e-mosty

ISSUE 02 / JUNE 2017

SUSPENSION BRIDGES

OSMAN GAZI BRIDGE, TURKEY

HÅLOGALAND BRIDGE
NORWAY

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Richard Cooke, David Collings and Ken Wheeler

Thank you for reviews of the articles, valuable comments and for all your assistance all the time

Dear Readers

*This issue of our magazine **e-mosty: Suspension Bridges** will take you on a trip through a life of a suspension bridge. First you can read how a bridge is being born - **The Hålogaland Bridge** in Norway is currently under construction with planned completion in 2018.*

*Then you can read about care which is devoted to the **Osman Gazi Bridge** in Turkey – the fourth longest suspension bridge in the world which is now celebrating its first year in operation.*

*And finally you can learn about rehabilitation and maintenance of older **suspension bridges in the USA** where also first dehumidification of main cables was carried out within the Chesapeake Bay Bridge Project.*

I very much thank to all people involved in preparation of this issue for their contribution, excellent cooperation and assistance.

*I have the honour to welcome **two new members of our Editorial Board:***

***Ms Derya Thompson**, Director of Complex Bridges and Structures at Jacobs, USA*

and

***Mr Ken Wheeler**, Industry Director, Engineering Structures, Australia.*

Ken has 40 years' experience in the successful delivery of major bridge projects in Australia, South East Asia, Central and North America. This experience includes design management, concept development, detailed design and documentation, construction engineering, temporary works design, site supervision and undertaking technical reviews, with particular emphasis in design and construct projects.

I am very happy they accepted our invitation and I hope our cooperation will bring a lot of good things to our magazine and at the same time I also hope they will enjoy it.

*We have become a medial partner of **Bridges to Prosperity**. We will promote their activities, bring you articles, videos, photos. I am very glad we can do it and I wish all people involved in this project a lot of success in their admirable effort.*

Magdaléna Sobotková

Chief Editor

And a few words about our magazine.....

We are an international, interactive and peer-reviewed magazine about bridges. I established it two years ago as a Czech – English magazine with the main aim to bring information about bridges worldwide to Czech bridge engineers. To my surprise the magazine very soon crossed the borders and last year in spring after we released March Issue: Asian Bridges we got readers from the whole world. Their number was fast increasing and this led, together with starting cooperation with Mr David Collings and Mr Richard Cooke, to a decision that the magazine will be published solely in English. Its Czech title remains as our readers have got used to it, e-mosty means "e-bridges", and I think that the logo can be easily remembered.

Our aim is to bring original articles about bridges worldwide, mostly technical, educational, informative and descriptive, and to utilise the most of the fact that the magazine is electronic – we can publish also drawings, photos, videos, links etc. The magazine will be released quarterly as it is now, and we will still keep it open access on our homepage www.e-mosty.cz.

Now, after two years, with an increasing number of readers, authors and also members of our editorial board, and a lot of challenging plans for the future I would like to ask you for cooperation. What can you do for us?

Partners

I do my best to keep the magazine open access, with the content educational rather than commercial and avalanched by advertisements. I believe that financing of the magazine may be provided by partners / supporters. You can help me find partners / supporters and/or become our partner yourself.

What can you do for it?

- Share the magazine if you like it
- Forward it to a person responsible for PR / Marketing
- Contact us on info@professional-english.cz

Your direct financial contribution

I have noticed that especially in IT and "creative" word the system of "Donations" perfectly works. If you like their software, game, film, song, you can easily donate, usually via PayPal. From this it was only a step to my idea to start with a concept of "Voluntary Subscription".

You can find a button "DONATE" on our web www.e-mosty.cz. If you like our magazine, please support us. The amount of your financial contribution is solely at your discretion and we very much thank you in advance.

New web

I have tried to get somebody who will be able to redesign our homepage www.e-mosty.cz. Generally it looks good, but some of its features are useless (repetitive publication of the same issues, the archive in Czech, wrong order of planned issues etc.) Unfortunately, I have failed to find a reliable and suitable person. A lot of promises and a waste of time and money and it has not moved anywhere.

I kindly ask you – if you know about somebody reliable willing and capable of redesigning / programming the web which now runs on wordpress template and needs only a few improvements, please let me know. Thank you.

e-mosty

PARTNERS AND SUPPORT WELCOME

I would like to offer you partnership with our magazine „e-mosty“ (e-bridges).

Information about the magazine can be found at **www.e-mosty.cz** and previous issues can be viewed in the archive section of the website.

Since May 2015 when the magazine was established we have achieved especially the following:

- Established the Editorial Board
- Released 7 issues (typically 4 per year)
- Achieved an international profile with increasing numbers of readers (over 1000 already) with positive reviews and feedback.

„e-mosty“ magazine is unique and covers a big part of the construction market.

The magazine is **open access** and we would like to keep to this policy.

BECOME OUR PARTNER

→ Support our magazine and show it worldwide

→ Promote your company

→ Help us with magazine production expenses

We offer you two types of partnership:

- Sponsorship of one issue (eg where your company participated in the construction of a bridge we are writing about), or
- General partnership of the magazine

In both cases we offer you advertisements, PR articles, your logo in every issue and on our web and other promotion. The price is negotiable, the magazine is low-cost and every support is welcome.

We are looking forward to possible future cooperation with you and your company.

www.e-mosty.cz

HÅLOGALAND BRIDGE NORWAY

Magdaléna Sobotková

Video: Statens vegvesen

Commencement of works: 2013

Opening of the bridge to traffic: 2018

Type of the bridge: Suspension Road Bridge

Main span: 1,145m

Total length: 1,533m

Location: Narvik, Norway

Client:: Statens vegvesen
(Norwegian Public Roads Administration)

Architect: DISSING+WEITLING architecture

Design: COWI, Johs. Holt and the Norwegian Geotechnical Institute

Contractors: Sichuan Road & Bridge Group (SRBG) for the steelwork (deck and cables) and NCC for the concrete

HÅLOGALAND BRIDGE

THE DESIGN AND THE CONSTRUCTION

Photo Credit: Pål Jakobsen

1. INTRODUCTION

The Halogaland suspension bridge crosses the Rombak fjord near Narvik in the northern part of Norway.

It will be part of the European Route E6 highway. With its main span of 1,145m it will be one of the longest bridges in Europe. Having transversely inclined cable planes it will become the world´s longest bridge with a spatial cable system; its main cable curves to form an oval in the horizontal plane with the hangers slightly inclined in the vertical plane.

Figures 1 + 2: Location of the bridge in Norway
Source: Google Maps

Facts about the bridge

- The two suspension cables that hold up the main span of the bridge have a diameter of 475mm in the main span, whereas the main cable diameter of the southern back span and northern back span are greater at 484mm and 492mm, respectively
- The main cable is 1,761 m long.
- The navigation clearance in the Rombak fjord will be 40m x 200m (width x height).
- The bridge deck of the 1,145m long main span is an 18.6m wide steel box girder. The bridge deck on the back spans (Viaducts) comprises a 15.4m wide concrete girder with cantilevered flanges.
- The bridge deck width allows for a 9.5m wide dual lane roadway and a 3.5m wide combined walkway and bicycle path.
- The speed limit will be 80 kph.

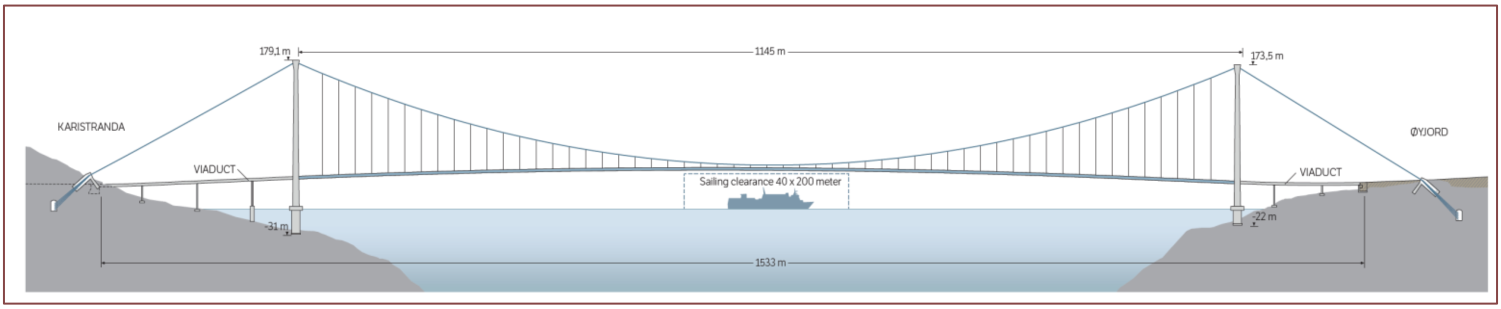
2. THE DESIGN

2.1 General Conditions

The fjords in Norway are surrounded by high and steep coasts. They are also very deep. The traffic is relatively low so the bridge carries just a single traffic lane in each direction and 3.5m wide walkway.

The viaducts, towers and anchorages for main cables are concrete. The bridge is constructed using 35,000m^3 of concrete.

The main span steel box girder is 18.6m wide. Concrete viaducts are 15.4m wide, with 5 piers 12 to 30m tall. The Viaduct from Karistranda is 244m and the viaduct from Øyjord is 152m.



Viaduct Karistranda
Viaduct span: 57–67–67–53 m

Viaduct Øyjord
Span 49-58-45 m

Figure 3: Elevation

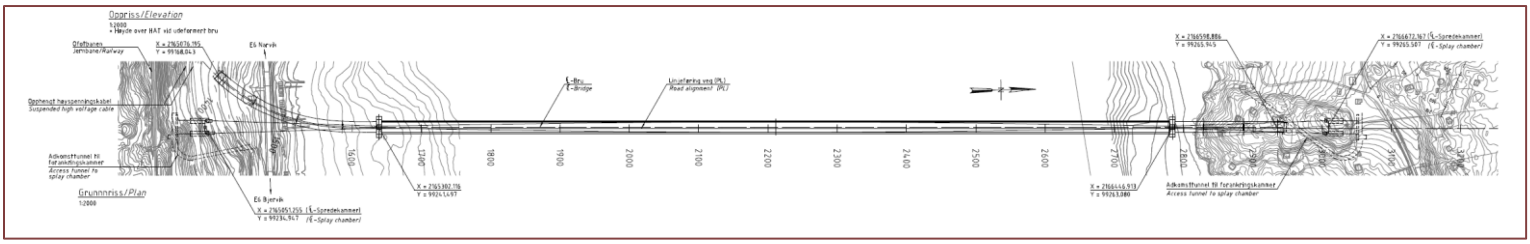


Figure 4: Plan

2.2 Towers

The towers are concrete A-frames. For a bridge with more lanes, the “A” would be very wide and the foundations would be very large – but this design is ideal for a narrow structure. An H-shaped pylon might appear too slender, given the tall height and narrow width needed; and a central pylon is impractical for a two-lane road.

Both towers stand the same height above the deck, though the uneven road and terrain levels on either side result in that one is 172.7m tall and the other is 167.1m.

The tower design determined the layout of the rest of the structure, especially the spatial arrangement of the cables and hangers. The two main cables meet at saddles on a narrow support on the top of the towers, splaying out at the centre of the bridge. As a result, the hangers are slightly inclined.

