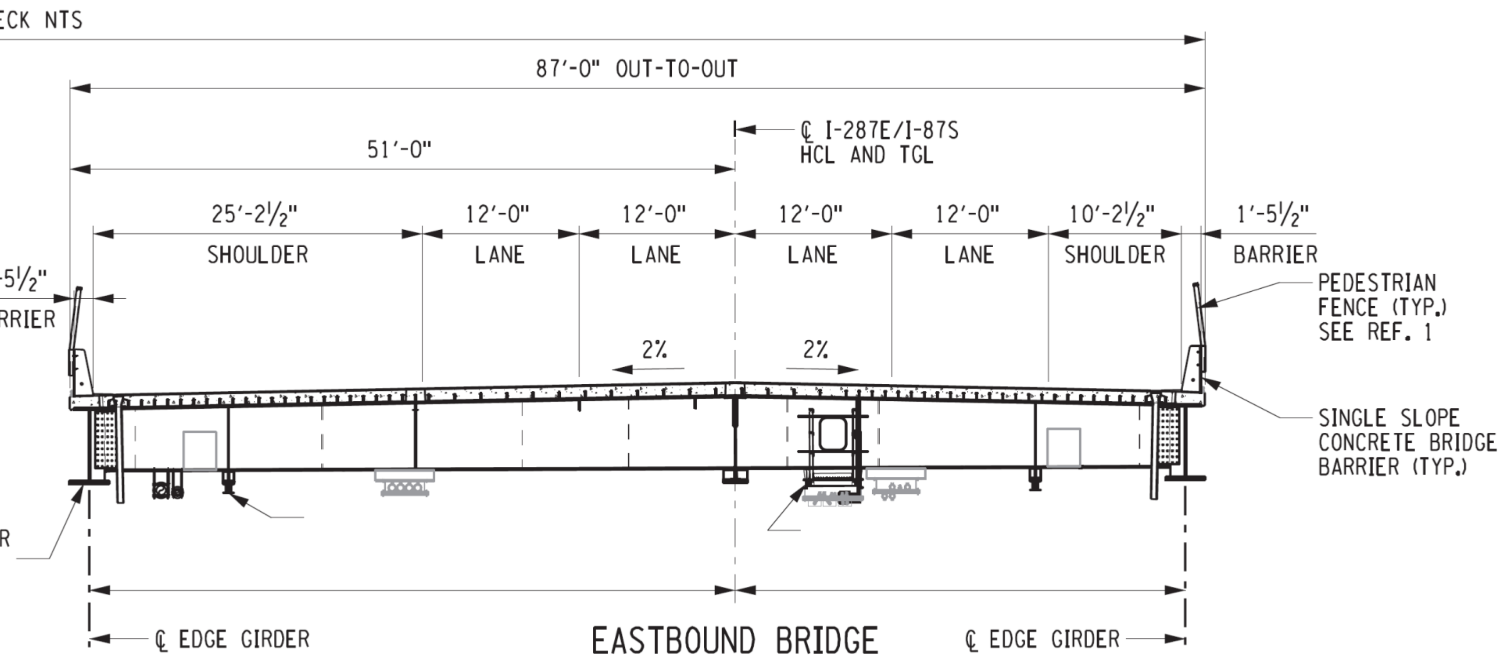
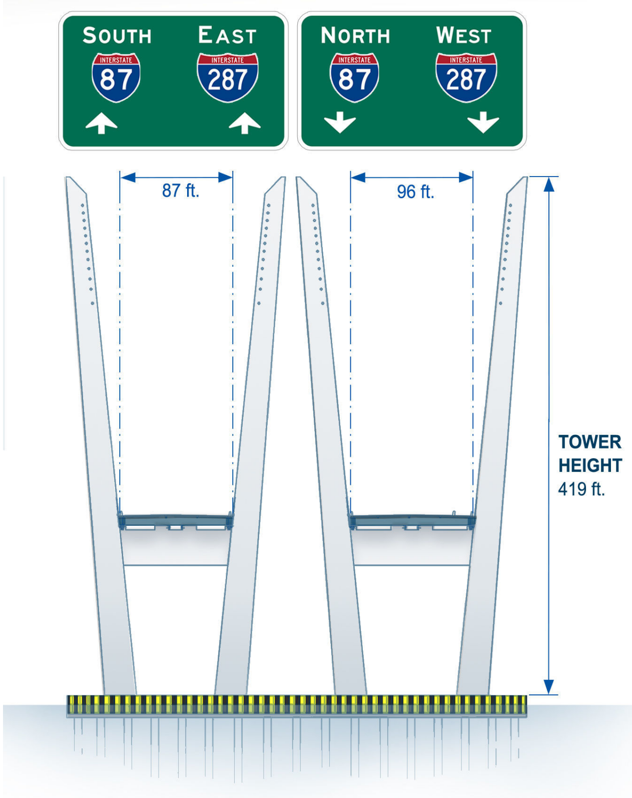
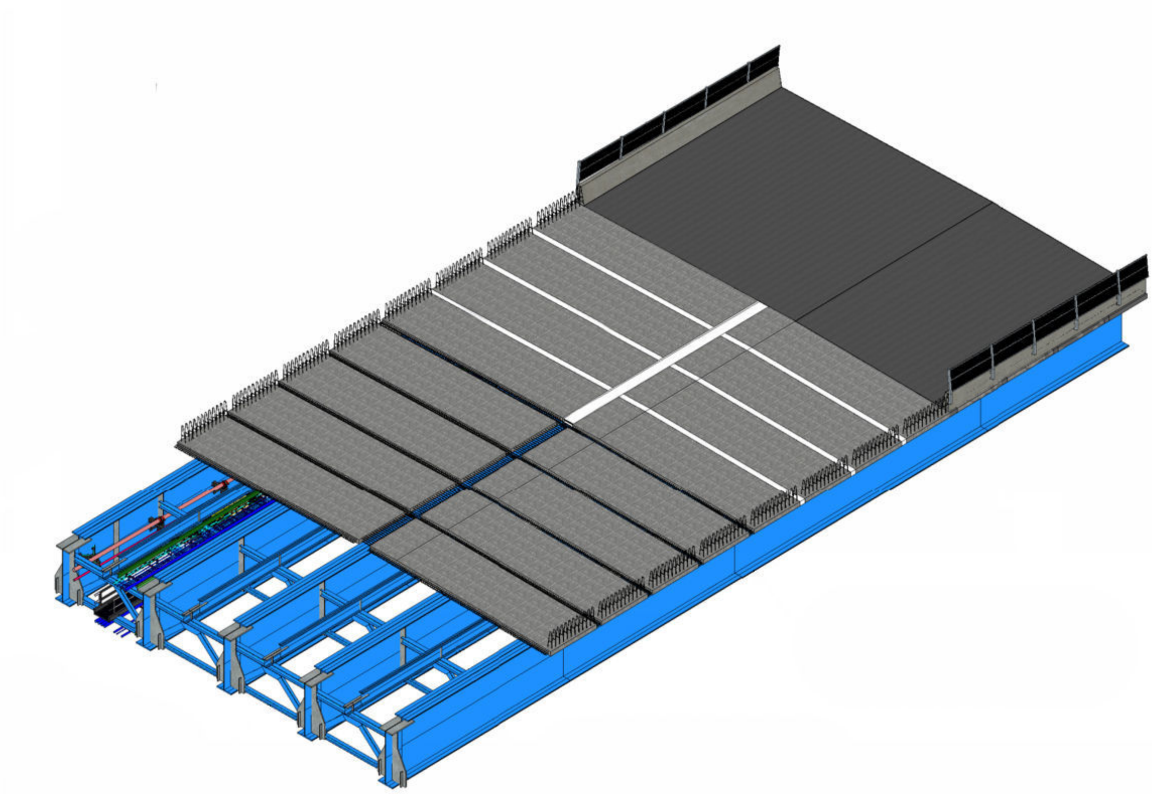
℄ I-287E/I-87S
191′-0"
PILE CAP (TYP.)
MHHW



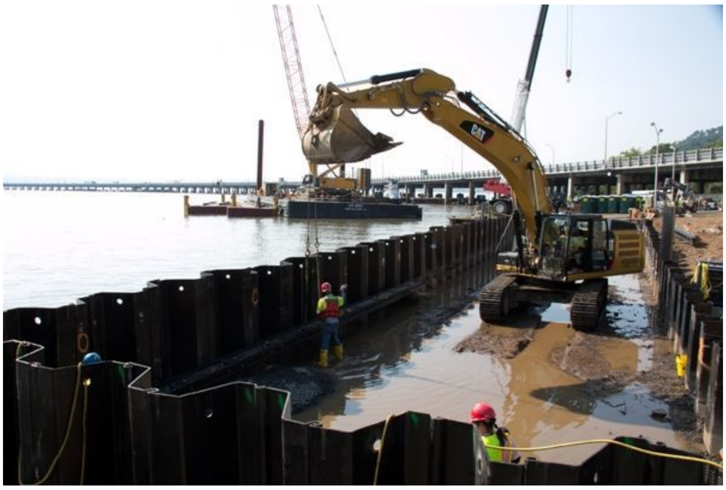
ECK NTS
87′-0" OUT-TO-OUT
51′-0"
℄ I-287E/I-87S HCL AND TGL
25′-2½" SHOULDER
12′-0" LANE
12′-0" LANE
12′-0" LANE
12′-0" LANE
10′-2½" SHOULDER
1′-5½" BARRIER
-5½"
RRIER
PEDESTRIAN FENCE (TYP.) SEE REF. 1
2%
2%
SINGLE SLOPE CONCRETE BRIDGE BARRIER (TYP.)
R
℄ EDGE GIRDER
EASTBOUND BRIDGE
℄ EDGE GIRDER



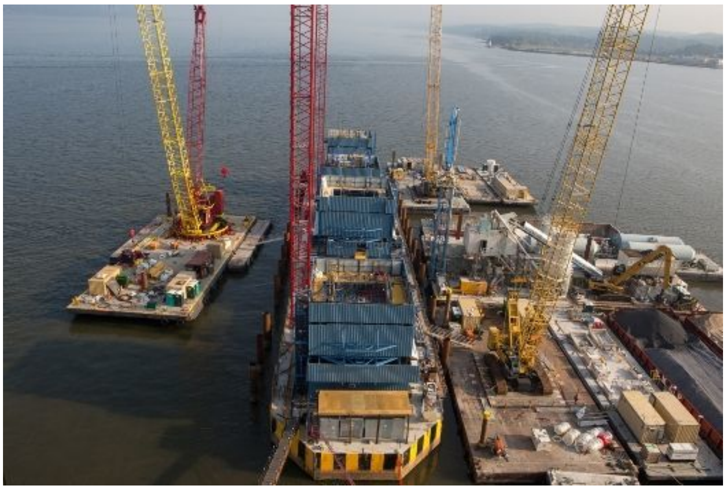


Road Deck: The bridge's 12-foot tall steel girder assemblies range in length from 350 to 410 feet and weigh up to 1,100 tons. The girders support road deck panels, which form the base driving surface. The 12-foot-long panels each weigh up to 74,000 pounds and are composed of concrete and galvanized steel. TZC has installed more than 5,500 deck panels on both spans to date, with just over 800 remaining. When all of the deck panels are in place this year, they will comprise a surface area of more than 65 acres – approximately equal to the deck space of all 19 U.S. Navy aircraft carriers in service.

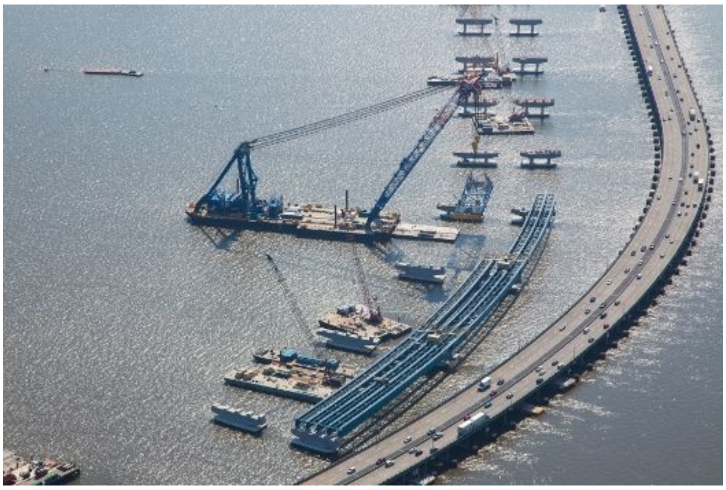
PHOTO GALLERY



Rockland Bulkhead Construction



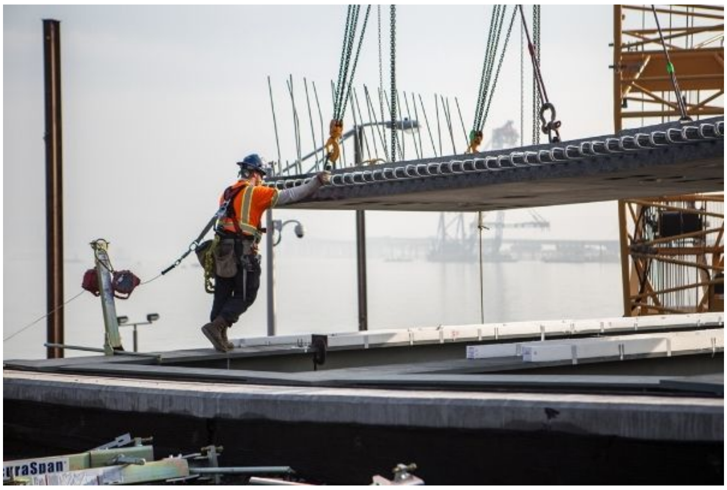
Construction of four towers



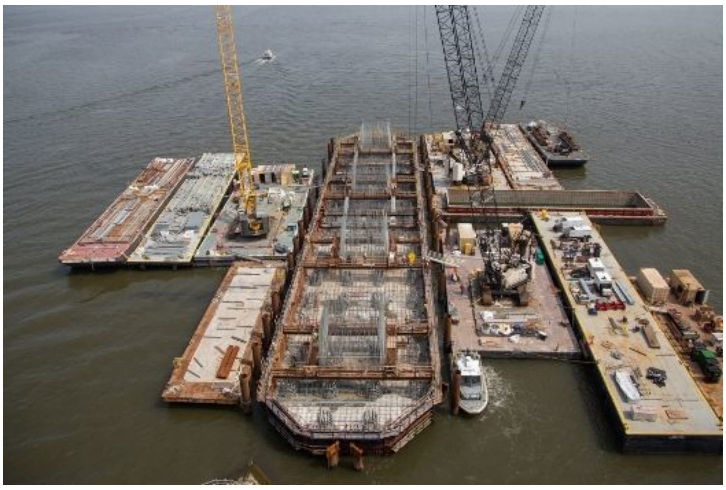
Girder assemblies begin to form the bridge´s Rockland approach

Girder assembly installed over the Metro-North Railroad Hudson Line

I Lift NY´s lifting frame is engineered to evenly distribute the weight of the new bridge´s steel girder assemblies

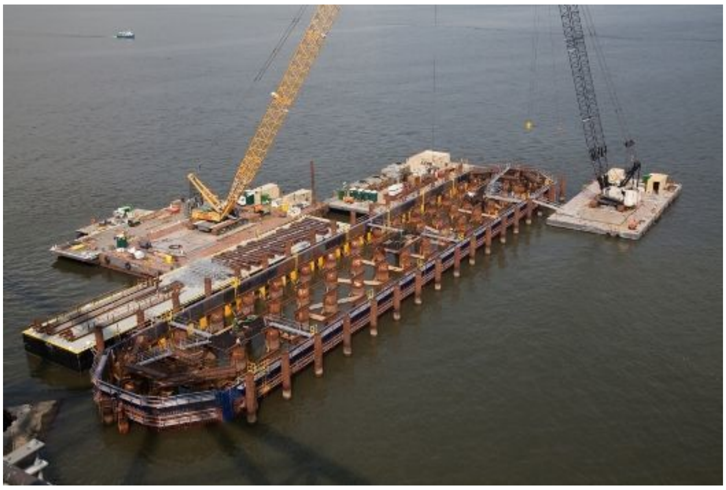


Installation of a new road deck panel



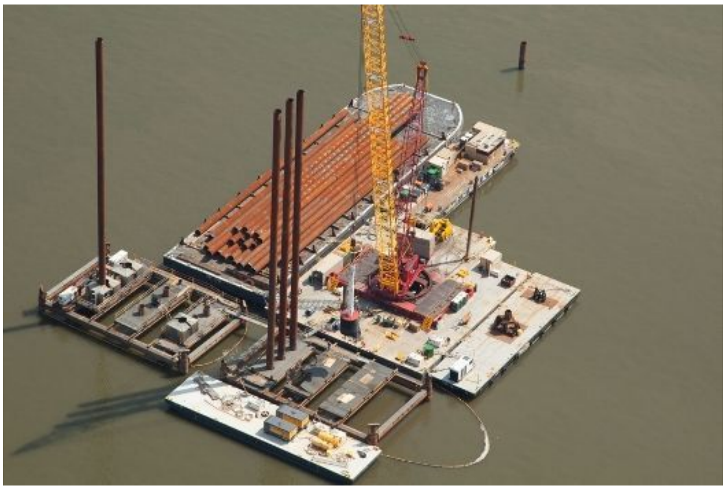
Main span foundations are reinforced internally with cages of galvanized steel

One of the project´s floating batch plants at the Westchester work tressel

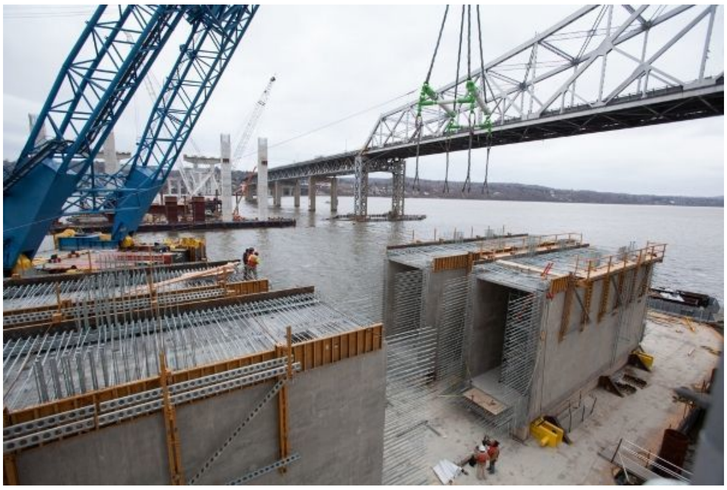


One of the project´s main span pile caps after being lowered into the Hudson River

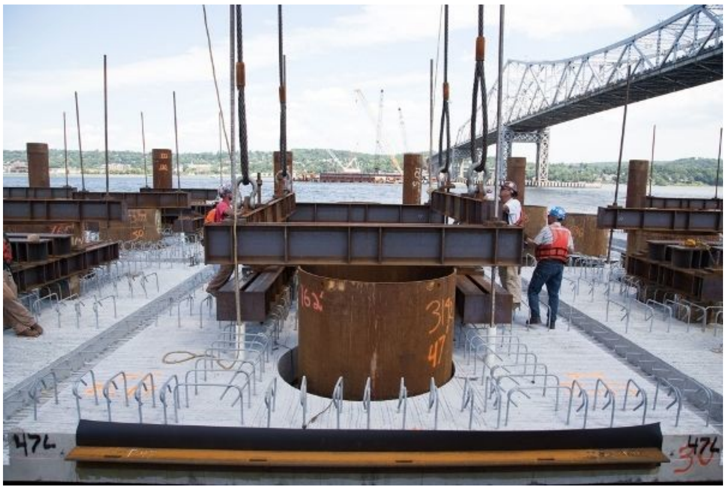
Pier 31 formwork for the pile cap being assembled

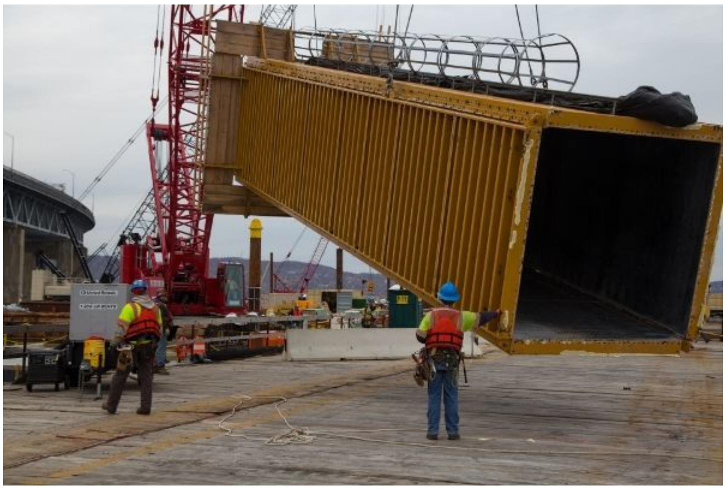


Pile driving operations



Precast crossbeams prepared for installation of the main span

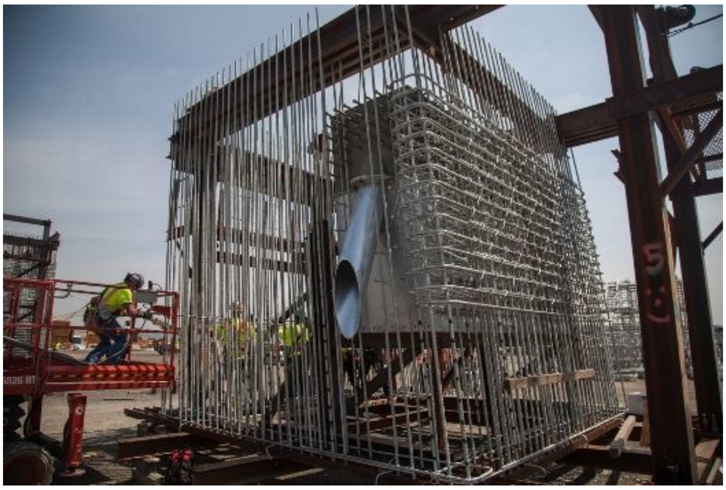




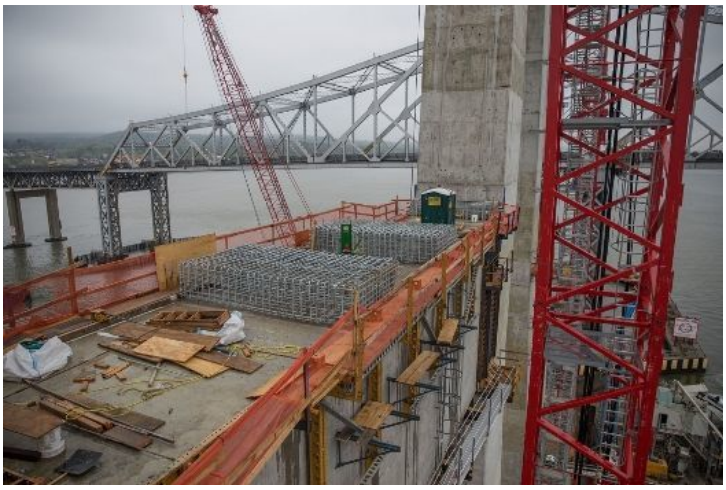
Precast pile cap installation
Removing the formwork for the pier 39 columns

A concrete crossbeam slowly lowered onto temporary steelwork

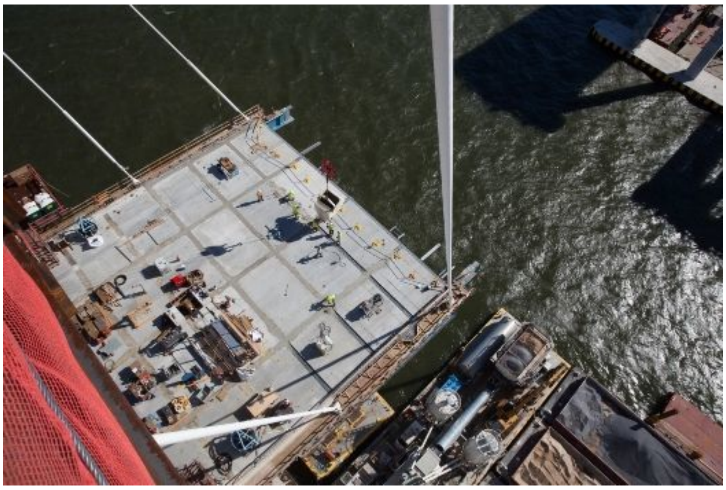
A view of the main span towers from a tower crane



Cage assembly of steel reinforcement for the main span towers. A steel tube helps guide the stay cables



Cages of reinforcing steel are prepared atop a main span tower crossbeam

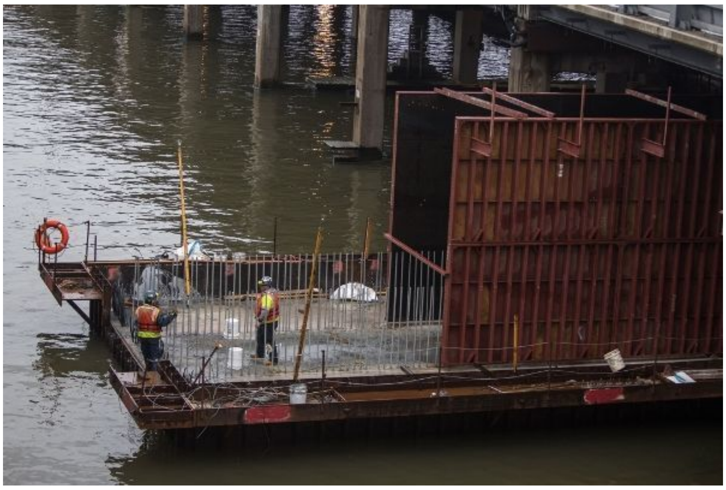


Casting the spaces between road deck panels on the main span

Grout application to finalize the main span tower crossbeams

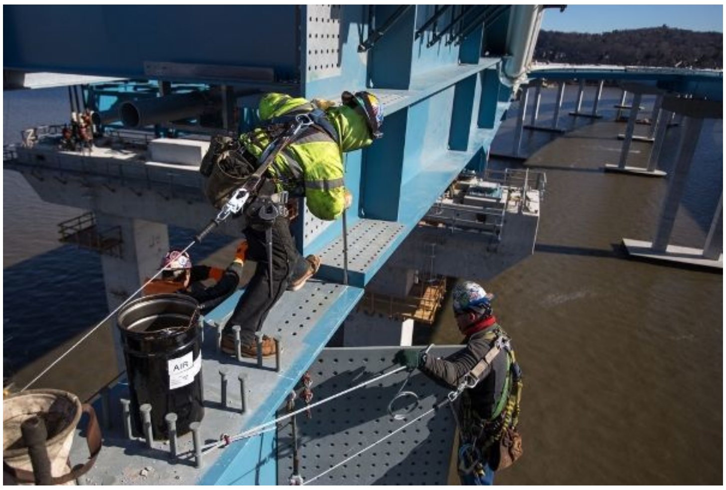
Surveyors ensure proper alignment

Utilization of post-tensioning device to tighten the connections on a main span tower



Preparation of the eastbound pile cap underneath the existing bridge

Installation of an expansion joint between the main span and the Rockland approach

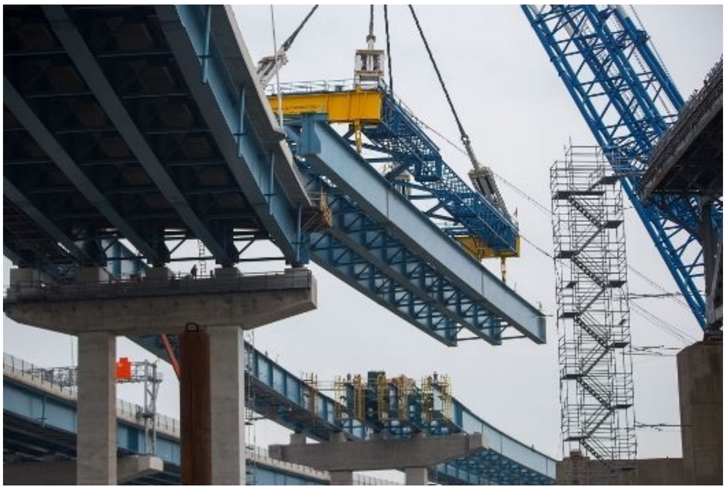


Adjusting the connection between a section of structural steel and the main span

A 750,000-pound section of steel precisely lowered into position

Ironworkers connect two steel girder segments above the Hudson River

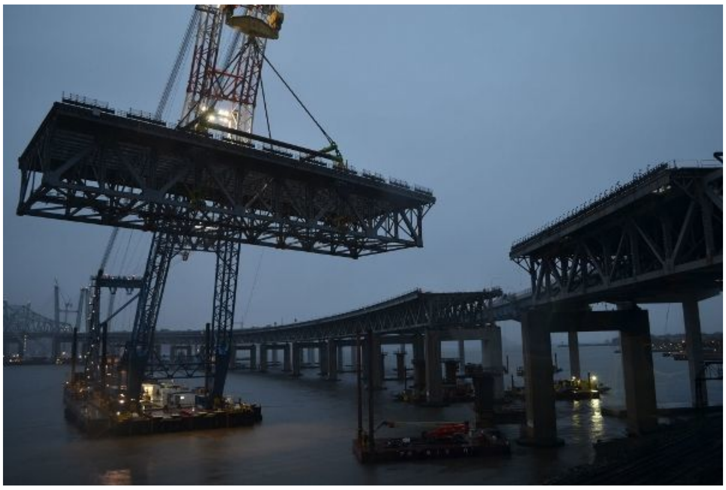
Connection of the final section of westbound steel