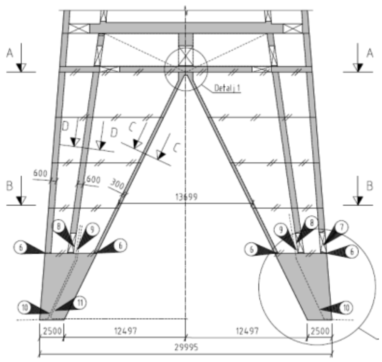
Each tower is topped with a “tower house”. It provides extra protection to the cable and the saddles. It is also an architectural feature, its internal lighting will be the only strictly non-functional feature on the bridge.

Tower Karistranda

Bottom caisson at -31.0m
Top concrete in tower + 172.7m
Top tower house +179.1m
Total height 210m

Tower Øyjord

Bottom caisson -22.0m
Top concrete + 167.1m
Top tower house +173.5m
Total height 195.5 m



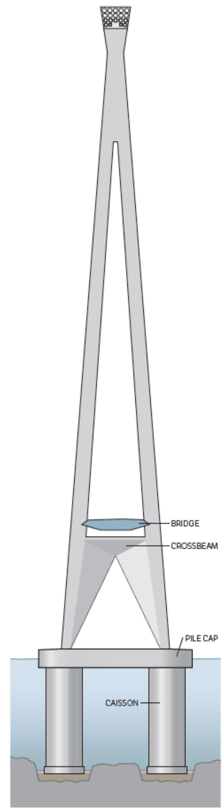


Figure 5 ↑: Tower rendering

Figure 6 ←: Tower leg

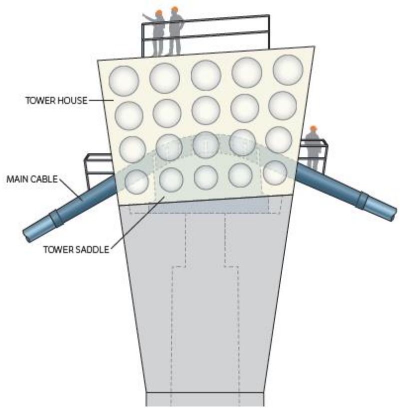


Figure 7: Tower House

Figure 8: Rendering of the Tower House
Source: DISSING+WEITLING architecture

2.3 Cable Structures

The cable structures comprise the main cables, the hangers, the tower saddles, splay saddles and the cable strand arrangement, and fixation in the anchorage chambers.

The spatial system set some extra challenges to the design of cable structures. The traditional longitudinal-horizontal-vertical reference system was less appropriate for the transversely inclined cable plane analysis and calculations.

Bespoke structural details were developed to suit the design such as positioning of tower saddles based on the spatial main cable geometry, main cable alignment across splay saddles, and special cable anchorage systems.

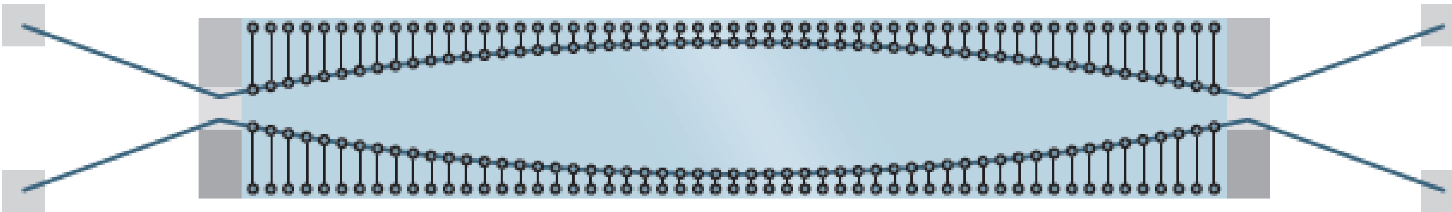


Figure 9: Top view of cable system with main cables and hangers. Main cable separation at mid span = 15.658m; at tower top = 3.000m and at northern anchor chambers = 18.500m

2.4 Main Cable

The main cable in the main span has a diameter of 475mm. In order to resolve the horizontal forces, there are extra cables in both southern and northern spans due to the steeper angle, and they are anchored into the tower saddle. The back stays are also relatively steep because the OFOT railway line is crossing close to the bridge axis on the Karistranda side.

The final geometry of the main cable is governed by the loads acting on the cable, i. e. loads from deck transferred through the hangers and the dead load of the main cable. As the load from the hangers is inclined, and the dead load is a gravity load it is impossible to obtain a perfect plane with the hangers. The angle between hangers and the vertical varies from 2.8° to 4.8°. A perfect plane would only be possible with a "weightless" cable.

Due to vertical curvature of the road the intersection line between the cable plane and the deck plane should be curved to be on a perfect plane.

In order to secure a simple construction of the lower anchorages in the deck, the distance between the lower anchorage points and the centre of the bridge is kept equidistant. Thereby the plane created is deviating slightly from the perfect plane.

2.5 Tower Saddles

The saddles are placed on concrete plinths on the top of the towers. Their positioning is based on geometrical vectors in a 3-dimensional space - contrary to conventional tower saddles based on plane geometry - therefore the tower saddle construction supports the cables similarly to conventional saddles in regular suspension bridges and the saddle has no out of plane forces for permanent loads. The transverse shear is transferred between the bottom of the plinth and the top of the tower.

Despite spatial geometry in the cable system all four saddles are made identical to simplify manufacture.

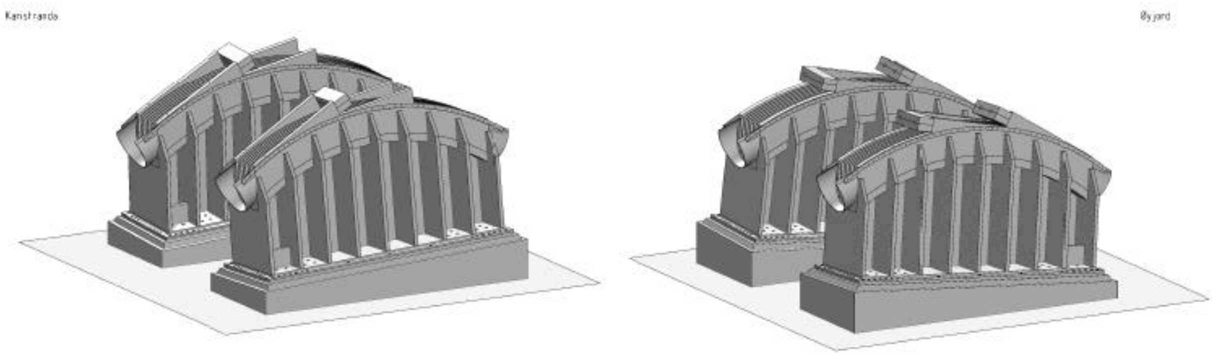


Figure 10: Tower Saddles

2.6 Splay Saddles

The splay saddles are designed to steer the spatial main cable into a simpler 2-dimensional layout at the anchorage chambers. This is done to simplify the anchorage chamber layout by avoiding "rotated" strand shoe geometry. The strands are divided in the saddle by a tailor made fill block which deviates the strands to their respective cable anchorage points.

2.7 Anchorage

The cable anchorage consists of splay chamber and anchorage hall which is a mountain hall 40m long and 15m high. It is the same for both splay chambers. The main cables pass over a splay saddle and are attached to an anchor block which in turn is attached to a tension cable.

There are 20 tension cables grouted to a casing which is bored 30m through rock to the anchorage hall. In the anchorage hall, there is a concrete slab that is 2.5m thick, 37m long, and 13m tall, where the tension cables for the two main cables are anchored; altogether 42 at Karistranda and 44 at Øyjord.

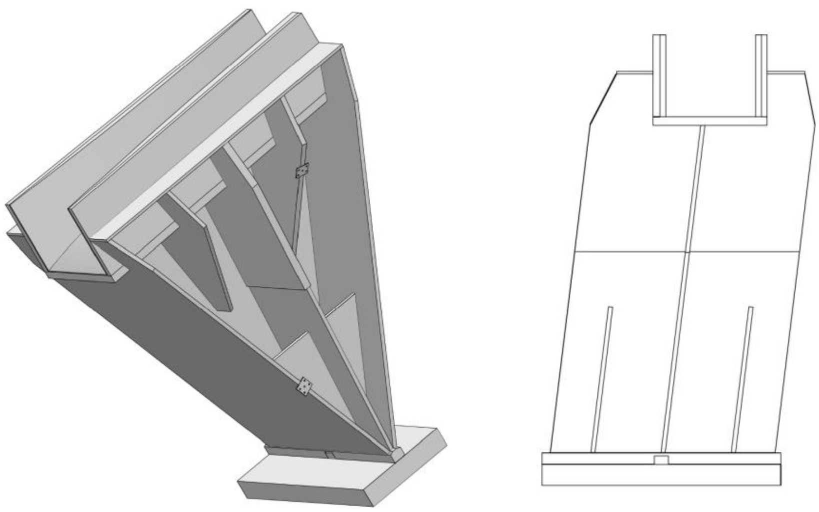


Figure 11 ← ↑: Splay saddle

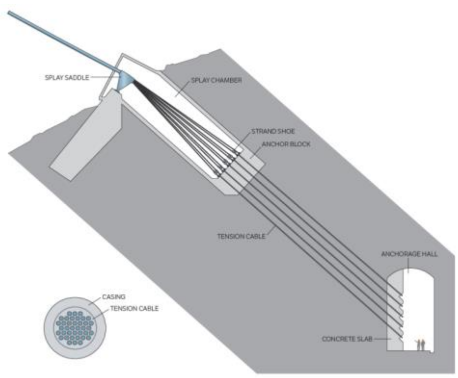


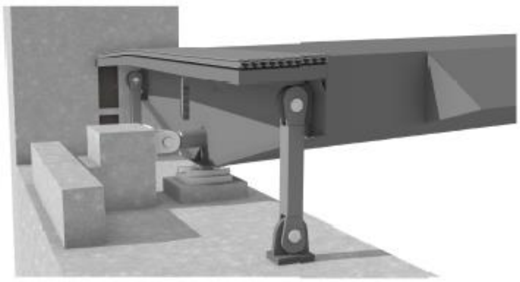
Figure 12: Cable anchorage with the section of a tension cable

2.8 The Deck

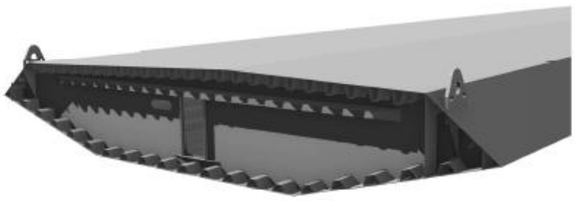
The bridge deck of the main span is an 18.6m wide steel box girder. Its shape is designed to minimize the effects of wind load and eliminate vibration problems due to vortex shedding.

The viaducts are supported directly on piers, the bridge girder in the main span is carried by the inclined hangers.

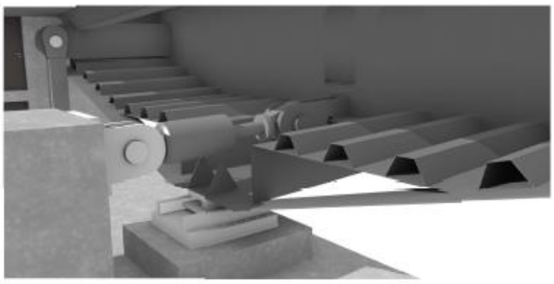
The total weight of the deck is kept to absolute minimum – the bridge girder including non-structural components such as roadway surfacing and crash barriers is 9.3 tonnes/m, of which the structural steel is 6.2 tonnes/m. The self-weight represents a large part of the total design load.