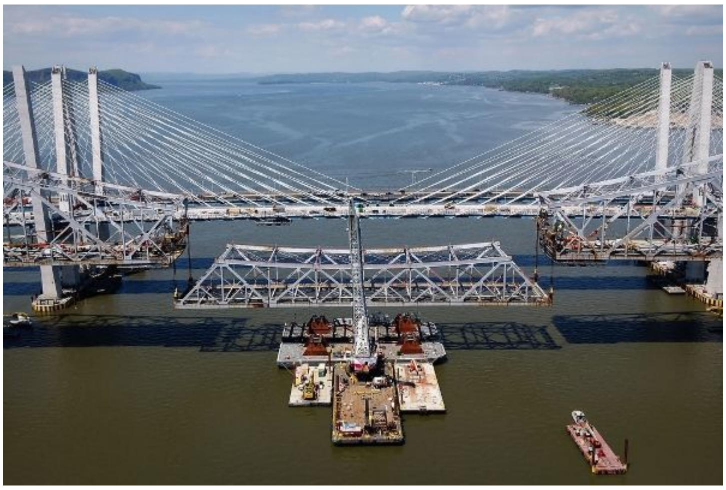
I Lift NY lowers the project´s final girder assembly with precision

Connecting of the cable-stayed main span to the Westchester approach

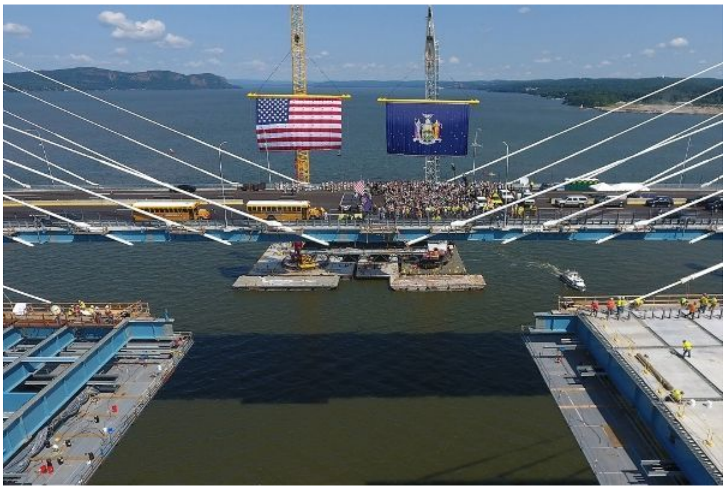
The eastbound Westchester approach will be completed after removal of the old bridge



The I lift NY removes a large section of the Tappan Zee Bridge near the Westchester shoreline



The Tappan Zee Bridge´s center span is lowered onto a barge



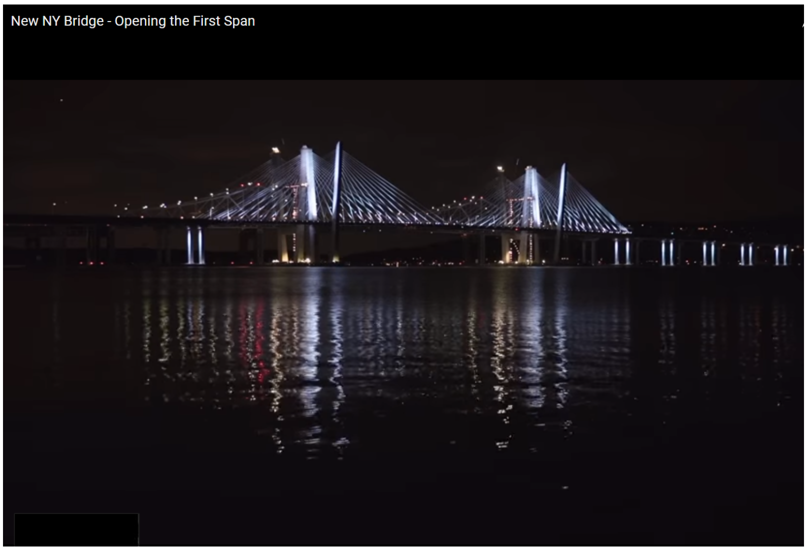
The US and New York State flags from barge based cranes at the main span

Photo Credit: New York State Thruway Authority

VIDEOS


THE NEW NY BRIDGE
OPENING THE FIRST SPAN
4 YEARS IN 2 MINUTES


THE NEW NY BRIDGE
TEAMWORK OVER THE HUDSON


New NY Bridge - Opening the First Span

INTERVIEW

WITH JAMEY BARBAS

Derya Thompson

How did you choose bridge engineering? Even before I met you in person, I remember reading about your important role in the reconstruction of the Williamsburg Bridge and many awards you received for your contribution to the bridge industry.

Thank you Derya for your kind words. When I started college, I had never met an engineer or really knew what engineers actually did. As a pre-med student at Barnard College in New York, I noticed an interesting new class being offered across campus at the Columbia Engineering School entitled Bio-Medical Engineering, and thought it would be worth investigating. I quickly discovered that engineers apply math and science to solve real world problems and thought that was pretty amazing. I was looking for a career that would have a positive impact on society and realized I could find it with engineering.

I'd like to mention that it was a pleasure to work with you, Derya, as you are an exemplary engineer and conscientious professional.

Please tell us a little about your education and early years as a bridge designer. Did you have a mentor who guided you in your career? How important do you see the mentoring / sponsoring process in developing young design engineers and empowering them to grow?

I applied to the School of Engineering and Applied Science at Columbia mid-way into obtaining my liberal arts degree from Barnard College in bio-psychology and finished both degrees simultaneously. There are some days I feel I use my degree in psychology more than my engineering degree! Because I was off sequence with my engineering classmates, I often referred to textbooks to catch up and research answers to my homework. In my early years of working, I was still in the habit of researching solutions - my supervisors noticed how hard I worked trying to solve problems on my own and took this for initiative. I was quickly promoted to greater levels of responsibility but made sure I did the technical design work along with the managerial assignments, as I firmly believe that managers of complex structures should be accomplished designers and analysts.

As a young engineer, I was a deputy to a Chief Engineer, Jerome Schwartz, who explained how he approached every project in our design firm. While I did not have any formal mentors, I had many informal ones. I learned from every supervisor and many senior technical colleagues.

I believe the mentoring / sponsoring process in developing young design engineers and empowering them to grow is critical. If it's not happening naturally in the work environment, programs set up to encourage mentoring have worked in my experience.

Can you tell us more about your current role in the prestigious Governor Mario M. Cuomo Bridge and how your career progressed to include the design or reconstruction of so many long span bridge projects, both locally and globally?

Presently, I am the Project Director on behalf of the New York State Thruway Authority. This is the largest construction project in the history of the Thruway Authority and the biggest bridge project in New York State history. I see my role as one that tries to ensure that the goals of the project are reasonably achieved. There are not only the usual objectives of maintaining schedule, budget and quality, but also important aspects of community relationships, sustainability and environmental protection. I am also working to protect this $4 billion dollar investment by enhancing our structural health monitoring and asset management systems.

I focused my career on complex structures and large transportation projects. The first half of my career was spent in design and management of long span bridges at a firm called Steinman (later under the name Parsons Transportation Group). The great suspension bridge designer, David B. Steinman, founded this firm and it specialized in long span bridges. Following my years at Steinman, I then asked a company called Arup if they wanted to build a bridge group in the Americas. They hired me immediately and as you know, I spent the next several years growing that business as their Americas Bridge Leader.

Who has most influenced your design and management methods?

I have worked with so many brilliant engineers and inspiring leaders that it is impossible to name them all. Each of them has influenced me in different ways. Blair Birdsall, one of David Steinman's partners and an expert in suspension bridge cables, was well into his eighties when he mentored me on the unique and ambitious project to spin new, supplemental suspension cables and thereby add a new level for rail to the existing Tagus River Suspension Bridge in Lisbon, Portugal.

My very first boss, Jerry Reiner, told me that the most important thing to remember is to do the right thing, be ethical in all your dealings, so that you can sleep well at night. That was 35 years ago and it has certainly influenced my leadership style.

What is your favourite historic bridge, and why?

The *Brooklyn Bridge is my favourite historic bridge as it was truly an amazing feat of engineering for its time and a great example of will and determination.*

Which bridge or other structure most influenced your early career, is it still an influence?

This is a tough question, but if I had to choose one it would the Williamsburg Bridge Rehabilitation which was a one billion dollar project in the mid 1990's to 2004 for the New York City Department of Transportation. As the project manager for the Designer firm, the Williamsburg was rehabilitated for another 100 years of service life. The project involved many firsts, such as the first orthotropic deck on a New York City suspension bridge, first full-scale testing of an orthotropic deck which resulted in improved welding details, first Preventive Maintenance Management System and first comprehensive cable evaluation for New York City. Much engineering innovation was derived from this project and applied on many subsequent long span bridges.

How do you use your creativity in your current role? How do you find balance between your executive and technical roles?

As you said, it's all about balance. Blending creativity with the technical informs better executive decision making. I believe creativity is used in both the executive and technical decision making. By nature of the job, many of the executive decisions have technical influences.

I use creativity by trying to think of solutions that are not typical, that come from a different way of looking at things. I encourage my team to do so in team meetings. I think this is where we have the most fun.

The design and construction of Governor Mario M. Cuomo Bridge have brought many innovations to the industry, including its fast track procurement and delivery. Can you tell us more about them and their impact in the delivery of similar bridges and projects?

Our Governor Andrew Cuomo championed the Design/Build procurement method in New York State that permitted the use of this alternative delivery for this project. The fast-track procurement did not skip any regulatory steps but allowed for expediency and sometimes parallel agency reviews to the benefit of the project schedule. Since then we have employed similar procurement benefits to other major transportation projects.

A very successful and innovative feature of the Governor Mario M. Cuomo Bridge actually lies in the philosophy of scalability. Virtually every aspect of the new bridge is designed and constructed considering the need to scale solutions according to the range of challenges presented. The main driver for this tactic lies in the lengthy approach structures rather than the main span.

From the pile foundations to precast substructure and superstructure elements, scalability allowed for cost effective design, fabrication and construction. For example, even though the geotechnical conditions varied greatly along the expansive site, steel pipe piles were utilized whether the piles were in bearing or relied on skin friction. The utilization of the same means and methods for these 1,000 piles allowed for significant cost efficiencies. Another example includes the precasting of approximately 6,000 deck panels while using no more than 18 adjustable forming beds.

What is your perception of the biggest change that has occurred since you first started to design bridges? Do you think that it is really necessary to develop new materials, new forms, new technologies?

When I first started to design it was unheard of to design for 100 years of service life. The Williamsburg Bridge was the first, that I am aware of, where we were mandated to extend this 100-year-old bridge for service for yet another century. We will certainly benefit from new materials and innovation. This is readily apparent in the comparison of the ailing old Tappan Zee Bridge with the modern and resilient Governor Mario M. Cuomo Bridge. However, in my view, the biggest change will be in the integration of design, how we thoughtfully plan our projects so that we respond with the best options by considering various inputs.

We can no longer plan and design in a linear manner that has a sequential hand off to specialists. Our future generation of engineers must be trained to consider many factors at once for sustainable design, that is site specific and takes into consideration multiple factors at once. I believe technology will aid in this evaluation.

Can you tell us how the sustainability and resilience are built in to the delivery of Governor Mario M. Cuomo Bridge?

The Governor Mario M. Cuomo Bridge has addressed sustainability on a number of levels, mostly by considering the materials, natural environment, society and future needs. Some examples include: designing for 100-year service life by using durable materials; significantly reducing the amount of dredging in the Hudson River; utilizing on-site floating concrete batch plants which have kept at least 30,OOO trucks off of local roads; heavily monitoring and providing for protected species; as well as providing a spacious pedestrian and bike path.

Resilience is accomplished with structural redundancy and the ability to perform well under extreme loading, both natural and man-made. This includes providing the extra capacity in the foundations and towers to accept future heavy rail, enhanced operational responsiveness and using instrumentation to monitor the structural health and allow for early preventive maintenance as necessary.

In addition, many of the Tappan Zee Bridge deck panels that were replaced about ten years ago are being recycled for use as bridges by other New York municipalities, the steel trusses and foundation pipe piles are being completely recycled, and steel and concrete elements are being used to establish artificial reefs off of several sites in Long Island to generate fish habitat.

Sustainability is not only about environmental responsibility, but also improving community and economic prosperity which this project has accomplished.

Another very frequently discussed topic in the Design-Built environment is the collaboration between the Owner and Design/Builder. Having been on both sides how does your past experience empower you in your current role? Do you utilise your Chief Engineer and Design Manager roles in your current role?

I think my past experiences as Chief Engineer or as Design Manager in Design/Build teams has helped tremendously. It is very beneficial to understand not only the roles and responsibilities of each party but to have a deep understanding of the challenges the other party faces on a daily basis.

It is important to be able to distinguish which design and construction issues are critical and for which ones compromises can be negotiated, where unforeseen issues can be mitigated or opportunities taken.

This understanding or empathy goes a long way in fostering collaboration between Owner and Design/Builder, to solve problems jointly and to get all parties aligned to the same ultimate goals.

Do you have a preference for working directly for the Owner or as part of a Design/Build team? Why?

I am comfortable in carrying out the responsibilities of either party. However, a gratifying aspect of working directly as the Owner, is the ability to set policy and planning from the very start. It is at project conception when you have the most opportunity for decision making that affects the design and construction process.