Bridge deck at tower



Diaphragm
with lower hanger anchorage



Bridge deck at tower, detail

End diaphragm

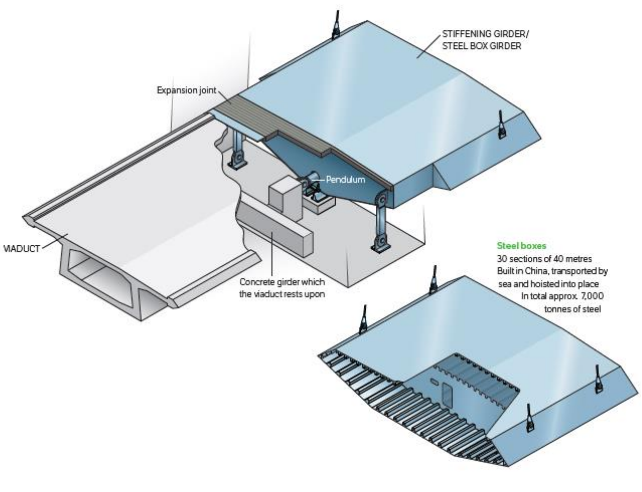


Figure 13: Deck composition

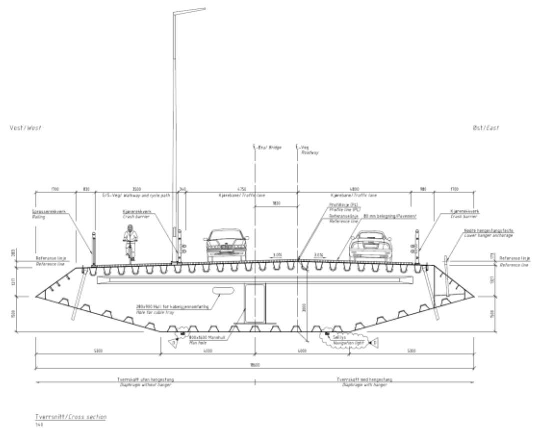


Figure 14: Deck section - main span

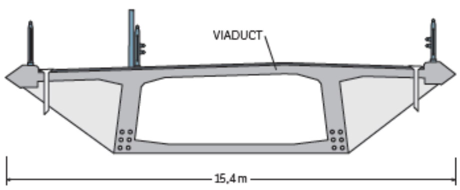


Figure 15: Deck section - viaduct

2.9 Aerodynamic Stability

Aerodynamic stability was extensively checked, including numerical analysis and wind tunnel testing. The bridge has a ratio of 1:9 span length to tower height above the deck. Its ratio of span length to the distance between the cables is 90 while typical values for suspension bridges are in the range 55-60.

This combination of a slender bridge with a long main span posed considerable design challenges in order to fulfil the requirements of ensuring aerodynamic stability at a wind speed of 63.1m/s at the bridge deck level. The deck and the inclination of the bottom plate were optimised to meet such requirements - the bridge box section is arranged with a slope of 15.8° of the lower inclined side plates relative to the horizontal bottom plate.

The numerical analyses and wind tunnel test showed a critical wind speed of 61 m/s. Wind tunnel tests carried out in smooth flow proved that there will be no vortex-induced vibrations, which saves potential costs for installing and maintaining any mitigation measures.

3. CONSTRUCTION

3.1 Tower Foundations

The towers are founded on rock at -31 and -22 metres below sea level.

Four caissons, with a 10m diameter, were manufactured. These caissons were filled with stone material as ballast. The caissons were produced by slip form casting. It was the first time that slip forming of caissons was permitted by the Norwegian Public Roads Administration. Slip forming is a construction method whereby concrete is cast in layers in a slip form that is raised at regular intervals. For production of the caissons a total of 3m of the foundation was cast and then lowered into the water every day.

In the tidal zone two caissons were linked by a pile cap up to 5m thick, a little more than 42m long and almost 16m wide.

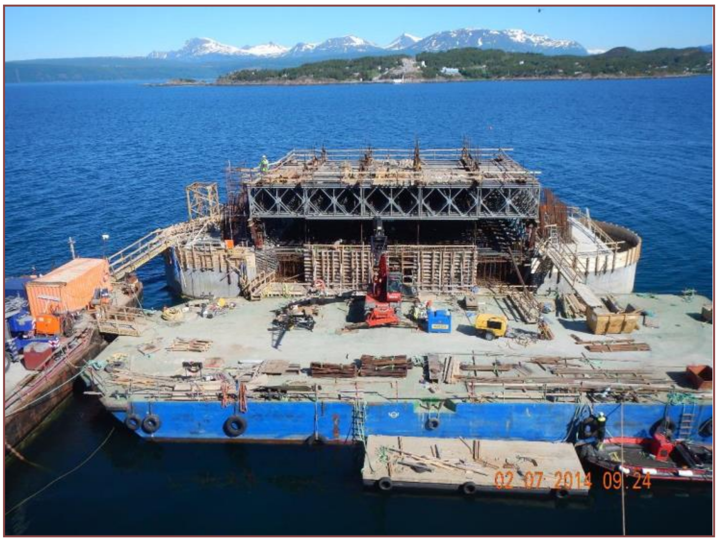
The caissons were placed at a depth of about 30m onto blasted bedrock on the seabed which was levelled by concrete.

3.2 The Towers

The A-shaped bridge towers are built in concrete. Climbing formwork was used from the caissons up to the height of the viaducts. Above this height the slip forming method was used.

After the pile cap was cast and cured, a climbing formwork was rigged and the bottom part of the tower columns was cast, in five stages. Just below the roadway the tower columns were connected by a crossbeam.

When the crossbeam was finished, further casting was done by slip form casting up to the connection at the top of the tower. The tower top was cast using conventional formwork. Inside the bridge towers, there is a lift in the one tower column and stairs in the other.

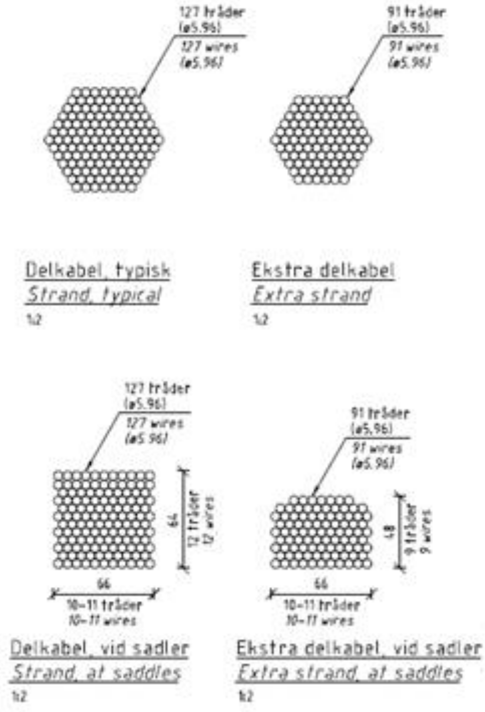


Figures 16 + 17: Caisson foundations

3.3 Cable system installation

3.3.1 Main Cables

The two main cables have a diameter of 475mm in the main span; 484mm at Karistranda and 492mm at Øyjord back span. Main cables are made up of 40 wire strands, each consisting of 127 steel wires each with 5.96mm diameter, additional back span cable strands consisting of 91 wires with 5.96mm diameter, with 2 additional strands on the Karistranda side and 4 additional strands on the Øyjord side. There are a total of 18,300 km of steel wires. Each cable weighs 2,010 tonnes.



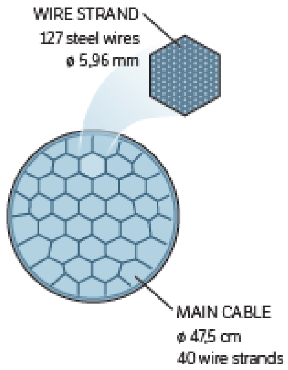


Figure 18 ↑: Main cable strands and additional back span strand

Figure 19 ←: Main cable and strand section

The A-shape of the towers influences how the cable system is installed. To obtain the correct shape, a special construction sequence is required allowing the two main cables to hang vertically during installation.

The splay saddles and the tower top saddles were mounted.

Temporary constructions such as tower top platforms, portal frames and the working platform (catwalk) were installed. The catwalk was designed as three separate catwalks (not as continuous system), and it was designed to follow the shape of the main cable during the construction period.

Main cables are made from PPWS (Prefabricated parallel wire strands). The strands were fabricated in the factory, with a socket at each end, cut-to-length, coiled to drums, and then transported to the site. Approximate weight of one drum with strand was 54 tonnes.

The two main cables were formed by pulling the strands from Øyjord side to Karistranda side, using the hauling system.

Video: Strand pulling over the saddle

Pulling of the strands was done symmetrically (one strand from the eastern side, then one strand from the western side of bridge). Adjustment of the strands length was also done during this time. The extra back strands leading from tower to anchorage were anchored at the tower saddle, see the picture 21 below.

After all strands were pulled and adjusted the compacting of the cables was performed.

This pressed all strand wires closer together and formed the oval shape of the cable. The void ratio (space between wires) of the cables was around 20%. This was done using the hydraulic compacting machines.
The cables were then fitted with clamps, to which the hangers are attached.

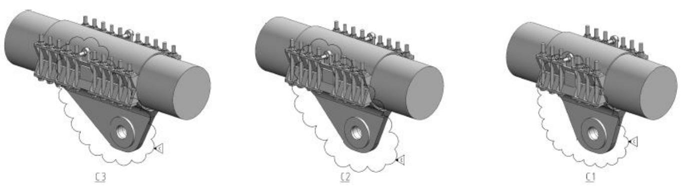


Figure 20: Cable clamps

It was followed by installation of the hangers (vertical cables), on which the box girder will be attached. The hangers are also made from steel wires in the form of locked coil cable with three layers of z-shaped galvanised locked wires. The hangers are protected by 7mm HDPE sheathing.

On both ends of the hanger there is a cast socket. The upper socket is attached to the cable clamp and the lower one is attached to the bridge deck. The hangers were also fabricated in workshop and then transported to the site.

In the first four stages of construction (installation of strands, compacting, installation of cable clamps and installation of hangers) cables were parallel to each other.

After the installation of the hangers, the cables were separated laterally from each other to form the final shape according to the design. The lateral shifting was done using the shifting beams and hydraulic jacks. At this stage, the main span´s catwalk was separated into two parts.

Then the cable bundle was wrapped with a soft galvanised wire to maintain its shape. Even though the strands were tightly compressed, the cable still contained around 20% air. The cables will be dehumidified by injection of dry air.

Figure 21: Anchorage of back strands at the tower saddle

Figure 22: Compacting of the main cable

3.4 The Deck

The stiffening girder is a steel box and constitutes the actual bridge deck in the suspension span. This is constructed as a closed steel box with trapezium-shaped stiffening trusses and transverse bulkheads in 30 segments. All boxes are 18.6m wide, comprising: 27 segments are 40m long, 2 segments are 19.2m long and 1 segment is 23m long.

They will be transported to the site using a ship with boxes placed on top of each other (see Drawing in the magazine on page 23 "Stowage plan of transportation vessel").