As an Owner you are better able to obtain information and define the project requirements, so that you can develop a site-specific design process – one that responds to the relevant information and establishes an integrated design, rather than a design process that is sequentially driven.

I know that you are a big advocate of STEM education. What are your plans in making yourself and your knowledge available to young bridge engineers and next generations?

The Thruway's project outreach staff and engineers have used the new bridge as a fantastic teaching example to present engineering to more than 60,000 students to date, encouraging young people from kindergarten through college to consider careers in STEM.

Personally, I have joined to teach certain classes, participated in WizGirls, a high school girl robotics team called Techno Chix and others as I hope to serve as a role model especially for young girls who, like me, may never have been exposed to careers in engineering.

What would you say your greatest achievement to date is or contribution to bridge engineering over your impressive career?

My greatest technical achievements regarding bridge engineering are mostly with respect to suspension bridge cables and developing schemes to replace or provide additional suspension bridge cables on existing suspension bridges, like Tagus River Suspension Bridge in Lisbon, Portugal and Waldo Hancock in Maine, U.S.A. It is good to see these methods are being studied and adopted on other suspension bridge rehabilitation programs currently underway.

Other achievements are organizational in nature. I have worked decades in the private sector to successfully develop new markets for various companies, serving to increase their revenues and profiles.

I have also advised on numerous mega projects by helping set up the procurement process and advising technically.

Thank you very much for your time.

JAMEY BARBAS – SUMMARY BIOGRAPHY

Registration

Professional Engineer:

New York

Education

BS,CE 1982

Columbia University

BA, 1981

Barnard College

Jamey Barbas, PE is the Project Director, charged with replacing the Tappan Zee Bridge in New York with the Governor Mario M. Cuomo Bridge – one of the largest bridge projects in the US, on behalf of the New York State Thruway Authority.

A transformative senior executive with a career in bridge design and construction, she has held leadership positions in several international consulting firms. Her industry experience includes the development of the infrastructure business for international firms, such as Arup, where she was the Principal that initiated the bridge practice and grew the infrastructure business in North America as well as the Senior Vice President and Global Practice Leader for Louis Berger. Her duties included leadership of the strategic, operational and technical aspects for the practice, as well as corporate leadership roles in Risk and Quality Management.

A registered professional engineer with over 35 years of experience in bridge management, design, construction and inspection, she has expertise on successful delivery of complex and long span bridges and tunnels utilizing Alternative Delivery such as Design/Build, Public Private Partnership and CMGC.

Barbas' experience includes a number of award winning, domestic and international projects. She has led the inspection, design and construction support services for the reconstruction of the Williamsburg Bridge in NYC - one of the largest bridge reconstruction projects ever undertaken in the U.S. and led the design of the major bridges of the AutoRoute 30 project in Montreal, Canada - one of the largest P3 bridge projects in North America.

Barbas is a native New Yorker, graduate of Barnard College and the Columbia University School of Engineering and Applied Sciences. She has written numerous technical papers and was named by Engineering News Record as one of their top Newsmakers of 2004 for her work in providing an emergency solution to a failing historic suspension bridge.

She also serves on the board of directors for Bridges to Prosperity, a non-profit that provides footbridges in rural communities to increase access to schools, health care and market.

RELEVANT PROJECT EXPERIENCE

Governor Mario M. Cuomo Bridge, Tarrytown, NY

AutoRoute 30 – Bid Design and Final Design, Quebec, Canada – MOT Quebec

Williamsburg Bridge, New York, NY – New York City DOT

Williamsburg Bridge Rail Reconstruction, New York, NY – New York City DOT

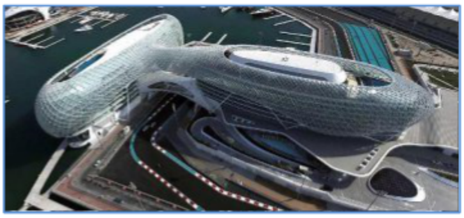
AutoRoute 25, Montreal, QC, Canada – Acciona/Bouygues

Waldo-Hancock Bridge, Bucksport, ME – Maine DOT

Forth Road Bridge – Edinburgh, Scotland –
Forth Estuary Transport Authority

25 April Bridge - Tagus River Suspension Bridge – Addition of Railroad and Suspension System, Portugal

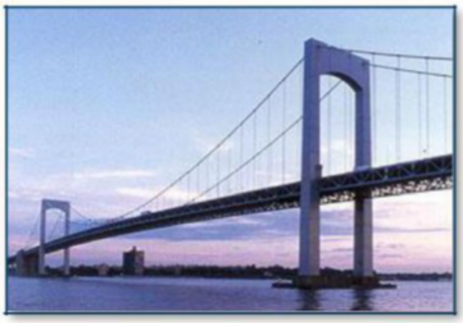
The New Sarah Mildred Long Bridge – Maine to New Hampshire, US



YAS Island Marina - Viceroy and Link Bridges- Abu Dhabi, UAE

YAS Island Marina in Abu Dhabi, UAE – Architectural Pedestrian Bridges over the Formulae One Race Track – ALDAR, Asymptote Architecture

Bear Mountain Bridge, Peekskill, NY – New York State Bridge Authority



Throgs Neck Bridge, New York, NY – MTA - Bridges and Tunnel Authority

AWARDS

NCSEA 2010 Excellence in Structural Engineering Award for YAS Marina Island Bridge

NYACE, New York Construction News, Concrete Industry Board, Art Commission and ASCE Awards for the Williamsburg Bridge

Nominated for the 2004 Award of Excellence, ENR's top 25 newsmakers for Innovative Suspension Bridge Received ARTBA Award for Leadership, Corporate Awards and Leadership Training Waldo-Hancock Bridge – Winner of 2004 Build America Award for Cable Strengthening Solution

ArtsWestchester, 2017 Honoree

TELEVISION

"Secrets of New York", PBS television – New York Bridges "Discovery Channel- Canada"

TEACHING

Lecturer for Steel Design and Fatigue of Bridges Course at Princeton University

BOARDS

Board of Directors – Bridges to Prosperity (non-profit)

PUBLICATIONS AND PRESENTATIONS

"Railroad Addition to Tagus River Bridge," ABSE Conference 1997, Lisbon, Portugal "The Reconstruction of the Williamsburg Bridge," 1999 ASCE Winter Seminar "The Reconstruction of the Williamsburg Bridge Transit Structure," IBC, June 2000 "Saving the Williamsburg Bridge," Civil Engineering Magazine, October 2000

"Reconstruction of the Williamsburg: Transition to a Modern Structure," ASCE Engineering History Congress, October 2001

"The Bear Mountain Bridge – Main Cable Rehabilitation," NYC Bridge Conference, October 2001.

"The Waldo Hancock Bridge: Inspection, Monitoring and Strengthening of the Main Cables", 4th International Cable Supported Bridge Operator's Conference 2004.

"The Rehabilitation, Survey and Monitoring of The Bear Mountain Bridge," 3rd International Suspension Bridge Operators' Conference, May 2002, Kobe, Japan, co-author with William M. Moreau of NYSBA.

"The Williamsburg Bridge Deck Replacement," 3rd International Suspension Bridge Operators' Conference, May 2002, Kobe, Japan.

"Reconstruction of the Williamsburg Bridge," 2nd International Suspension Bridge Operators' Conference, Westpoint, NY, April 2000

Guest Lecturer at Columbia University, Princeton University and the New York State University at Buffalo.

Jamey has presented numerous technical papers for Cable Supported Bridge Owners in the US, Japan, Denmark and UK.

ABCD – Association for Bridge Construction and Design - Key note speaker 2010, Harrisburg, PA SEoNY 2010- Key Note Speaker, NYC

Footbridge 2011, Design and Construction of Link Bridge, Yas Island, Abu Dhabi, 2011 Poland The Institution of Civil Engineers - ICE Americas Convention 2012

The Challenges of Urbanization - Speaker, NYC, IQPC- 4th Bridges Summit -Speaker 2012, NYC American Society of Highway Engineers 2013 – Design Build Industry Forum, Speaker, NYC ACEC – Annual Convention -Design Build Panelist, 2013, Washington DC ENR-Groundbreaking Women in Construction Panelist, May 2015, New York City

Hellenic American Chamber of Commerce – The New NY Bridge, April 2016, New York City HANAC – Woman of the Year 2017

Risk Based Inspection of Complex Bridges in the USA

Barry Colford, AECOM

Figure 1: Inspecting the Brooklyn Bridge

1. Introduction

Currently, in the USA, the Federal Highways Administration (FHWA) requires all bridges with a span length equal to or greater than 20 ft. to be inspected every 24 months as per the National Bridge Inspection Standards[1]. In addition, the inspection of fracture critical bridges requires 100% hands-on access for the full-length of all fracture critical members. The Standard also states that increased inspection frequency may be required after consideration of factors such age, traffic characteristics, and known deficiencies.

In addition, individual States can establish criteria to determine the need and level of effort required for increased inspection frequency. It is recognized that complex bridges, such as movable bridges and cable supported bridges, may require special inspection procedures but there are no set guidelines for such structures.

This prescriptive inspection regime based on a minimal set interval has been written to suit State and other local authorities with a large number of standard shorter span bridges and has obvious strengths and weaknesses. It ensures uniform coverage of all structures while allowing some flexibility but does not differentiate between simple and more complex structures. In addition, although there is now more and more consideration of element level inspection, such a regime of set inspections is difficult to apply to large complex structures.

Additionally, the inspection of bridges has tended to concentrate solely on the condition of the bridge elements without taking into account the overall risk of failure of an element.

Risk can be defined in many ways, but perhaps the simplest is to define it as the possibility of loss, injury or other adverse condition occurring. More specifically, it is the combination of the probability of an event occurring and the consequence of the event occurring.

The likelihood of occurrence is determined by the condition of element (as well as other metrics such as the capacity/demand ratio and fatigue susceptibility). However, the consideration of the outcome of failure and overall risk, and a risk ranking of all elements has not been carried out in a methodical and systematic way.

Establishing a risk-based inspection regime, that addresses the specific characteristics of the bridge, is the most effective method of managing and mitigating risk on these large complex bridges.

A risk based inspection regime can be as simple or as complex as the owner requires or made to suit the condition of a particular bridge. In all cases, a risk based inspection will have inspection frequencies that vary from those prescribed by national and state authorities.

Therefore, consultation and discussion between all relevant parties involved has to be a first requirement before adopting a risk based regime.

In fact, the FHWA requirements for the inspection of fracture critical members is in fact a recognition of the need for risk based inspection albeit in a partial form.

When applying risk based assessments to bridges one of the largest risks may be construed as structural failure.

2. Background to Risk and Bridge Inspection in the US

In 1967, the Silver Bridge, a pin-connected link suspension bridge over the Ohio River at Point Pleasant, West Virginia collapsed suddenly with the loss of 46 lives.

As a result, a 1968 Federal Act initiated a national bridge inspection program that recognized the need for periodic and consistent bridge inspections and subsequently, the first National Bridge Inspection Standards (NBIS) were developed in the USA, in 1971.

Another structure failure in the US, at the Mianus River Bridge in Connecticut in 1983 (see Figure 2), caused more concern related to fatigue and fracture-critical bridges. This failure and further research resulted in fracture-critical inspections being mandated. In 1987, scour caused failure of the Schoharie Creek Bridge in New York. This failure resulted in the initiation of the underwater bridge inspection program.

Figure 2: Mianus River Bridge Failure

The safety risks associated with the 600,000 bridges in the USA were tragically highlighted when the Interstate 35W Bridge (I-35W) in Minneapolis, Minnesota, collapsed on August 1, 2007, killing 13 people.

Following that collapse, the US Federal Highways Administration (FHWA) asked the American Association of State Highway and Transportation Officials (AASHTO) to determine whether or not the FHWA's National Bridge Inspection Program was delivering the highest level of bridge safety. The conclusion was that limited progress had been made in implementing data-driven, risk-based bridge oversight.[2]

In June 2009, the US Congress passed the MAP-21 Bill which, amongst other things, requires each State to develop a risk-based asset management plan for the National Highway System (NHS) to improve or preserve the condition of the assets and the performance of the system[3].

As a consequence of that requirement, State DOTs have been putting in place Asset Management Plans. Ohio State DOT (ODOT) has a huge inventory of structures including two significant cable supported bridges.

Figure 3: Anthony Wayne Bridge in Toledo, Ohio

One of these is the Anthony Wayne Bridge in Toledo - a classical 1930's US Suspension Bridge with a 382 metre main span (see Figure 3).

ODOT has a proactive inspection and maintenance regime for this bridge including suspender replacement; internal inspection of the main cables; re-painting and re-decking; installing cable and anchorage dehumidification; replacing cable band bolts and handstrand ropes and replacing the tie downs.

A significant number of the longer span complex bridges are owned and operated by toll agencies and these agencies are now also looking to implement Asset Management Plans.

These toll agencies are quite diverse and may own a number of complex and other bridges as well as diverse assets such as toll plazas and buildings, tunnels, airports, ferries and harbors.

The issue facing many of these toll agencies is that for large complex bridges, and especially cable supported bridges, carrying out a biennial inspection is expensive (with costs around $500,000 per inspection) and generates large amounts of data every two years much of it which doesn't vary between inspections.

In addition, some elements that are deemed to be critical require special ad hoc inspections at more frequent intervals.

3. Risk Based Approach

3.1 Understanding Risk

Many owners of complex bridges in the US are now looking for an alternative approach to the prescriptive fixed frequency, national inspection regimes. An alternative approach would be to vary the frequency of inspection according to the risk of damage or failure of a particular structural element or family of elements forming part of the structure. If this can be done then it will be beneficial in three separate ways.

- The elements that are most at risk of failure are inspected more frequently.
- Resources and staff can be used more efficiently because staff are not spending time inspecting elements where the risk of damage or failure is low.
- By increasing the inspection frequency of critical and vulnerable bridge components, the long term structural integrity of the bridges is more certain.

In addition, the reduction in frequency of inspection of components with a low risk rating will result in a decreased risk to those carrying out the inspection and may reduce risk to the public.

Before setting out a risk based inspection regime, the bridge owner/operator should determine their priorities and objectives.

These may vary between organizations but are likely to include the following principles:

- Minimize the risk to the safety of the users of the bridge and their staff
- Ensure the long term structural integrity of the bridge
- Minimize disruption to users
- Establish focused management resources to the most critical components
- Carry out all of the above in a fiscally responsible manner

In carrying out a risk based inspection strategy there are three main risk headings that have to be addressed. These are:

- risk to life or serious injury
- risk of catastrophic structural collapse (which may of course also result in the first risk occurring)
- risk to the operational capacity or serviceability of the structure.

An operational risk is one where if a bridge element was damaged or failed, then a catastrophic structural collapse would not occur. The main effect of an operational risk would likely be disruption to users with subsequent political and other social consequences.

The acceptance of risk is of course very subjective and varies over time. The past ten to twenty years has seen a marked change in society's attitude towards risk. All bridge owners would likely agree that dealing with risks involving public safety are a priority and the risk of structural collapse must be minimized.

However, dealing with operational risk can be more challenging. The more difficult choice is balancing the risk of injury to users or even potential loss of life against significant disruption to traffic.

In some US States there has been some development of using risk in bridge inspection but it is usually used to determine condition rating rather than inspection frequency.

For example, the New York State Department of Transportation (NYSDOT) carry out bridge inspections at element level, up to a set number, and an overall condition rating for each bridge is determined by combining the ratings of individual components using a weighted average formula.

This formula assigns greater weights to the ratings of the bridge elements having the greatest structural importance and lesser weights for minor structural and non-structural elements.

In order to properly manage risk, all risks must first be identified. The management of risk requires coordinated activities to direct and control the task or processes at hand with regards to the identified risks. Risk cannot always be avoided, so the best way to address it is through an effective management strategy.

In the context of bridges and inspections, the ever present risk is that a structural element has deteriorated or been damaged, and the condition of the element has not been picked up during inspection, or the frequency of the inspection is such that the deterioration or damage has occurred between inspections.

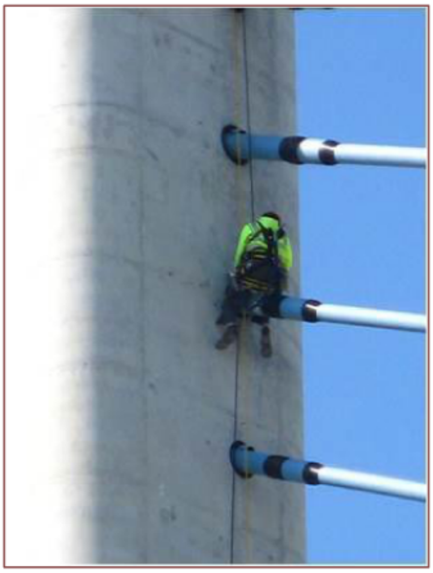
The likelihood of this occurring depends on how vulnerable a structural element is and the accessibility of the element for inspection. The consequences of such an incident occurring depend on how critical the element is to the structural integrity or operation of the bridge.

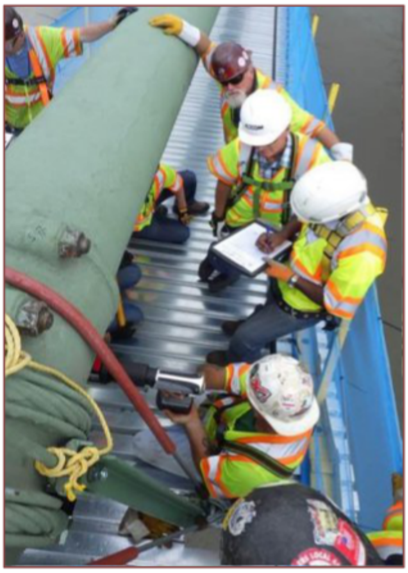
3.2 Application to Complex Bridges

When dealing with large complex bridges it is usually not possible to avoid or transfer risk and acceptance of them is not an option when public safety is involved and usually not an option when the consequence of failure results in significant disruption. Establishing a risk-based inspection regime, that addresses the specific characteristics of the bridge, is the most effective method of managing and mitigating risk on these large complex bridges.

In physical terms, certainly on older suspension bridges, the overwhelming amount of inspection is focused on steel elements, including members and connections plus protective coatings. However, there are often considerable reinforced and post-tensioned concrete elements on cable supported bridges as well as deck surfacing and highway lighting.

Electrical and electronic systems, and the stock of permanent and temporary bridge travelers or access gantries and platforms, also require a considerable specialist inspection resource. In addition, there are usually significant amounts of other facilities, equipment and vehicles all requiring regular periodic inspection.





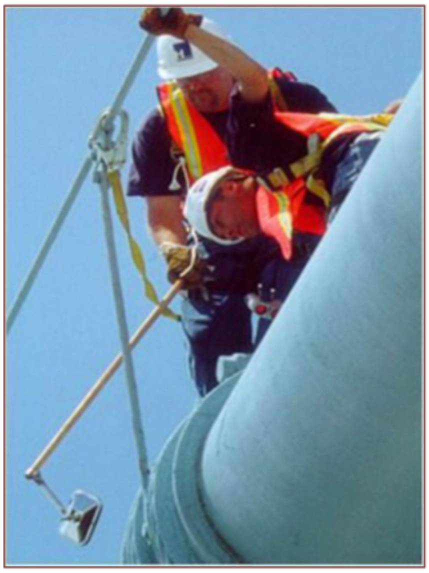


Figure 4 (from the left): Inspecting stays. Checking Cable Band Bolt Tensions. Inspecting cable bands

Setting up a risk based inspection regime requires, in the first instance, a detailed knowledge of all the components of the structure including current load ratings, and inspection and maintenance records.

For a new complex bridge the input of the engineers' involved in the design is vital. For existing bridges, it is important that the knowledge and experience of staff involved in the inspection and maintenance of the bridge is utilized when a risk based inspection regime is being planned.

A risk based inspection regime can be as simple or as complex as the owner requires or made to suit the condition of a particular bridge. In all cases, a risk based inspection will have inspection frequencies that vary from those prescribed by national and state authorities.

Therefore, consultation and discussion between all the relevant parties involved has to be a first requirement before adopting a risk based regime.

3.3 Failure Mode, Effects and Criticality Analysis

One method that has been used successfully is to determine the vulnerability of each bridge component based on its failure mode, likelihood of detection and the probability of this failure occurring. The criticality of each bridge component is also assessed based on the effect a failure of the component would have on the structure and to the bridge users.

An assessment can then be carried out in the form of a Failure Mode, Effects and Criticality Analysis (FMECA) whereby each component is assigned a quantitative score based on defined criteria.

The result of the assessment is then used to determine a Risk Priority Number (RPN) to rank elements and highlight those of most concern.

This assessment determines a minimum frequency of inspection for each component and highlights to the inspectors the most probable modes of failure.

This FMECA process can be carried out on all bridge components and is subject to re-assessment following any future incidents, load ratings or structural assessments, maintenance works and after all inspections. This is important, as the level of risk will vary over time based on the influence of associated factors – such as the condition of materials and age of the bridge.

It is also possible to have differing inspection frequencies for different parts of the same element. The free lengths of suspenders are very unlikely to suffer any damage and may not require to be closely inspected every two years.

However, at socket level where the ropes are very prone to deterioration, as shown in Figure 5, the inspection frequency may be determined to be less than two years.

In addition to the FMECA analysis, it is also essential for the bridge owner to assess the specific risk factors when determining the approach to a risk based inspection. Examples of risk factors include age of structure; high average daily traffic; history of bridge specific issues; industry recognized problems such as redundancy; difficult inspection access etc.

Figure 5: Typical Suspender Socket detailing used in the US.

All of these risk factors need to be assessed in terms of criticality to the overall system and disturbance to the travelling public so that a degree of importance can be established. It is also important to assess these risk factors in terms of vulnerability to determine the likelihood that an exposure could cause an event to occur. Once all of these tools are assessed for the critical bridge components then a complete plan with appropriate inspection procedures can be developed to provide a roadmap for the inspection teams to prepare and perform a thorough, quality inspection.

3.4 Rating Risk

A level of vulnerability can be assessed quantitatively and a subjective scoring determined. Parameters for vulnerability such as a failure mode and structural capacity against demand plus vulnerability to damage whether deliberate, accidental, or environmental can also be assessed and given a score. The likelihood of detection must also be considered and is based on the availability of access for inspection. The vulnerability score can be determined from the square root of the product of each vulnerability score rounded up to the nearest integer.

The level of criticality can also be determined by considering and quantifying the effect of a failure on the safety of the public and the staff; the effect on the structural integrity of the bridge; the disruption to the travelling public, the economic impact and the effect on the reputation of the bridge owner if such a failure occurred. The criticality score can be taken to be the maximum score determined from one of these metrics.

The degree of difficulty of detection by inspection or other means of identifying a potential fault can be also determined quantitatively.

The product of multiplying the vulnerability, criticality and probability of detection scores results in a Risk Priority Number (RPN). That is RPN = criticality * vulnerability * probability of detection.

This number can then be used to evaluate all the bridge components and to determine the minimum frequency of inspection. Following the determination of an RPN for each element or family of elements, a minimum inspection frequency can also be developed to suit each bridge.

It should be emphasized that at this stage the determination of frequency of inspection will likely be subject to some discussion between the owner and engineer. It will be influenced by staffing arrangements and the owner's appetite for risk.

4. Development of Technique

The use of risk based techniques can also be extended to determine the prioritization of both maintenance and capital projects on complex bridges. This is an important development that may help extend the service life of bridges and optimize expenditure.

This risk based inspection, maintenance and capital planning approach has already been successfully used on some UK long span bridges and is being adopted by owners in the US.

5. Conclusions

A prescriptive fixed frequency based inspection regime is not best suited to complex bridges, and this is especially true of cable supported bridges. Many bridge owners are aware of this and are looking at alternative inspection strategies. Risk based inspection methods as set out in this paper have many advantages not least in targeting and prioritizing the most critical and vulnerable elements of a bridge. Additional advantages include making the best use of scarce inspection staff and reducing risk to both staff and bridge users.

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SHOWCASING CANADIAN STEEL BRIDGES FROM COAST TO COAST

Hellen Christodoulou, Ph.D.ing., B.C.L., LL.B., M.B.A.,

CISC-ICCA Quebec Region Manager

Founded in 1930, the CISC-ICCA (The Canadian Institute of Steel Construction) operates as a technical, marketing and government relations organization representing the Canadian Steel Industry; it is Canada's voice for the steel construction industry, providing leadership in sustainable design and construction, efficiency, quality and innovation.

The CISC promotes the use and benefits of steel in construction, adds value to the design and construction community and supports the needs of the membership and industry through technical expertise, knowledge transfer, research and development, industry codes and standards, certification, and advocacy.[1]

Across the Canadian provinces, the CISC-ICCA Regions hold Design Award Competitions every two years, with Quebec being the exception holding them annually. During the Galas the CISC-ICCA Regions reward teams who carry out exceptional projects in steel, one of the categories being "Bridges".

The Design Award Galas showcase steel construction projects for their beauty, uniqueness and originality. The nominated project and project teams, selected by a prominent jury, receive special congratulations and special recognition during these events. Each team member, such as the Architect, Engineer, Steel Fabricator, Detailers. etc. receive a commemorative plaque to mark the occasion.

There have been many bridges that have been awarded this prestigious award and this article highlights some of the most noteworthy selections.

THE STRANDHERD-ARMSTRONG BRIDGE

Project Team

Engineer: Harbourside Engineering Consultants

Bridge Designer: Parsons (formerly Delcan)

General Contractor: Horseshoe Hill Construction

Steel Erector: Montacier International

Steel Fabricator: Cherubini Metal Works

Steel Detailer: Tenca Steel Detailing

The Strandherd-Armstrong Bridge, located south of Ottawa, connects the communities of Riverside-South and Barrhaven, between Strandherd Road and Earl Armstrong Street.

This new link promotes the development of these communities, reducing travel times and improving the public transport offer. It offers easier access to services, businesses and jobs, as well as schools and recreation areas. It also contributes to the improvement of the Ottawa area network.

The Bridge has a total length of 143 meters and the arches rise to 21 meters above the roadway and have a 125-metre opening. The lightness, strength of the material and its flexible use, permitted aerial launch work that could not have been implemented.

The environmental objectives and the respect for this heritage site were certainly governing factors. The goals were achieved and undoubtedly exceeded, steel made this exceptional structure possible.

The bridge supports four lanes of traffic, one of which is dedicated to public transport, and one cycle lane per direction taking place between the three arches. Two sidewalks, outside the arches, complete the cross section. The large width of the deck - 54.7 m abutment and 58.7 m in the center - is mitigated by the spaces provided for the passage of the arches, promoting natural lighting of the banks under the deck.

The structure has a total length of 143 m. The arches, culminating at 21 m above the roadway, have an opening of 125 m. Each arc is constituted by a lattice of tubes forming a triangle of 4.25 m wide by 3.50 m high for the central arc and 3.50 m by 2.50 m for the lateral arches.

The tubes, 508 mm in diameter, are bent with a radius of about 90 m. The two upper tubes are interconnected by spacers "K" and with the bottom chord by diagonal spacers. These spacers, also in tube, have a diameter ranging from 219 mm to 273 mm.

On the central hundred meters, these arches support a mixed deck through twenty-five pairs of lines. With the exception of the first two and last lines, in tube, all the others are cables composed of waxed sheathed galvanized strands, with seven strands for the suspension of the road parts and four for those of the bridges.

At the ends, between the last line and the abutment, the deck is supported by steel columns resting on the support mass of the arches.

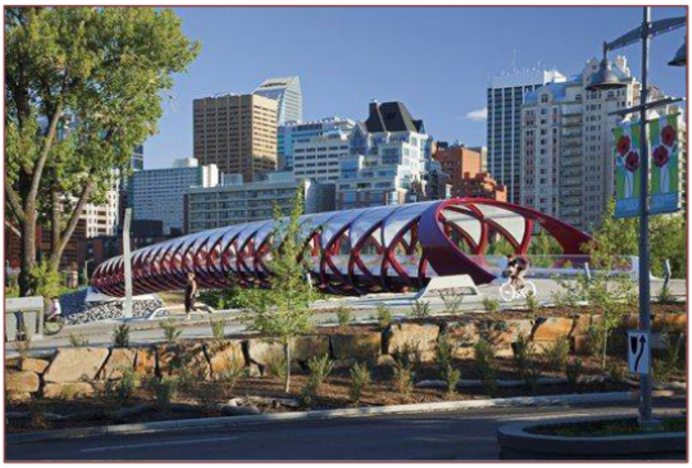
The concrete slab, 225 mm, is supported by a grid made of steel boxes in both directions. In the current zone, the transverse boxes are rectangular, with a width of 500 mm and a height of 900 mm.