They will be lifted directly from the ship by floating crane to their final position and attached to the suspension hangers, which are attached to the main cable at 20-metre intervals. The middle section will be installed first, and further installations will be made symmetrically from the middle.

After all 30 segments are lifted to correct position they will be welded together.

The steel boxes are dehumidified inside by dry air being blown through them. A transport vehicle with room for two people is installed inside the steel box, for future inspections and maintenance.

3.5 The Viaducts

The length of the concrete viaducts is 244m and 152m. On the Karistranda side, the viaduct was constructed by using a specially manufactured movable casting carriage. It was almost 120 m long and weighed 800 tons. The casting carriage stretched across the E6 expressway all the way to the first pylon. The viaduct on the Øyjord side was constructed at ground level and lifted into place.

Figures 23 +24: Steel deck segments prefabrication in a workshop

References:

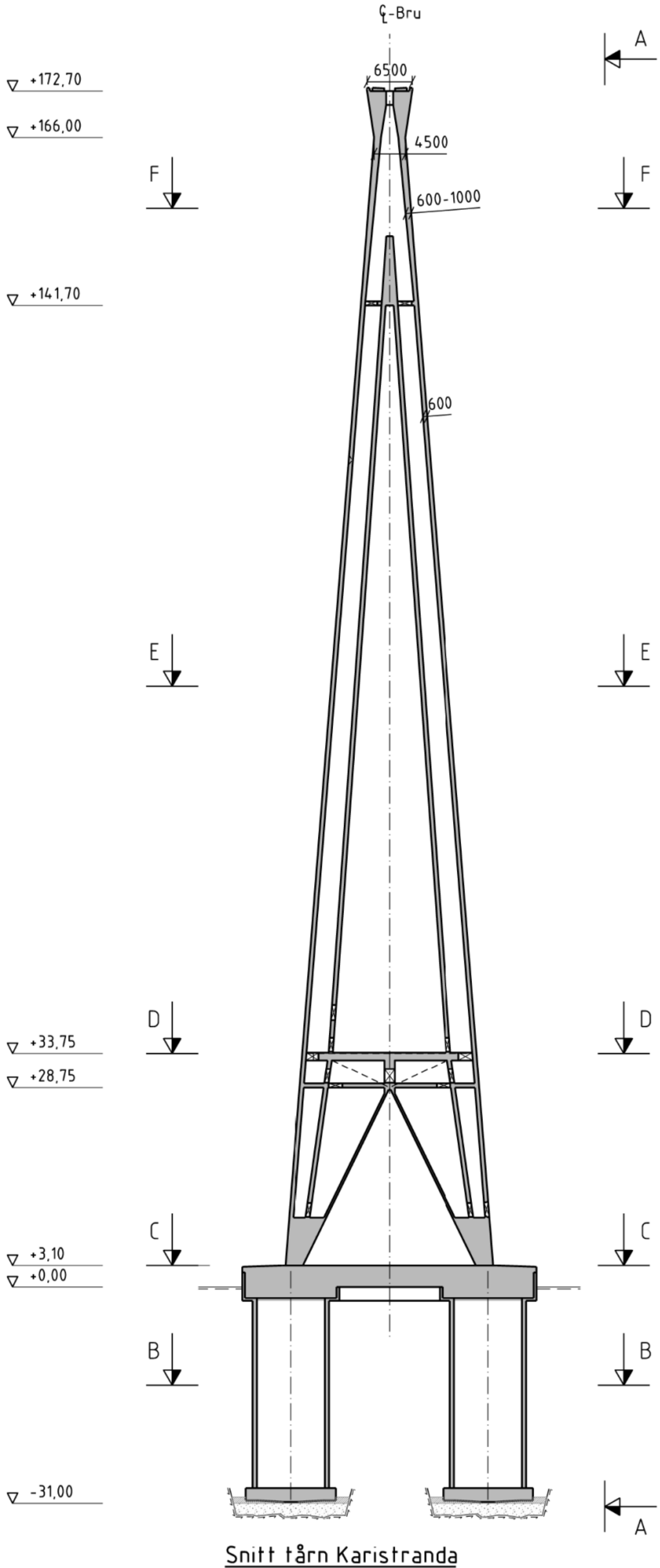
FORSBERG, Torben – PIHL, Jesper: Hålogaland Bridge Cable Structures. 35th Annual Symposium of IABSE / 52nd Annual Symposium of IASS / 6th International Conference on Space Structures, London, September 2011

NCC Group

https://www.ncc.group/our-projects/halogaland-bridge/

Statens Vegvesen, www.vegvesen.no

http://www.vegvesen.no/Europaveg/e6halogalandsbrua/Nyhetsarkiv/e6-h%C3%A5logalandsbrua-ferdig-%C3%A5-trekke-b%C3%A6rekablene



Snitt tårn Karistranda

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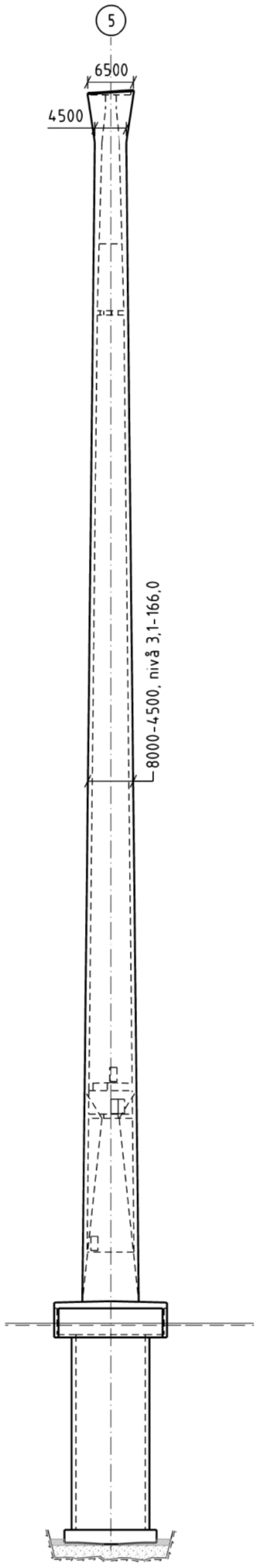

Oppriss A-A

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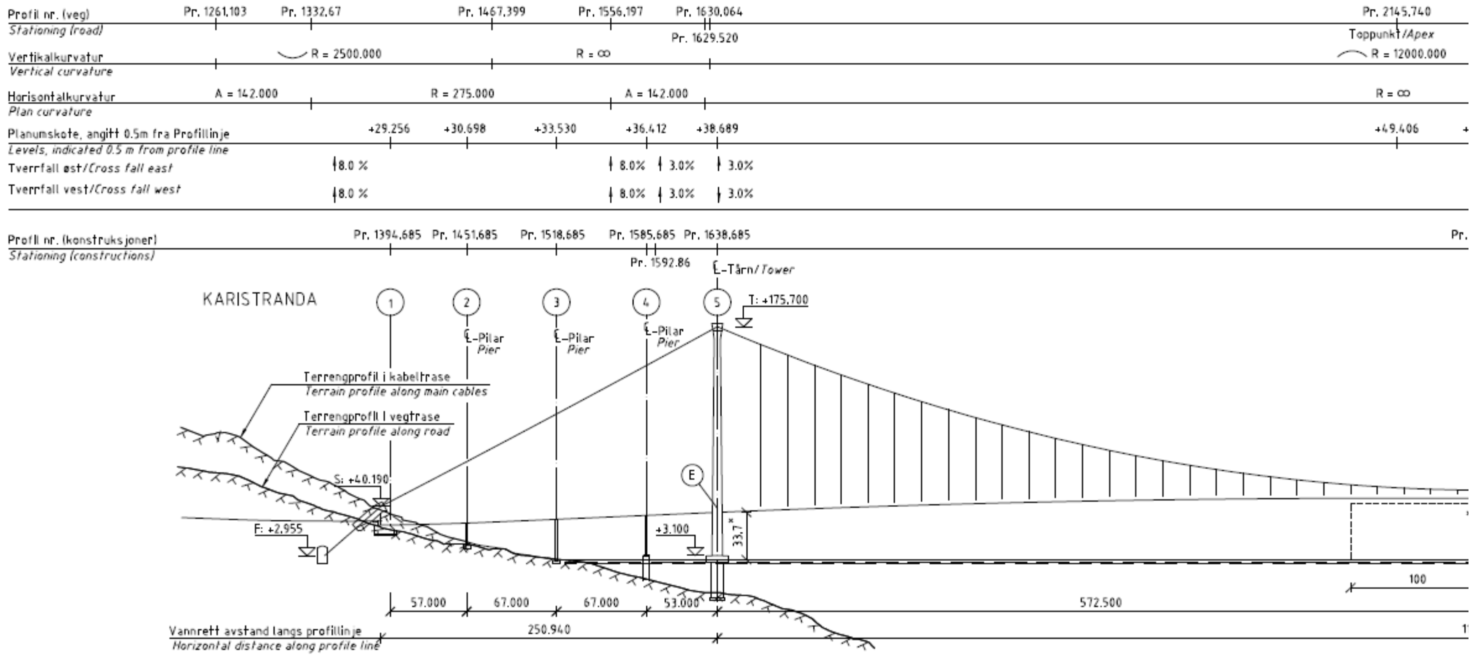
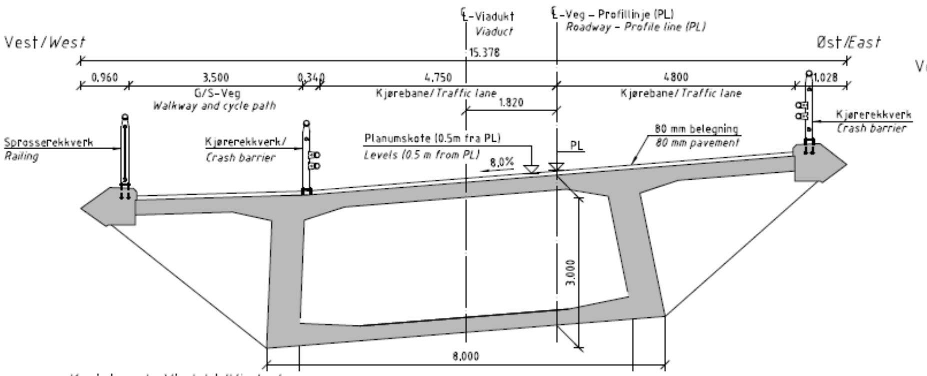