The spar caissons have a trapezoidal shape, with a base of 1200 mm and a height of 900 mm. The thrust of the arches is transferred to the foundation by concrete thrust blocks associated with the abutment. This system is based on fifteen boxes of 1.80 m in diameter anchored to the rock.

Once the central part of the structure - deck, arches and lines were assembled on temporary supports, temporary transfer beams were installed at the ends of the arches and connected by cables to balance the thrust. The temporary supports were then removed, arches loaded, and the structure was "slipped" on a system of rails supported by river booms.

Once this operation was complete; the ends of the arches were added, and the rail system was removed. The structure was then lowered on its thrust blocks, allowing the removal of the balancing cables and the transfer blocks.

THE PEACE BRIDGE



Project Team

Architect: Santiago Calatrava LLC

Structural Engineer: Santiago Calatrava LLC/Stantec Consulting Ltd.

Project Manager / General Contractor: Graham Infrastructure Ltd.

Erector: Norfab Mfg. (1993) Inc

The Peace Bridge spanning the Bow River in Calgary has become a favorite with photographers since it opened in May 2012.

Designed by world-renowned architect Santiago Calatrava, the stunning structure is a pedestrian/cyclist bridge that connects the vibrant neighborhoods of Sunnyside and Hillhurst to the city's downtown core.

It has become an instant icon of the city and has vitalized the surrounding neighborhoods.

It is crossed by about 6,000 people daily, including a growing number of people using alternative modes of transportation to their workplaces as well as recreational users. The bridge is a popular spot for photo shoots and has become one of the prime meeting points in Calgary.

The bridge structure is a sleek helix-shaped steel truss system developed over a semi-elliptical cross-section in a single span of 126 meters. The deck is eight meters wide to accommodate pedestrian lanes on either side and a central bike lane separated by curbs.

The location of the bridge presented a design challenge that made structural steel the ideal solution. The Bow River at that point is about 120 meters wide and six meters deep.

For environmental and safety reasons, an in-stream support pier was not an option. This meant the bridge would need to comprise a single 126-metre-long span.

The site is also beneath the flight path of Calgary's downtown heliport. Flight path restrictions, in combination with limitations due to the Bow River's 100-year flood levels, squeezed the allowed structural depth of the bridge to a maximum of only 5.85 meters.

Due to the challenging design criteria of a long span, wide bridge deck, and low structural depth, structural steel was chosen for its high strength-to-weight ratio.

The bridge structure is symmetrical along the center of the deck section, with the two identical halves connected at the top and bottom chords.

This symmetry and repetition in design elements allowed the bridge to be prefabricated in numerous manufacturing facilities and assembled in a single on-site shop.

BURGOYNE BRIDGE

Project Team

Fabricator: Walters Group/ Canam Group

Detailer: Walters Group/ Tenca Steel Detailing, Inc.

Erector: Walters Group

Engineer: Parsons Owner: Niagara Region

General Contractor: Pomerleau

Deck Contractor: Vixman Construction Ltd.

One of the main landmarks of the 1915 city of St. Catherine is now history. The Niagara Region and the City of St. Catherine wanted to replace the Burgoyne Bridge with an aesthetic structure that could be considered a signature, even emblematic work for the area, while respecting the heritage aspect of the site.

The Burgoyne Bridge is a vital link in the city of St. Catherine and since the structure was over 100 years old, it needed to be replaced with a new structure, with the restriction of having no disruption to traffic.

The original structure of the Burgoyne Bridge was a steel lattice girder and concrete deck located on the same foundations as the new structure on the west side.

The bridge is comprised of seven continuous bays with a total length of 380 meters including a 125-meter and 85-ton section long arch, spanning the Twelve Mile Creek and Highway 406.

The span of the arch consists of a simple lattice arch with two trapezoidal box girders projecting from each side and suspended steel cables on either side of the transverse floor beams.

The six spans of the approach, ranging in length from 20 to 44 meters, are made of two trapezoidal steel box girders covered with reinforced concrete decks. The superstructure is supported by large reinforced concrete pillars and reinforced by reinforced concrete foundations.

The constraints of the valley and existing roads being unconventional, lead to more challenges and creativity for the construction of this bridge. In addition, the superstructure was to be built without interruption of traffic on the existing bridge or the provincial highway passing underneath.

Moreover, the size of the beams and the limitations on the site prevented the use of a large crane under the bridge.

So, instead of erecting the structure in a conventional way, the progressive method of launching the beams was used pushing each of the beams all along what has already been built.

Completion of the installation of the first beam lasted 59 days throughout the winter. Once this span was in place, two traffic lanes were opened on the new structure and the old structure was removed, allowing the continuity of the circulation throughout the erection of the second span and the triangular arch.

The 32 beams were assembled sequentially where, two by two, the beams were bolted together, placed on the bearings supported by pillars.

Temporary steel towers supporting the structure of the arch during erection were put in place and then removed once the project was completed. The very well-organized erection was made during the night when the highway below was closed.

ALLUMETTES BRIDGE

Project Team

Structural Engineer: Delcan, a PARSONS Company & DPHV

Project Manager / General Contractor: Pomerleau

Fabricator: Canam-Ponts, division de Groupe Canam

Detailer: Tenca Steel Detailing Inc.

Erector: Montacier

This 280-meter long road bridge replaced the Allumettes Bridge over the Ottawa River main canal southeast of Pembroke, Ontario, connecting the province of Ontario and the city of L'Isle-aux-Eaux - Allumettes, in Quebec.

The structure, consisting of two box girders cut into 22 segments, comprises 1,880 tonnes of steel components. The complexity of this project is characterized by the high weight of box beams up to 91 tonnes and its tight schedule. The bridge was commissioned in August 2015.

The design of this structure over the Ottawa River presented several major challenges, including environmental constraints, the proximity of the existing bridge and the presence of a geological fault at the bridge.

During the design phase, the option to reduce the number of piles in relation to the existing bridge was chosen by the owner as this limited the environmental impacts of the project.

Optimization of the concept led to the choice of a variable-inertia steel caisson bridge, continuous over three spans, including a main span of 10 meters and two 85-meter bank spans.

Considering the location of the bridge and the tight construction schedule, a steel structure had the double advantage of being able to be quickly built in fabricator plants and then transported by truck for assembly during all year periods.

The use of beams with variable inertia, in addition to allowing the optimization of the use of the material, gave a slender and harmonious aspect to this large structure.

The presence of a geological fault at the right of the structure represented an important stake during the design.

As a result of multimodal modeling and seismic analysis of the bridge, caisson piles with rock socket were retained for the pile foundations. Seismic isolators were incorporated to reduce the impact of an earthquake on the structure.

In addition, special control measures had to be taken to ensure that the sockets of the caisson piles had the necessary length to withstand the forces while remaining in the sound rock zone, without encroaching on the shear zone of the fault characterized by a highly fractured rock.

The main beams were erected using a combination of conventional methods and atypical methods: the edge spans were erected from temporary piers, using mobile cranes and temporary piers, while the assembly the central section of 90 meters in length was made by jacking the two box beams simultaneously from a barge.

Since the structure is continuous, the beams had to be lifted about 1.3 meters to the abutments to achieve geometric compatibility allowing the bolting of construction joints.

The required erection method involved the use of a 400-metric-ton crawler crane, temporary supports, several jacks, and a 1.3-meter abutment lift to connect the splices in the center section.

The use of a steel frame was the large contributor to the success of the project, which was completed in less than 18 months, the main assembly of the structure was done in the heart of winter, thereby saving precious months, without stopping work.

Once the bridge was fabricated, the team entered a time trial race with the general contractor to complete the assembly before the spring breakup. Given the bathymetry conditions of the Ottawa River at this location, a temporary barge bridge was put in place, making assembly of the structure more complex.

To respect the schedule, it was decided in the preliminary draft not to fabricate the structure in a linear way as usual, but rather to manufacture the box girders according to the assembly order desired by the general contractor.

This required particular logistics during the fabrication of the components, which made it possible to deliver the beams in time. The design team was also forced to adapt to the singularity of this project by partitioning the shipment as soon as the drawings were approved to allow for a rapid production.

The weight of some beams reached more than 90 tons, exceeding the lifting capacity with the fabricator's plant, therefore Engineers were asked to find a solution for moving these parts.

The team of experts therefore set up a system consisting of hydraulic cylinders and rollers that made it possible to slide each of the boxes out of the factory without having to use the cranes. Beams were shipped to the site, as soon as the fabrication was complete, so as not to delay assembly.

Challenges were even more complex than anticipated, as some restrictions issued by the Department of Transport, such as height, weight, or certain traffic barriers due to construction, were not known at the outset. All challenges were met and the project was successfully completed.

Hunt Club Pathway Connection to the Southeast Transitway

Project Team

Structural Engineer: Delcan, A Parsons Company

Project Manager / General Contractor: Louis W. Bray Construction

Fabricator: Canam-Ponts, division de Groupe Canam

Detailer: Canam-Ponts, division de Groupe Canam

This 246-foot-long (75 meters) pedestrian bridge was erected over the Ottawa Airport Parkway to link the Hunt Club community and the Southeast Transitway in Ottawa, Ontario. The structure is a cable-stayed bridge with two asymmetrical spans, one of 170 feet (52 meters) in length and the other 76 feet (23 meters) in length. The deck is composed of three orthotropic steel deck panels. The bridge opened to pedestrians and cyclists in November 2014.

Initially, the bridge was not designed with a steel deck. Because of a weight issue, however, it was essential to lighten the superstructure. A lightweight, economically feasible and durable deck had to be developed and erected, within a very short timeframe.

With special collaboration from Parsons, an orthotropic steel deck proved to be the ideal solution. Such a deck can be up to two times lighter than a similar concrete deck and is designed for a service life of more than 75 years. It is manufactured and takes very little time to erect at the job site.

The fabrication of the orthotropic steel deck was entrusted to Canam-Bridges. It was a challenging project on several fronts. Special care had to be taken with fabrication methods, in-plant handling and welding sequences, given the dimensions of the three deck sections and their relative flexibility during the fabrication process. It was particularly important to control the deformations induced by welding operations of secondary elements to the top plate of the deck.

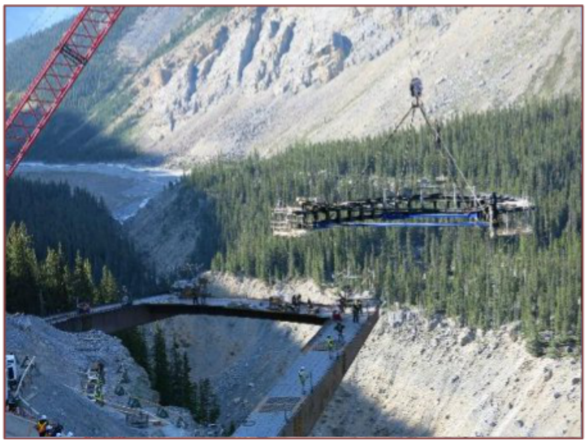
For the thin wearing surface, the use of Bimagrip, a highly resistant polyurethane-based product with an aggregate top layer, helped decrease the structure's overall weight and speed up on-site work. Because this type of wearing surface is installed at the fabrication plant, there is no need to wait until the panels are erected on site and then apply the surface course, therefore reducing the construction schedule.

Once the fabrication of the deck was completed, there was a challenge remaining: delivering 19-feet-wide (5.775 meters) deck sections. Transporting such wide loads requires coordination over the entire trip, and more specifically between the transport companies and various entities such as the Quebec's Ministry of Transportation, cities of Quebec City, Montréal and Ottawa, and the Ministry of Transportation in Ontario.

Efficient planning and excellent cooperation between the various actors made it possible to deliver the deck sections on time.

The orthotropic steel deck supplied by Canam-Bridges significantly reduced the weight of the structure and contributed to successful completion of the project. The decision to use a steel deck allowed addressing the various design and building challenges while meeting the extremely tight schedule of the project.[2]

GLACIER SKYWALK



Project Team

Fabricator: Beauce Atlas Steel Fabricators

Engineers: Read Jones Christoffersen Ltd.

In the fall of 2010, Brewster Travel Canada issued an Expression of Interest request for design build teams to create a new and exciting tourist attraction.

They wanted to create an experience that would attract people from around the world to Jasper National Park. "Gobsmacked" and "Visceral" were terms Brewster used to describe their expectations. The resulting Glacier Skywalk is a thrilling and dramatic structure featuring 30m of curved glass walkway extending 30m beyond the cliff face and suspended 280m above the Sunwapta River.

By cantilevering the structure, Read Jones Christoffersen Ltd., as design lead and structural engineer, was able to deliver the unique and exhilarating experience they wanted while blending the Skywalk in with the natural environment.

The Brewster company, which operates various tourist sites in the Rocky Mountains, began and started in 2012 the construction of this observation bridge whose half-moon end composed of a floor and glass railings allowing spectacular sighting on the Sunwapta River and the Athabasca parish priest.

This bridge is embedded on a cliff sidewall mounting on a slope of 280 meters and with a 45-meter cantilever.

Brewster engaged the services of the RJC Consulting Engineer located in Calgary to execute the structural plans and specifications. They chose a structure of steel caissons of variable geometry to support the half-moon-shaped glass bridge with a radius of 10 meters at the end of these caissons and attached to blocks of glass, with anchors weighing 10 imperial tons each at each end.

The overhang of the two box girders was 35 meters and 15 meters. The ratio of the dead weight of the steel versus its high resistance convinced the professionals to use steel as the material for this structure overhang which respected the allowed and anticipated deflections.

The box structure remained apparent "uncoated". The client opted for a finish showing the raw appearance of steel exposed to the elements and blending into the rocky landscape. The atmospheric steel was therefore chosen and retained for the execution of the caissons and secondary floor structure.

The constructability challenge was to not exceed the weight and size limits for transporting and erecting these parts. The contractor PCL awarded the contract to Constructions Beauce Atlas in June 2012 for the supply and delivery of the box girders, transverse beams and secondary beams.

This project located 4,200 km from the Beauce Atlas facilities in Ste-Marie of Beauce was in itself a challenge because of the distance separating the fabricator plant from the site and also because the assembly granted by the customer directly to a steel fitter included a logistics and a schedule set at quarter of tower that had to be respected because otherwise would have caused significant impacts.

Beauce-Atlas was very much involved in the design from the beginning of the project to ensure the feasibility of the project and find the best options for the fabrication, delivery and assembly of these parts.

The splices of the caissons were therefore established jointly in order to limit the weight. The longest box consisted of 4 sections including 2 weighing 70 tons imp. and the other 2 50 tons imp. They ranged in size from 26 to 50 feet by 12 feet tall and 10 feet wide. The shorter box consisted of 2 sections of 40 and 45 tons imp. with a length of 38 and 40 feet, a height of 9 feet and a width of 10 feet.

The splices were made of bolted plates however the first two caissons of the longest caisson deposited on the anchoring groups in tension and compression had to be welded in addition and due to the efforts too great.

This type of project required precision in shop drawings and in the fabrication to be identical to the bridge project intended. The preparation of the plans and shop drawings were prepared by Génifab in Quebec City, a company specializing in the design of bridges and special projects.

The fabrication was done at the Beauce Atlas Ste-Marie plant and part of the fabrication contract was subcontracted to Metacor in Terrebonne.

The limitation of the deformations during the welding of the caissons, the precision of the workpieces constituted the main challenge for the fabrication process. A pre-assembly of the elements had been done in the plant in order to ensure the conformity of all fabricated elements.

The project was erected in the summer of 2013 and completed in the fall of 2013. The access is closed during the winter and the project was therefore opened and inaugurated in May 2014.

It was a truly success right from the start. Great words of praise have been received by all members of the team. This project offers a publicized, public and touristic showcase of an accomplishment achieved through the availability and use of steel materials on the Canadian market.

The Craigflower Bridge

Project Team

Architect: Hughes Condon Marler Architects

Structural Engineer: Herold Engineering Limited

Project Manager / General Contractor: Don Mann Construction Limited

Fabricator: Surespan Structures Limited

Detailer: Exact Steel Detailing Limited

Erector: Ruskin Construction Limited

The Craigflower Bridge has been in operation since the early colonial days of Victoria, and this recent replacement is believed to be the fourth bridge on this site.

As part of the Hudson's Bay Company's historic Craigflower Farm, the bridge served as a transportation link between Craigflower School and Craigflower Manor, both National Historic Sites. The bridge site also has unique archaeological merit, encompassing three distinct periods and types of human habitation which span thousands of years.

Herold Engineering was selected as the Prime Consultant and bridge designers for the project for the Municipality of Saanich and the Town of View Royal who were dual owners of the bridge.

The 120-metre-long bridge replaces a very narrow and busy 80-year-old two-lane creosoted timber trestle bridge with a four-span structure using continuous Vierendeel steel trusses and a non-symmetric partial precast and composite cast-in-place concrete deck that varies from 20 m to 22 m.

Being in a semi-marine environment, it was desired that welded connections minimize the use of mouse-holes and other openings. Connections were therefore specified using a combination of CPJ and PJP weld methods.

Surespan was contracted by Ruskin Construction to supply & deliver Architectural arched steel trusses & half-depth concrete deck panels for the Craigflower bridge in Victoria, BC. The arched steel trusses were metallized to protect them from the elements and the process provides them with a lovely silvery/grey appearance. Surespan received an award from the CISC (Canadian Institute of Steel Construction) for the steel trusses.

Key challenges on the project were design, schedule, budget, traffic disruption on a very busy roadway, First Nations archeological constraints, a very environmentally sensitive marine crossing of the Gorge Waterway, and the maintaining of pedestrian access during construction, including access to both an adjacent elementary school and a secondary school.

Construction of the piers also required the relocation of existing oyster beds to adjacent areas.

DEH CHO BRIDGE PROJECT

Project Team

Structural Engineer: Sargent & Associates Engineering Ltd., Infinity Engineering Group Ltd.

Project Manager / General Contractor: Ruskin Construction Ltd.

Fabricator: Rapid-Span/Structal JV

Detailer: Tenca Steel Detailing

The $200 million bridge is the first built over the Mackenzie River, Canada's longest river, and is the largest bridge project undertaken in the Northwest Territories.

The bridge provides year-round service for cars and trucks along Highway 3, connecting Yellowknife in the Northwest Territories with Highway 1 in the South.

The remote location, severe winter conditions of up to -40 degrees Celsius and ambitious construction schedule, required new thinking regarding design and erection.

Ecological, lightweight bridge design principles and innovative design methods such as Assembly Line Design Approach, Failure Mechanism Concept and Fuse Design Philosophy were applied.

This led to 20% cost savings for steel and 30% for concrete. It also resulted in the world's longest continuous superstructure, with a length of 1045 meters and expansion joints only at the abutments.

This makes the Deh Cho Bridge one of the longest continuous superstructure in North America.

The bridge is symmetrically designed. The end spans are 90 m long, followed by three spans of 112.5 m each.

The main span bridges the navigation channel and spans 190 m. The Deh Cho Bridge superstructure is designed for two lanes of traffic. Accordingly, the width of the superstructure is relative small with only 11.29 m.

The superstructure depth of 4.75 m can be described as very slender when considering the main span of 190 m which corresponds to a span to depth ratio of 40.

The two A-pylons are around 33 m above top of the piers. Each pylon supports 12 locked-coil cables with a diameter of 100 mm.

Superstructure steel is about 3,500 tons or 3.5 tons per meter bridge length. Pylon steel is relatively small and accounts for only 256 tons for both A-pylons.

The Deh Cho Bridge deck is one of the thinnest in North America with an average thickness of only 235 mm. In total we used 2,775 m^3 or around 2.7 m^3 per meter bridge length. The construction cost exceeded slightly the 200 Mio. Dollar target line. This corresponds to approximately of 18,000 Dollar per square meter.

The panels act a single span structure spanning in transverse bridge direction. Later when the in-fills are cast we will achieve composite action with the truss floor beams.

This two-way structural system is much more efficient than the one-way single span system.

Steel as a material was an excellent choice for a bridge in harsh climate conditions and at a remote site location. The degree of prefabrication and quality control that you can achieve with steel products is just outstanding and unbeatable.

The symmetrical superstructure consists of two vertical Warren trusses connected by Chevron cross frames and wind braces at top and bottom chord levels.

The articulation scheme utilizes disk bearings at the piers and abutments. The bearings guide the superstructure in the transverse bridge direction but allow longitudinal movements due to temperature changes.

Two steel A-pylons located at the tallest piers flank the navigation channel located in the bridge centre. The eight piers of the bridge are founded on concrete spread footings which are cast into the Mackenzie River bed using cofferdams.

Classified as an Extradosed Bridge System, the "open" steel box girders have significant bending stiffness and are only locally reinforced with stays and "king posts." The Deh Cho Bridge has a very different structural behavior than similar looking cable-stayed bridges.

The superstructure design was optimized to maximize prefabrication and allow a fast-paced erection technique.

The top priorities were robustness, durability and the ease of inspection and maintenance. The goal was to achieve the highest returns on investment over the next 75 years of service.

The Deh Cho Bridge project is a lighthouse of the bridge engineering discipline.

It also provides evidence that modern progress in an industrialized society is possible in a responsible manner and in harmony with Canada's Aboriginal people and Mother Nature.

Sir Ambrose Shea Lift Bridge

Project Team

Fabricator:Canam Ponts-Divison de Groupe Canam
Engineer :Parsons
Detailer : Vet Dessin
Detailer : Les dessins de structure Tenca
Contractor : H.J. O'Connell Construction

On September 23, 2016, the new Sir Ambrose Shea Lift Bridge in Newfoundland and Labrador, opened to traffic.

Located on the Avalon Peninsula in the town of Placentia, approximately 100 km west by southwest of the capital city of St. John's, it was built as a replacement to an existing structure constructed in 1961 and As-built directly adjacent to the existing bridge.

In addition to being aesthetically pleasing with architecture reflecting the local culture and tourism potential of the region, the new bridge is designed to be durable, efficient and reliable.

The new bridge was constructed adjacent to the existing bridge to minimize disruption to navigation and road traffic. Some of the important design considerations for this new bridge were durability, efficiency and reliability.

The approximate cost of $47.7 million included construction, engineering and demolition and removal of the old bridge. The three-span bridge superstructure measures 93 meters in length and includes 1,100 tons of structural steel, including 10 girders for the approaches, and four box girders and stringers for the lift span.

The four-hollow structural tubular towers stand over 30.5 meters tall and measure 508mm wide by 25.4mm thick and they are comprised of a three-dimensional steel truss shaped representative of sails, and each tower component is connected by a three-dimensional exoskeleton truss housing the machinery operating the lift span.

Another welcoming feature was the 1.8m wide pedestrian sidewalk.

The bridge includes 9,200 meters of steel piling, 3,800 cubic meters of concrete and 150 tons of reinforcing steel. The three-span bridge includes a center movable span (vertical lift span) flanked by two simple fixed composite plate girder spans.

The functional requirements for this bridge were important considerations to the architectural features and appearance of the bridge, in view of the bridge's high visibility in the historic community of Placentia, the town's heritage, culture, and local environment and the importance of tourism to the local economy.

The new vertical lift bridge is comprised of three spans; a center 33m lift span, flanked by two 32m approach spans, accommodating two vehicle lanes with a sidewalk on each side. Under the lift span, the clear width of the navigation channel is 25m, with a minimum vertical clearance above high water of 3.05m when lowered and 21.34m when raised. The power and communication utilities were relocated from the existing bridge. To avoid affecting vehicular traffic and to improve alignment, the horizontal alignment of the new bridge is parallel to the existing with a 22m offset to the East.

The unique architectural features were inspired by the Salford Quays Vertical Lift Bridge in Manchester, England and include the two vertical towers on each side of the lift span. Envisioned to represent boat masts and antennas, these aesthetically sleek elements emphasize verticality.

Steel tubular members make up this bridge tower silhouette. The transparent machine rooms at the helm of the towers are captivating and attention drawing. To create a focal point of interest and visibility in a harmonious contract to the dark surrounding hills, sea and sky, the color choice for the main elements of the bridge superstructure was white; a safe environment and inviting pedestrian experience, with a wider sidewalk (1.8m) in comparison with a narrow 1.2m walkway on the existing bridge.

The structural steel was fabricated by Canam-Bridges and shipped from Quebec for erection, so its transportation, though challenging, was exceptionally handled by Canam-Bridges. The approximate 100-ton lift span, with some of the mechanical and electrical components of the permanent structure, was erected from a barge. The very complicated erection process required the shutting down of the marine channel.

Design had to consider transportation, erection, and long-term durability. This was achieved by designing the tower members with sealed and welded tubular pipe members. Flange bolted connections were designed to allow the contractor to fabricate the towers in manageable segments to be transported and handled on site without the need for field welding.

This option allowed the contractor to fabricate each of the towers in 10 segments, assemble them on site, and erect them using a crane from a temporary work trestle. Bolted connections minimized the erection duration of the towers significantly, to a few days in comparison to field welding which would have required substantially more time and a significant window of good weather, which is hard to achieve at this project site.

The design team was committed to making the most effective design choices when selecting members, details, and systems to ensure the durability of the structure. The due diligence process included the observation of the existing bridge's performance history, given its constant exposure to very harsh environmental conditions.

To ensure durability and optimal, constructability choices included:

- The use of sealed tubular structural sections;
- Opting for enclosures for mechanical machinery and components;
- Positioning of mechanical and electrical components in machine rooms 25m above the water level, to reduce the effect of salt spray and salty ocean water exposure;
- Using galvanized reinforcing rebars within the concrete elements;
- Minimizing expansion joints by using semi-integral abutment details at the approach spans;
- The selection of metallization for all structural steel components compounded with a top two-coat paint system as extended corrosion protection.

The framing system is comprised of two main longitudinal box girders with transverse floor beams in between supporting the deck. The lift beams are two box beams that support the longitudinal box girders at the ends of the lift span, which is designed to travel vertically 18.44m. They are used to lift the span during operation with the use of 32 -38mm diameter wire ropes. The ropes which are connected to a total of four counterweights, each weighing about 50 tons, are within the tower and are supported on 3.0m sheaves, to balance the lift span.

The contractor assembled the lift span, which was designed with optional splices, on a barge from shore, to move it into position. The center span was a major challenge because it involved shutting down the shipping lane for several days to allow the erection of a 100-ton span using strand jacks to lift it into position. he tight construction tolerances for the movable components and the small deflection requirements for the structural members supporting the mechanical equipment, were an added challenge. All stages of design and construction required extensive multi-disciplinary coordination.

Due to its location in the open surrounded by hills, the bridge was subject to high winds, changing tides, and fast current. These were critical factors considered in the design, to ensure structure stability at all stages of construction, which were also big contributors to limited on-site crane operations. Additional challenges were met since the tide at the bridge site changed direction three times a day and the current reached up to 8 knots.

The towers consist of a three-dimensional truss, shaped to mimic nautical lines. Components of each tower are connected by a three-dimensional exoskeleton truss which houses the enclosure for the machinery.

The tower structural members are comprised of closed circular hollow structural sections (HSS) 508mm in diameter for the main tower legs and varying from 168 to 273mm in diameter for the diagonal members. The tower design had to accommodate the counterweights, the counterweight and span guides as well as the access stairs.

The counterweights for the lift span were housed inside the towers and are comprised of built-up steel boxes filled with steel plates. The machine rooms are accessible using stairs located within the towers. An aerial view of one of the towers showing the machine rooms is stunning and an attractive feature of this bridge.

The abutment foundations are supported on30-324mm diameter friction pipe piles driven about 16.5m into the soils at the north abutment and 20m at the south abutment.

The abutment and pier piles are closed ended and filled with concrete for added stiffness.

At the piers, several pipe piles had to be driven open ended to account for the stiffening of the soil within the cofferdam from the pile driving operations. Access for the piers construction was facilitated by the construction of a temporary work bridge from shore.

The aesthetically pleasing bridge has become an iconic structure and an architectural landmark for the town of Placentia, an integral part of the local culture and an important part of the region's touristic hub, as a focal point in the community attracting visitors and new businesses to the area.

The use of steel enabled the designers to deliver a project that surpassed the imposed design requirements, providing the best sustain- able option for optimal net positive effect on social, economic, and environmental aspects.

CP RAIL BRIDGE AT OUTREMONT AVENUE WITHIN THE UNIVERSITY OF MONTREAL CAMPUS

Project Team

Fabricator: Central Welding & Iron Works
Engineer: Les Consultants SMi
Detailer: Genifab
Contractor: Roxboro Excavation

In 2013, the University of Montréal, a major university in the metropolitan area, started construction of its new campus, the MIL Campus, in Outremont, on the abandoned grounds of a former Canadian Pacific yard. However, before it could proceed with the work, it was necessary to open the site and move, from south to north, a double track of the old railway network.

The city wanted to implement an Architectural element and distinctive effort to obtain an unparalleled result.

This initiative required precision in many aspects, including from quality and from the point of view of work that would be accompanied by a lighting component.