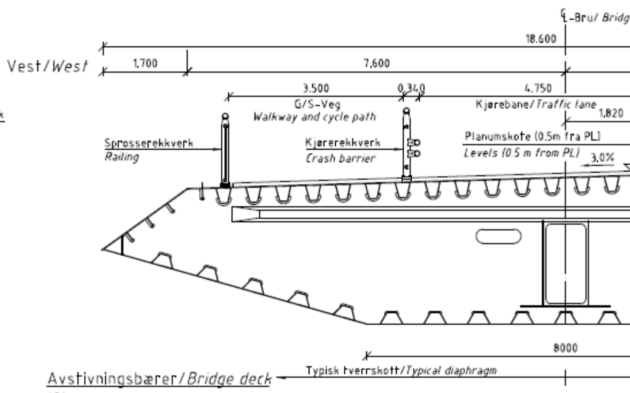
Oppriss/*Elevation*

1:2000
× Høyde over HAT vid udeformert bru



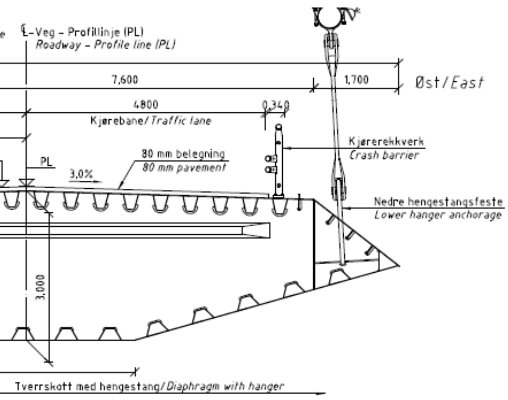
Karistranda Viadukt/*Viaduct*

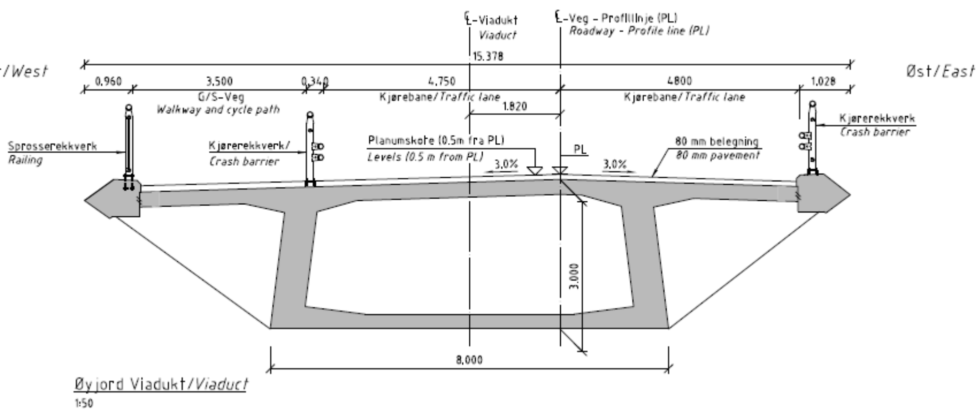
1:50



Avstivningsbærer/*Bridge deck*

1:50





Øyjord Viadukt/*Viaduct*
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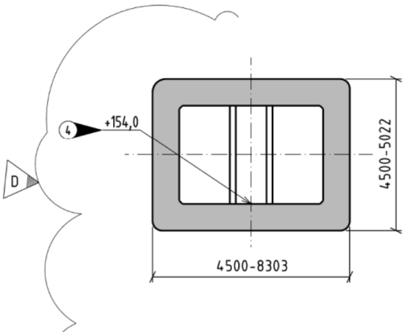
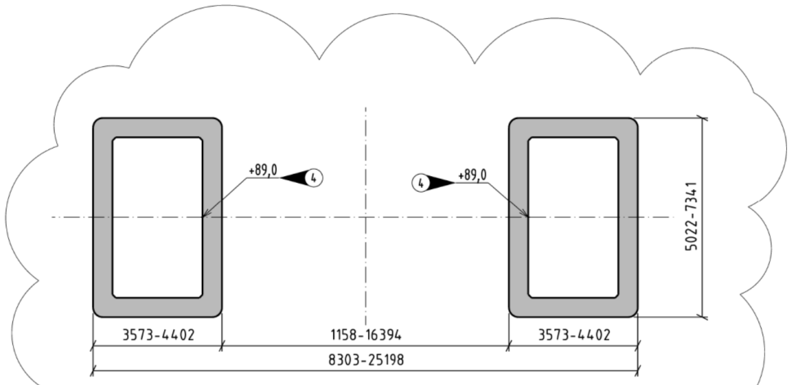


Snitt F-F
1:100
(∇+141,7-∇+166,0)



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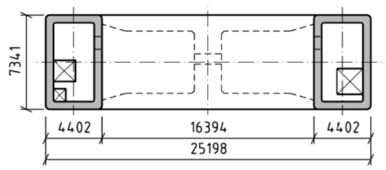
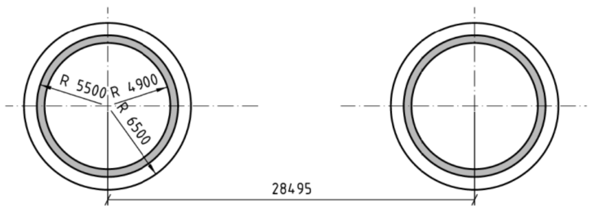
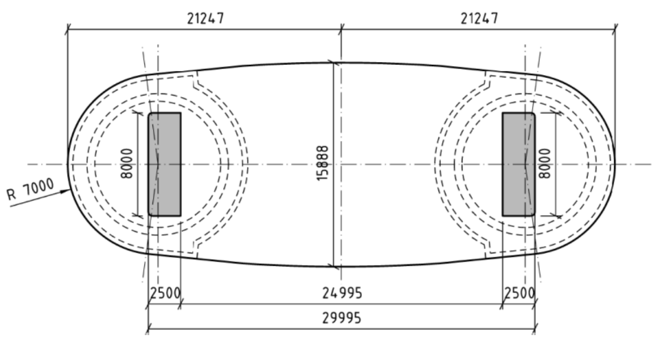


Snitt D-D
1:250

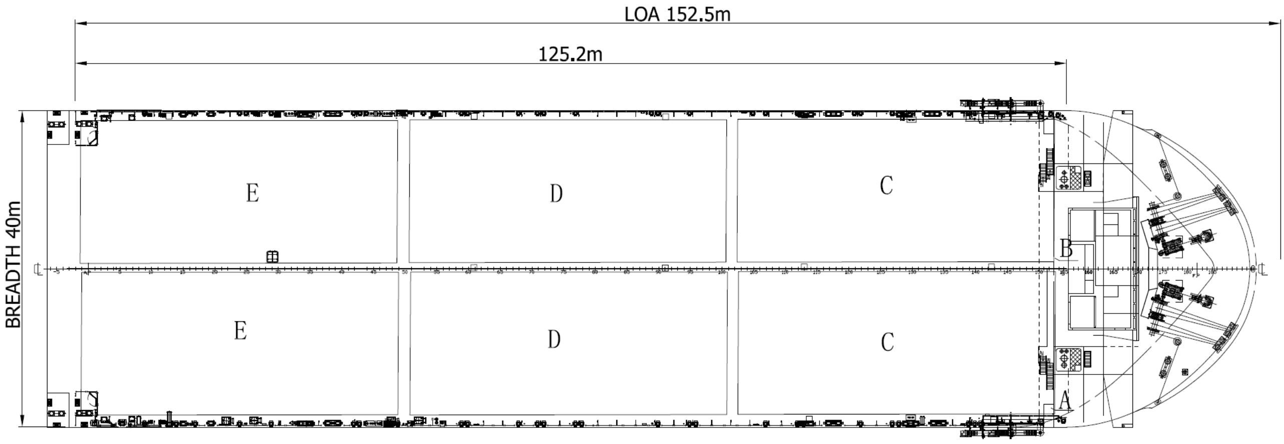


Snitt B-B
1:250

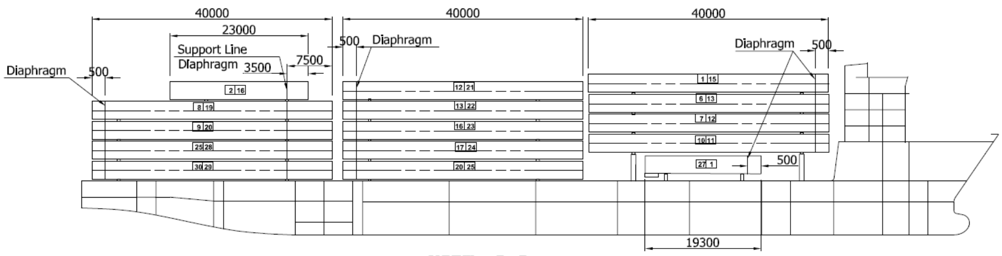


Snitt C-C
1:250

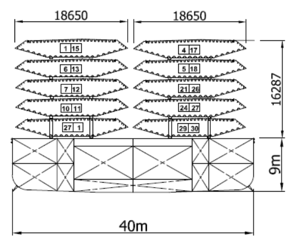
The Stowage Plan of Transportation Vessel



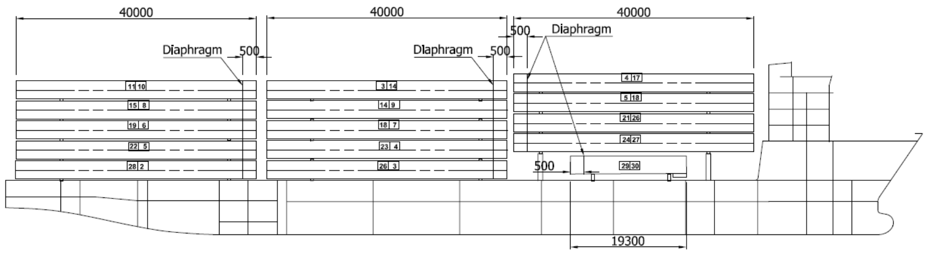
INSTAL (LIFTING) SEQUENCE	NO. OF BRIDGE SEGMENT



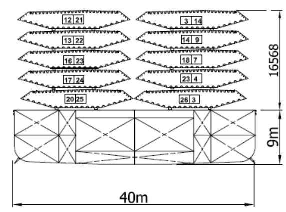
VIEW B-B



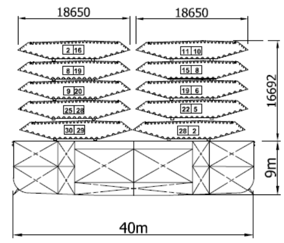
VIEW C-C



VIEW A-A

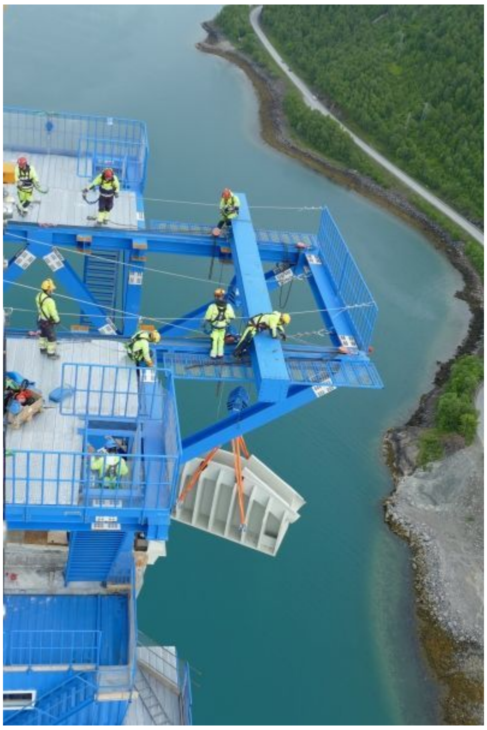


VIEW D-D



VIEW E-E

PHOTO GALLERY



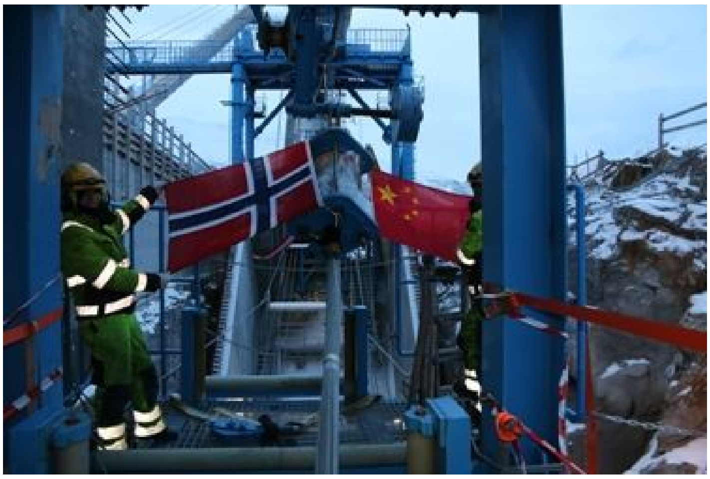














Photo Credit:

pages 24, 25 and 28: T. R. Pedersen, SRBG

pages 26 and 27: Mrs Shi, SRBG

OSMAN GAZI BRIDGE
ONE YEAR IN OPERATION

Fatih Zeybek, Director of Maintenance
OTOYOL YATIRIM ve İŞLETME A.Ş

Figure 1: Osmangazi Bridge and Approach Viaducts viewed from the North shore of Izmit Bay

1. INTRODUCTION

Osmangazi Bridge is the fourth longest span suspension bridge in the world with it's 1550 meter main span. The bridge and the first phase of the motorway were opened to traffic on 30th June, 2016.

The bridge is part of a Build-Operate-Transfer scheme including the build and operation of the adjacent 420 km motorway stretching from the outskirts of Istanbul, the largest city of Turkey to Izmir. Construction of the whole motorway project is financed by loans obtained by the Concessionaire (Otoyol Yatırım ve İşletme A.Ş.) from 12 banks.

Otoyol A.Ş. has subcontracted the operation and maintenance of the bridge and the complete motorway for a period of 22 years to a dedicated company GIIB (Gebze Izmir İşletme ve Bakım). The routine maintenance of the bridge will be done by the Operator GIIB and the heavy repairs by the Concessionaire based on the recommendations of the Bridge EPC Contractor. The bridge was built using a FIDIC Silver Book Engineer, Procure, Construct (EPC) contract.

The maintenance activities are prepared based on the Osmangazi Bridge maintenance strategy for the 100 year Design Service Life, which was one of the essential parameters of the detailed design of bridge.

2. LOCATION AND IMPORTANCE OF BRIDGE CROSSING

There are two options to pass the Izmit Bay. The first one is around the bay which is about 90 km and the other one is using the Eskihisar-Topçular ferry which is a few kilometres west of the bridge site.

Under normal conditions it takes about 1 hour and 20 minutes using either option. However it takes only six minutes to pass through Osmangazi Bridge Crossing.

Figure 2: Sketch of location of Osmangazi Bridge and road around Izmit bay

3. OPERATION OF BRIDGE

Toll collection, toll check, traffic safety, ITS (Intelligent Transport System), traffic management, de-icing & snow clearance, cleaning and controlled access of Osmangazi Bridge traffic is operated and maintained by each relevant department of GIIB within the whole Gebze-Orhangazi-Izmir motorway system.

Osmangazi Bridge is one of the iconic structures of Turkey and is already a strategic part of the transport system as well as being an economic asset. It is essential to ensure it is available for use at all times and is safe for all users. Therefore a number of protective security measures are taken by the Turkish Government in addition to the design and operation actions taken by the Concessionaire.

Figures 3+4: Toll gates and toll collection operation building of motorway at km:10+200 at the South End of the Bridge

Figure 5: Lane closure by GIIB traffic safety department

Figure 6: Lane closure and snow clearance by GIIB traffic safety department

4. SOCIAL RESPONSIBILITY

An exhibition center comprising plans, drawings, photographs and models of the construction of Osmangazi Bridge has been established by the Concessionaire. It is the first bridge museum in Turkey with free admission from the public service area named Oksijen3 at the 3rd km of the motorway.

Figure 7: Osmangazi Bridge exhibition center at service area km:3+500

5. INSPECTION AND MAINTENANCE STRATEGY OF GIIB

The majority of older long span suspension bridges are in the United States whereas the more recent ones are being constructed in the Far East and Europe. Turkey is the one of the countries where the latest and innovative long span suspension bridges are being constructed.

Inspection and Maintenance (O&M) strategy of GIIB (Gebze Izmir İşletme ve Bakım) uses in-house facilities for concentrated routine inspections and outsourcing facilities in case of specialised principal inspections.

The O&M activities through the regular inspections, periodic and specific maintenance will allow GIIB to have a safe and fully operational bridge and to maximise the life of the bridge elements and essential equipment.

The maintenance manuals and yearly planning include instructions for inspections and keep the Osmangazi Bridge in a conditon so that it can achieve the specified design service life in an optimal manner taking into account the following:

- Availability (bridge is kept open for users and traffic disruptions are minimal)
- Costs (minimal operation and maintenance cost)
- Safety (the Bridge shall be safe for users and O&M personnel)

- Environment (the environment interacting the Bridge shall be protected) and
- Aesthetics (the standard of appearance shall be acceptable and comply with the intentions of the design).

5.1 Scope of Inspections

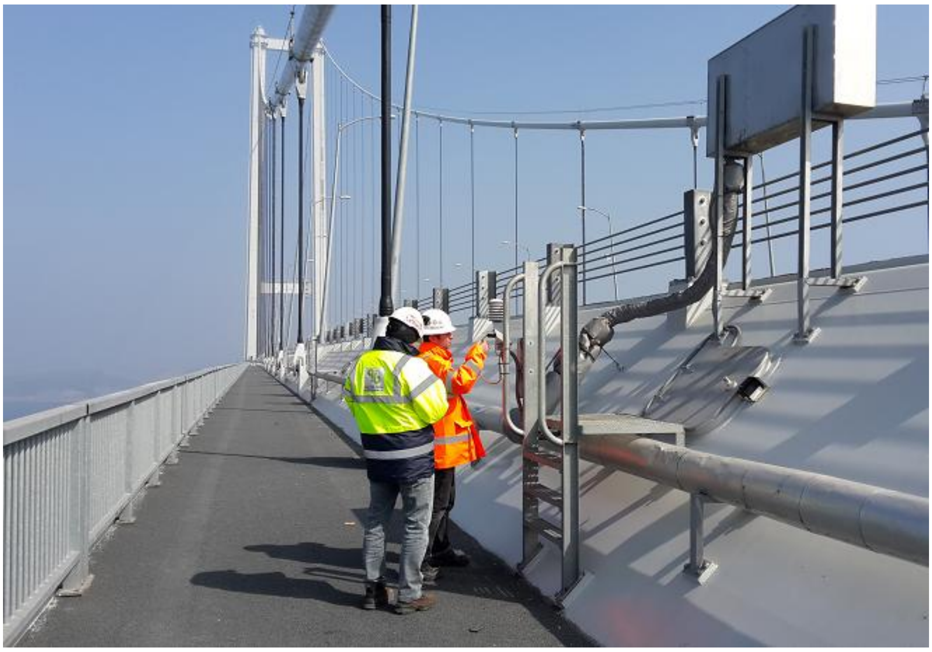
An Inspection programme has been established to fulfill the requirements of the maintenance strategy. The data from the SHMS (Structural Health Monitoring System), SCADA (Supervisory Control and Data Acquisition) system and other sub-control systems (such as the dehumidifation system) are used to make assessment and optimize the required maintenance and comprise of following:

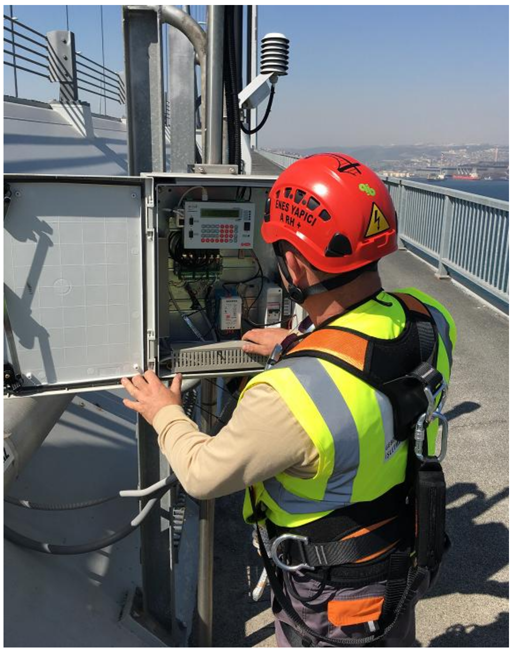
- Visual inspection (routine, maintenance and principal inspections)
- Testing on site, destructive and non-destructive methods (maintenance and special inspections)
- Monitoring systems (SHMS, SCADA, sub control systems of e.g. dehumidification, light etc.).

5.2 Routine Inspection and Maintenance

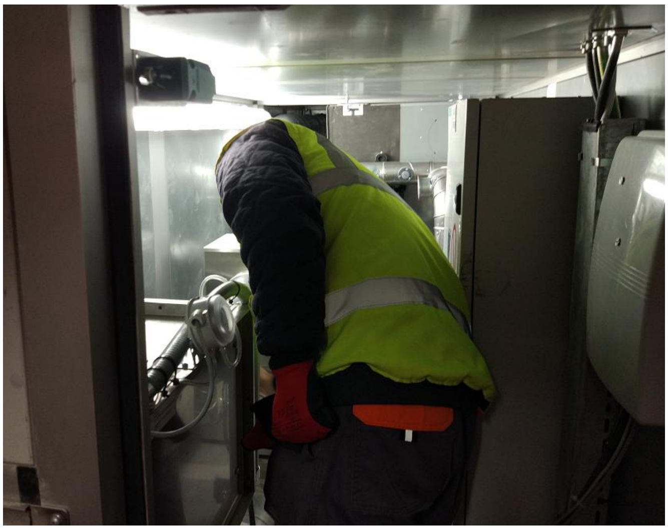
Routine inspection comprises a defined programme for continuous, on a routine basis, inspection of the state of the bridge, so that the bridge continues to be safe, functional, fully operational and structurally safe under traffic. Routine inspections also shows GIIB if there is any need for further inspections or maintenance before the deterioration of any bridge element.