These target points were to eventually take a simple and conventional railway bridge and turn it into a beautiful bridge project of uniqueness and grace that everyone would appreciate.

The first stage of the development involved the construction of a new railway bridge that would allow the urban and institutional development of the area. The railway bridge would span the new street between Durocher Avenue and the future extension of Outremont Avenue. A steel bridge with a span on concrete abutments was as always, the clear choice.

The choice of the type of the structure was made according to the following criteria:

- The boulevard below the viaduct must not have any obstacles between its traffic lanes, so the viaduct must not have a central pier, but rather favor a single longer span;
- Optimize as much as possible the lowering of the boulevard and minimize the elevation of the embankment;
- Respect a minimum clearance of 5m between the top of the boulevard and the underside of the viaduct;
- Promote a simplest construction-installation method.

After the analysis, the structure that best met the criteria was a TPG (Through-Plate Girder Bridge) and deck which was chosen as the future railway viaduct.

As for the design consideration, given the large dead loads of 630 tons and the presence of two railway design vehicles (Cooper E90), which would generate approximately 1520 tons, with high main beams having a height of 3650 mm and stiffened by a system of horizontal and vertical stiffeners. Knee-brace internal stiffeners were incorporated at each main beam location to support the top of the beam to support the ballast platform.

The viaduct, approximately 27.76 m long and 10.0 m wide, supports two railway tracks installed on a ballasted steel floor (rails fixed on wooden sleepers embedded in the ballast) so that this section on the viaduct reproduces the same track conditions as on the adjacent embankments.

The weight of rails, sleepers and ballast and loads from railway vehicles are transmitted to the steel floor system connected to transverse beams (spacers) close to 700 mm, which in turn are supported by two main beams. For both ends of the viaduct, the arrangement of the spacers, their dimensions and their connections have been adapted to take into account the particular load distribution due to the angle.

The ballast lanes provide considerable protection for the viaduct's steel floor system against damage from a potentially derailed car, as well as to the public traveling down the boulevard, from any ballast or other traffic-related material. railway or maintenance operations.

The firm of steel detailers Genifab, also participated in this project, they generated the 3D model of the steel structure with the details of the elements of the structure and they completed the drawings for the erection of the steel on the building site.

For maintenance and rail inspection purposes, two inspection bridges were added to the deck, one on each side. With the help and collaboration of the Architect, the designers replaced the guardrails of the walkways with two architectural balustrades. The viaduct is supported on two reinforced concrete abutments integrated into a set with the retaining walls and sidewalks along the boulevard.

SMi, the structural Engineers had partnered with Civiliti for the architectural and lighting component. This first collaboration with the Architects and designers of this Montreal firm has resulted in a resounding success for the new railway bridge by winning two awards at the 10th edition of the Grands Prix in Design. In designing a lighting system for both the railings and below the bridge, SMi engineers have attached paramount importance to both aspects of the lighting design, as well as to the safety elements.

The project, a real visual marvel, illustrates how simple utilitarian equipment can be transformed into an urban object that creates delight for passers-by. Focusing on the poetry and subtlety of lighting, the designers wanted to soften the disruptive effects of a site transformed in depth. The future Outremont site project of the University of Montréal goes well beyond the limits of university activity. It embraces urban collective life by providing a new living environment that will serve both the interests of the university community and those of the residents of the surrounding neighborhoods[3].

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CISC Quebec Region Manager

ENGINEERING FOR DEVELOPMENT IN THE AMERICAS

Bridges to Prosperity's History in Latin America and the Caribbean

Alissa Smith
Director of Business Development
Bridges to Prosperity

Alan Kreisa
Director of Engineering
Bridges to Prosperity

Many of us in the developed world cross bridges every day – on our way to work, to school, to town centers. We walk over them, we drive across them, and we bike by them.

Easy, reliable access is something we take for granted, lamenting when construction or closures impede us or reroute us.

For nearly 1 billion people around the world, however, a lack of access to essential services is a daily reality. In the remote, rural farmlands of countries like Bolivia, Nicaragua, or Peru, residents are isolated from health clinics, schools, markets, jobs, and government services for days, sometimes months, at a time.

Heavy rains swell rivers, and what once was a slowly-moving stream that could be crossed on foot becomes a swift, impassable torrent. For the families who live in these remote communities, a bridge can mean not only life or death, but educational opportunity, critical access to healthcare, and economic prosperity.

Bridges to Prosperity is a nonprofit organization that works with local governments and communities to connect the rural last mile around the world. Over our seventeen-year history, we've honed our cable-stayed bridge designs and refined our technologies and construction process for the rural environment, and are the only organization solely focused on transportation infrastructure as an effective and efficient tool for development. We are committed to beautiful, functional design, and driven by transformative connection.

Figure 1: School children crossing a river during the dry season in Panama

Figure 2: A young man crosses the Rio Abajo suspension bridge in Nicaragua

Bridges to Prosperity began work in the Americas in 2006, with the construction of three bridges in Peru that would serve 4,500 people, connecting them to schools, clinics, hospitals, and markets. Since those first three bridges, we've served more than 400,000 rural residents in nine countries in Central and South America and the Caribbean through the construction of nearly 200 footbridges. As we've sophisticated as an organization and designed for new and ever-more technically-challenging conditions, we've constructed bridges at longer spans, in more remote areas, and with tighter timelines. What follows is an exploration of a sampling of projects to be constructed this year in the region.

Figure 3: The Bridges to Prosperity team works on scaffolding at the San Vicente suspension bridge site

San Vicente, Nicaragua – 67-Meter Suspension Bridge

13°26'06.0"N 85°47'01.7"W

Over the last three years, the communities surrounding the Gusanera River at the key San Vicente crossing point have seen three injuries and three lives lost as a result of the dangerous crossing.

During the rainy season in Nicaragua, the river will flood for, on average, eight days at a time, and when it becomes too dangerous to cross on foot or horseback, the community is cut off from essential services, including the market, hospital, and both the primary and secondary schools.

This means that the 1,200 children in those communities lose valuable class time, impacting their learning and, ultimately, their opportunity to thrive. This rainy season lasts months, meaning the river is uncrossable for nearly 90 days out of every year.

The community worked to construct a dirt road to approach the crossing, and continued to maintain it in the hopes that a bridge would be built. The 67-meter suspension footbridge that the Bridges to Prosperity team in Nicaragua worked alongside them to build spans the river at the community's key crossing point, and means not only saved lives but a hope fulfilled, and the chance for community members to elevate themselves and their families out of poverty.

Figure 4: San Vicente community members cross with livestock prior to bridge construction

Figure 5: The San Vicente community crosses their newly-completed bridge

Banacito, Panama – 106-Meter Suspension Bridge

8°48'28.4"N 80°20'24.0"W

The Toabre River is an impassable obstacle for the residents of the Banacito community for nine months or more each year.

For the remaining three months, it is only crossable by boat or on horseback, and the next nearest crossing point if one is on foot is a two-hour walk downstream.

The Toabre River flows directly to the Caribbean Sea, and is a vital vein in Panama's Cocle region, but intense rains and drastic flooding make it equally dangerous for residents of surrounding communities.

More than 300 subsistence farmers and their families live in Banacito, and send their children to a secondary school on the opposite side of the river.

Because the river is so dangerous to cross, many students remain on the side of the river with the secondary school for weeks at a time, only seeing their families on weekends, when they have time to wait for the height of the river to drop enough to make an attempt to cross.

The hospital is also found across the river, as is the market and key government services, meaning that emergency medical situations are very rarely addressed by a doctor and farmers focus their efforts on rice and yucca, which is less likely to spoil if they're unable to make it to market within the week.

The 106-meter long suspension bridge that will provide year-round access to the Banacito community is currently under construction.

Given the community's relative isolation and Panama's long rainy season, the Bridges to Prosperity team had to work quickly to ensure that trucks delivering materials to site were able to access the riverbank.

The community constructed flat "barge" type boats out of wood to transport materials, such as cement, gravel, and tools, across the river, and the local canoe boat operator has made, on average, six to eight trips across the river each day in support of the construction team.

Construction is slated to be completed in June 2018.

Figure 7: Members of the Banacito community cross the river by boat (pre-bridge construction)

Figure 8: Members of the Banacito community feed the construction team

Duraznal, Bolivia – 54-Meter Suspended Bridge

20°25'08.6"S 64°24'31.9"W

110 families, including 50 children, live in the community of Hoyada in the Azurduy district of Bolivia. They are primarily farmers, raising corn, oranges, peaches, chili peppers, and peanuts, or tending cattle.

Over the last three years, two community members have lost their lives attempting to cross the San Antonio River, which swells during the rainy season.

During periods of heavy flooding, 550 people are cut off from the primary school and a health clinic in Duraznal, and the market in Azurduy (already a three-hour walk).

This is often the case between the months of December and April, meaning that members of the community are forced to make decisions about what crops to plant, when to send their children to school, and the availability of healthcare based on the possibility that they won't be able to reach these critical services for nearly half of the year.

Last year, the Bridges to Prosperity team in Bolivia partnered with the Municipality of Azurduy and the local community to construct a 54-meter suspended bridge that provides year-round access, guaranteeing a safe path for farmers and their families. Construction of both the sub- and super-structure took three months, and the bridge was inaugurated and opened for use in December of 2017.

Figure 6: *The newly-completed Duraznal suspended bridge, ready for inauguration*

SAN VICENTE BRIDGE

DRAWINGS IN PDF HERE

BANACITO BRIDGE

DRAWINGS IN PDF HERE

DURAZNAL BRIDGE

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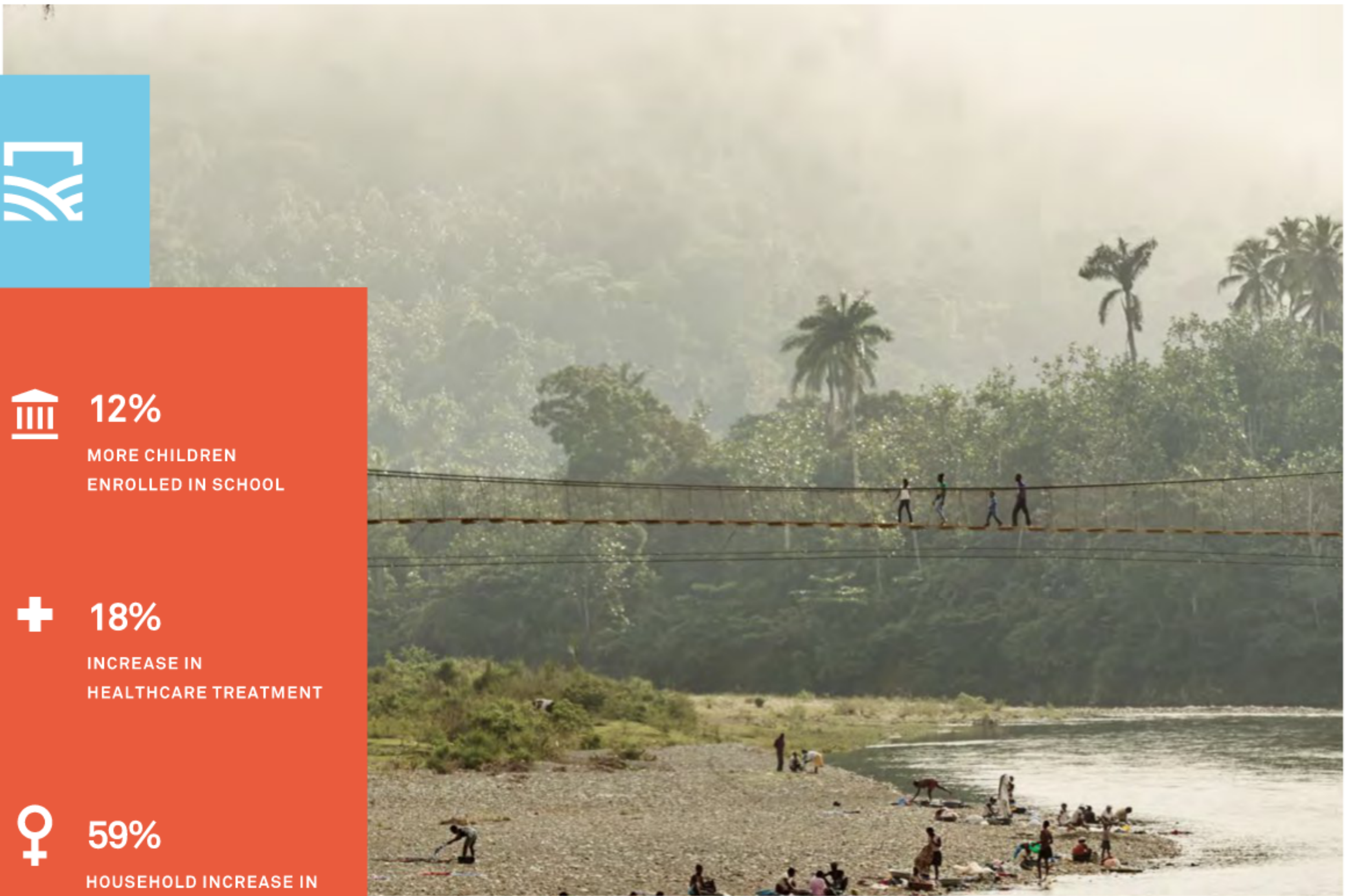

12%
MORE CHILDREN ENROLLED IN SCHOOL

18%
INCREASE IN HEALTHCARE TREATMENT

59%
HOUSEHOLD INCREASE IN WOMEN ENTERING LABOR FORCE

30%
INCREASE IN LABOR MARKET INCOME

Bridges to Prosperity

Bridges to Prosperity envisions a world where poverty caused by rural isolation no longer exists.

Our programs provide access to healthcare, education, and markets by teaching communities how to build footbridges over impassable rivers, in partnership with organizations and professionals. We prove the value of our work through a commitment to the community and its bridge that lasts long after the opening celebration.

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Vessels and Equipment for Bridge Construction

Vessels Used for Bridge Construction.

Technical overview of vessels and equipment used on major bridge structures

Hans Tompot, Naval Architect

Vessels for Osman Gazi Bridge, Turkey

Vessels for Substructure Construction: Initial and final launching of the caissons and their submerging: *Erdal Ergül*
Vessels and Maritime Equipment Used For Contruction of Osmangazi Bridge - Superstructure*: Fatih Zeybek*

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Richard Cooke on Bridges.

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Your articles, ideas and contributions are welcome!

Please contact us to discuss more details. Thank you.

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American Bridges

Anthony Wayne Bridge