Figure 8: Routine inspection of accumulator of deck gantry man lift





Figures 9 +10: Routine inspection along inspection walkway



Figures 11 + 12: Routine inspection of dehumidification pipes at South Anchorage Block Back Chamber East

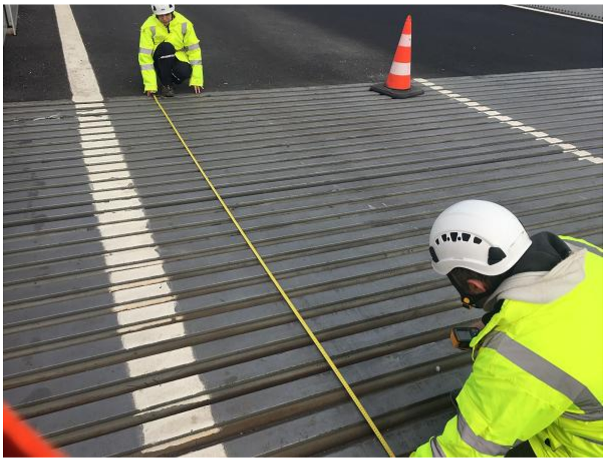


Figure 13 ↑: Routine inspection of water jet at deck gantry

Figures 14 + 15 →:
Routine inspection of expansion joints

The following table describes some of the primary tasks:

Scope	Inspection Task	Maintenance Task	Frequency
Outside of Piers, Anchorage Blocks, Towers	Surface of concrete and steel, attached elements and access ways use of available access ways and binocular.	Initiation of corrective works if needed.	Annually
Outside Girders	Surface of steel surfaces, attached components and access ways. Use of girder gantries or use binocular where gantry is not available.	Initiation of corrective works if needed.	Annually
Inside of: -Girders -Tower -Anchorage Block	Walk through. Signs of un-tightness of access ways, ingress of water and integrity of M&E components. Check of dehumidification system up and running.	Initiation of corrective works if needed.	Semi-annually
Inside pier	Walk through. Signs of un-tightness of access ways, ingress of water and integrity of M&E components.	Initiation of corrective works if needed.	Annually.
Main Cable	Walk on main cable and check of condition of cable, hand strands and attached items.	Initiation of corrective works if needed	Quarterly.
Hanger Cables	Surface of steel surfaces, interface to girder. Use binocular for free stretch and upper socket.	Initiation of corrective works if needed	Quarterly.
Bearings and Hydraulic Buffers	Inspect each. Function, position and condition of bearings and buffers. Check also suppliers O&M Manual.	Initiation of corrective works if needed	Semi-annually
Expansion Joints	Visual inspect. Condition and function of road expansion joint. Check for odd noise, unintended movements, and loose or worn components. Check also suppliers O&M Manual.	Preventive maintenance work to prevent function failure. Initiation of corrective works if needed.	Monthly.
Carriageway and Inspection Walkway	Drive through by walkway and occasional stops with walkabouts for closer inspection. Condition of road surfacing, barriers, parapets, wind screens, drainage, fire system and other installations.	Cleaning. Collection of litter and dropped items. Fixation of loose items. Initiate interim repair of potholes. Setup of warning signs.	Daily and on standby
Girder Gantries and Cable Carriages and Hanger Basket	Inspect and test. Function and safety of installed gantries and carriages. Check for odd noise, unintended movements, and loose or worn components. Check also suppliers O&M Manual.	Preventive maintenance work to prevent function failure or major repair. Initiation of corrective works if needed.	Monthly.
Lighting	Drive/walk through. Function of external lighting of road and inspection walkway, maritime and navigation lights	Change of bulbs and fuses	Weekly.

Table 1: Scope and extent of overall Routine Inspection Programme

5.2.1 Daily Routine Inspections

Daily inspections are carried out visually by personnel walking or driving through and making stops whenever needed for closer inspection and intervention. The personnel look for any abnormalities influencing the safety and function of the Bridge. The main aspects are:

- Safety for traffic and personnel.
- Functionality/safety for structures, which may be reduced due to damage caused by abnormal loads, e.g. adverse weather conditions or collisions by vehicles.
- Any abnormal movement of structural elements.
- Function of traffic sign boards and other installations for operation of carriageway.

The daily Routine Inspection has close interfaces to the operational aspects of the Bridge and is coordinated with the traffic safety department.

5.2.2 Weekly Routine Inspections

Weekly routine inspections/maintenances are carried out by GIIB technical personnel including:

- Carriage way and inspection walkway (routine inspection)
- Architectural lighting (routine inspection)
- Bridge control center and SCADA system (routine inspection)
- Generators (routine inspection)
- Traffic barriers, windshields, access equipment, lighting columns, sign boards and other installations (routine maintenance)

5.2.3 Monthly Routine Inspections

Monthly routine inspections/maintenances which are carried out by GIIB technical personnel comprising:

- Expansion joints (routine inspection)
- Tower gantries, deck gantries (routine inspection and routine maintenance)
- Dehumidification system (routine inspection and routine maintenance)
- Weak voltage main and secondary panels (routine inspection and routine maintenance)
- Transformer buildings (routine inspection)
- Elevators (routine maintenance)

5.2.4 Quarterly Routine Inspections

Quarterly inspections/maintenances are carried out by GIIB technical personnel for:

- Main cable system (routine inspection)
- Hanger cable system (routine inspection)
- Aviation and navigation lighting systems (routine inspection and routine maintenance)

5.2.5 Semi-annual (6 monthly) Routine Inspections

Semi-annual inspections/maintenances include:

- Inside of deck, tower and anchorage rooms (routine inspection and routine maintenance)
- Bearings and hydraulic buffers (routine inspection)
- Drainage system (routine inspection and routine maintenance)
- Fire fighting systems (routine inspection and routine maintenance)
- Main cables, hanger cables, traffic barrier wires (routine maintenance)
- Expansion joints (routine maintenance)
- Surfacing (routine maintenance)

5.2.6 Annual Routine Inspection

Annual inspections/maintenances are carried out by GIIB:

- Outside of deck, concrete piers and anchorage rooms (routine inspection)
- Inside of concrete piers (routine inspection)
- Inside and outside of towers (routine inspection)
- Communication system (routine inspection)
- Cathodic protection systems (routine inspection and routine maintenance)
- Security system (routine inspection and routine maintenance)
- Cabling, transformer, internal lighting (routine inspection)
- Lightning protection and grounding (routine inspection and routine maintenance)
- Paint of deck and towers (routine maintenance)
- Bearings (routine maintenance)
- Traffic barriers, windshields, access equipment, lighting columns, sign boards and other installations (routine maintenance)
- Access facilities, doors, hatches (routine maintenance)

- Internal and external lighting (routine maintenance)
- Cabling, transformer (routine maintenance)
- Communication system (routine maintenance)
- Dehumidification of main cable (routine maintenance)
- Hydraulic buffers (routine maintenance)

5.3 Reporting

After each major inspection, inspection reports shall be prepared which include detailed descriptions of any damage or deteriorations with pictures. Hard copies and soft copies of inspection reports are recorded. Those records will be used in planning and execution of future maintenance and repair works.

After maintenance, detailed reports shall be prepared which include description of the maintenance, and maintenance costs spent. These will help and be used in planning/evaluation of alternative maintenance strategies for high cost future maintenance operations and prediciting the remaining service life of components.

5.4 Access for Inspection and Maintenance

All structures of Osmangazi Bridge are accesible for inspection, maintenance and for replacement purposes. The most suitable equipment to provide safe, efficient and effective access were chosen and provided during the design phase.

For all equipment installed at high level, facilities for maintenance were designed either as permanent working platforms or as flexible mobile elevating platform.

The tower internal area, tower top and saddle enclosure areas, tower external faces, anchorages and caisson interiors, expansion joint areas, main cable and hangers are all designed to have permanent access as described below.

The walkways of the bridge deck serve as a dedicated access lane, to be used by maintenance vehicles for reaching the designated maintenance location in a fast and efficient manner without disrupting normal traffic.

Access Facilities	
Suspended Deck	Access Door & Hatch to Deck, Interior Walkway, Inspection Gantry, Access to Inspection Gantry
Articulations	Platforms
Cable & Hanger	Access to Saddles and Main Cable, Walkway on Main Cable, Cable Carriageway, Hanger Basket
Tower	Access Door & Hatch to Tower, Access Ladder and Platform, Access Ramp from Tower to Deck, Inspection Cradle for Tower Exterior
Tower Foundation, Anchorage Block, Piers	Access Door to Splay Chamber, Access Stairs in Splay Chamber, Access Door to Pier, Access to Tower Foundation Caisson Shaft

Table 2: Access facilities for inspection and maintenance

Access equipment can be categorised as light, medium and heavy duty types according to the type of inspection and maintenance purpose.

Details of the movable gantry and fixed walkways are shown in the picture below.

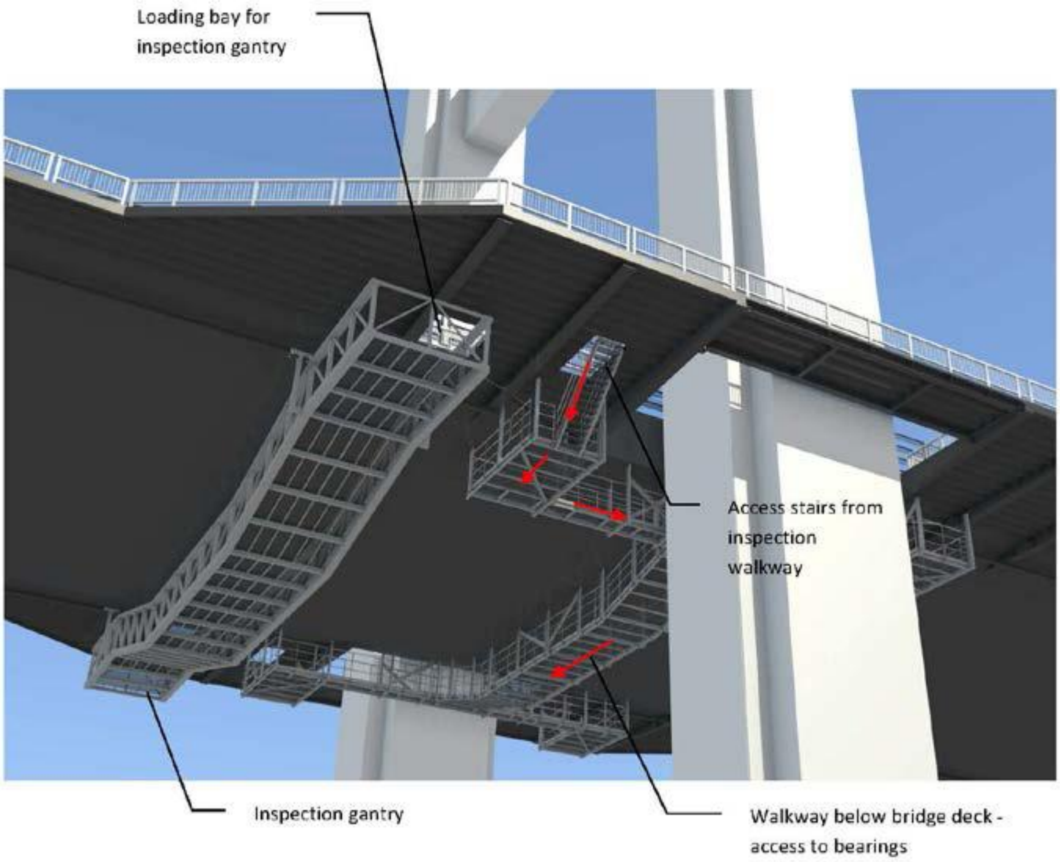


Figure 16: Movable deck gantry and fixed walkways

6. DEHUMIDIFICATION SYSTEM

Corrosion of cable wires and structural steel elements are main factors adversely affecting condition of the steel bridges. Cable dehumidification is now an established and effective method for old and new bridge main cables. In the US, Japan, Denmark, UK and recently in Turkey the main cables of many suspension bridges are equipped with cable dehumidification system.

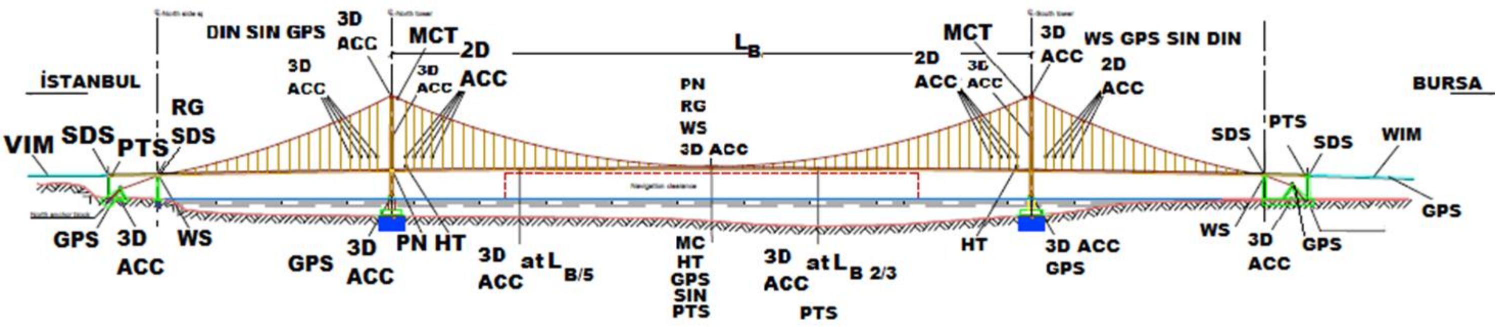
The cable anchorage chambers, internal deck box sections, the inside of the towers and the main cables of Osmangazi Bridge are designed and equipped with the latest dehumidification systems.

7. SHMS (Structural Health Monitoring System)

The Structural Health Monitoring System is an integral part of the structure of Osmangazi Bridge. Osmangazi Bridge is heavily instrumented with various devices for monitoring the structural behavior (such as vehicular weight, wind speed, seismic, other environmental and structural parameters) and effects on the bridge (such as strains, acceleration, displacement, temperature).

The data from those sensors and equipment are transferred to the Bridge Control Center through the SCADA system and displayed, recorded and processed to make assessment and optimize the required maintenance.

Below sketch shows the location of SHMS sensors:



8. SCADA

Osmangazi Bridge is provided with a SCADA (Supervisory Control and Data Acquisition) system gathering all monitoring and control functions of the bridge.

The SCADA is an automatic control and monitoring system to monitor and/or control the Electric and Mechanical systems such as various lighting systems, mechanical systems, fire services systems as well as data communication and SHMS.

The SCADA system does not have any remote terminal units, but will collect any relevant data from the technical computer systems and in that way be able to access local distribution units.

These technical systems are:

- Power Management System (PMS)
- Central Control and Monitoring System (CMS)
- Fire Detection and Alarm System
- Structural Health Monitoring System (SHMS)

The SCADA system communicates with these technical systems via local area network in the Control room and through a fiber optical data communication network with the distributed electronic units/control panels located along the Bridge.

9. CONTROL AND MANAGEMENT BUILDING

The control and monitoring of the technical installations on the bridge are carried out from two control rooms located at the following facilities:

- Main Control Room in the Main Control Building
- Slave Control Room in South Substation Building

These rooms are the center of SCADA to control and monitor all bridge structural and operational functions. A picture of the SCADA room of the bridge control center is shown in the Figures 17 + 18.

The bridge control is also visible on the Main Control Centre located at Bursa province that is acting as overall motorway control center.

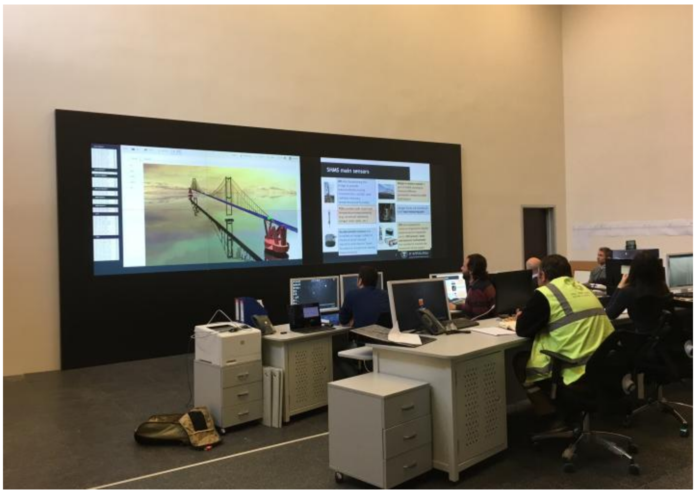


Figure 17: Bridge Control Center Scada Wall

Figure 18: Bursa Main Control Center Scada Wall

10. TRAINING

Post operation training and H&S training were carried out to keep all personnel ready and aware of requirements stated in the maintenance and inspection manuals.

11. CONCLUSION

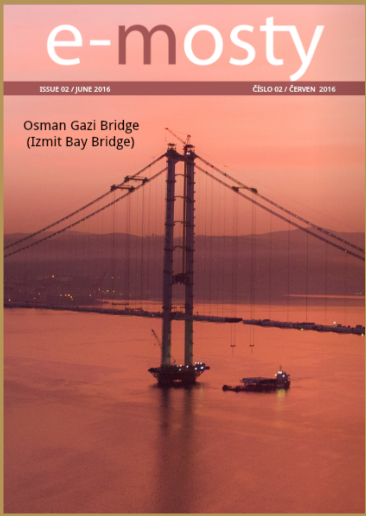
GIIB inspection teams have worked throughout the year checking closely the condition of bridge elements, recorded, reported and updated findings during inspections. Meanwhile maintenance teams have worked throughout the year cleaning road surface, drains, fixing deficiencies as per the requirements described in the manuals. All works interfering with road traffic are planned and executed in close coordination with the traffic safety department.

In the first year of operation there has been no need for principal inspections and special inspections since there have been no issues or damage associated with unforeseen problems.

The operation and maintenance activities through the regular inspections, records of various monitoring devices, knowledge of actual behaviour of bridge leads to periodic and specific maintenance which then allows the operator to have a safe and fully operational bridge and to extend the life of the bridge and its equipment.

Figure 19 ←: Training forf working at height

Figure 20 ↑: Training of operators of the under deck inpection unit



JUNE 2016

DESIGN

CONSTRUCTION

DRAWINGS

PHOTO GALLERY

AUTHOR: FATIH ZEYBEK

JUNE 2017

ONE YEAR

IN OPERATION

AUTHOR: FATIH ZEYBEK

OSMAN GAZI BRIDGE ON E-MOSTY

INSPECTION, PRESERVATION AND REHABILITATION OF US SUSPENSION BRIDGES

Barry R. Colford, Vice President, AECOM
Shane R. Beabes, Associate Vice President, AECOM

Delaware Memorial Bridge

1. INTRODUCTION

The preservation of bridges provides different challenges to the bridge engineer than those faced when designing a new structure. These challenges are likely to be more numerous and increase in scale and complexity when dealing with long span cable supported bridges.

In the USA, as is the case in most countries, these long span bridges are almost always vital links in the nation's infrastructure and any failure, either at the serviceability or ultimate limit state level is likely to cause significant disruption to the public.

There are approximately 147 major cable suspension bridges across the globe with a main span length greater than 300m and over 50% of these major suspension bridges were built after 1988. As a result of the suspension bridge construction over the last several decades, twelve countries share over 90% of the inventory, with China and the U.S. having the most, followed by Japan, Norway and Canada (Figure 1).

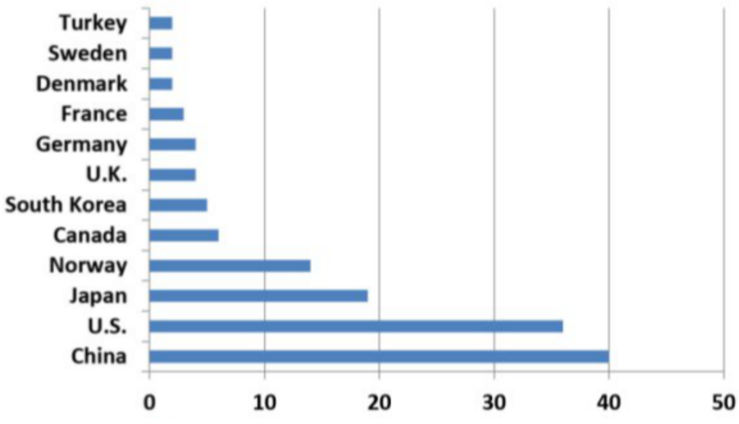


Figure 1: Global Cable Suspension Bridge Inventory (Spans > 300m); Country by Number of Bridges

North America as a whole has a combined total of nearly 30% of the world's suspension bridges. Notable bridges in the U.S. include Verrazano-Narrows, Golden Gate, Mackinac, George Washington, East Bay in San Francisco and Tacoma Narrows – the longest being Verrazano-Narrows with a main span of 1282m. Notable bridges in Canada include Lions Gate, Angus L. Macdonald, and A. Murray MacKay with suspended spans reaching up to 472m.

The U.S. has the oldest major cable suspension bridge inventory with an average age of 73 years (Figure 2). The older of these bridges includes Williamsburg (1903), Brooklyn (1883) and Roebling (1867) with Wheeling (1849) being the oldest in the U.S.

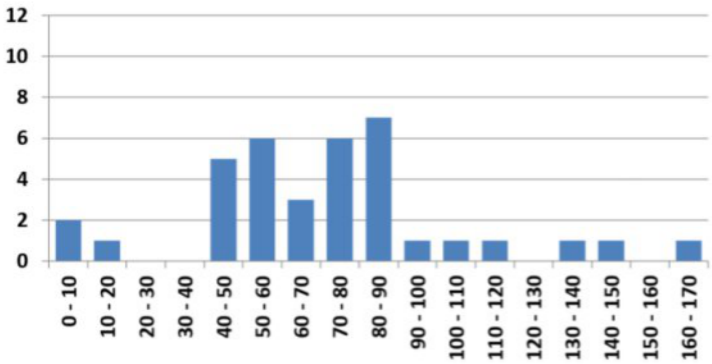


Figure 2: Distribution of Age of Major US Suspension Bridges

However, since Verrazano Narrows opened in 1964 only three new long span suspension bridges have been constructed in the US at Carquinez, Tacoma and the notable self-supporting East Bay Bridge in San Francisco.

The preferred form of long span bridge in the US is now the cable stayed bridge. The new Tappan Zee and Goethals Bridges are both cable stayed bridges. Although it is worth noting that there are no cable stayed bridges currently in the US with spans exceeding 500 metres.

Therefore, because of the relatively young age of the cable stayed bridge stock in the US and the age of the older suspension bridge inventory, most of the work carried out on existing bridges in the cable supported bridge market in the US is ensuring that the existing suspension bridges have a service life equivalent to their design life.

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

Cable supported bridges are different from other bridges in many ways and one significant difference is that some of the most critical structural elements are above the heads of the very users of the bridge. This makes both inspection and maintenance very challenging and ensuring there is safe access and effective containment is one of the key elements required before any inspection or maintenance work is carried out.

Funding of course is always an issue. Typically long span suspension bridges in the US are tolled and are owned by stand- alone public agencies. It is not usual for them to be owned by the State or Federal Government. Of course there are exceptions to the tolling and ownership rule. Brooklyn, Manhattan and Williamsburg Bridges in NYC are not tolled and are owned and maintained by the New York City DOT. In many cases the Bridge Authority will also be responsible for other facilities and infrastructure as diverse as subways, ferries, ports and airports.

As toll increases are rarely popular, there is always a challenge for the bridge engineer to ensure that adequate funds are made available for work to be carried out on the bridges. This is never easy especially for preventative maintenance works but it is one that engineers cannot ignore.

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

To achieve these goals, engineers have to be prepared to have robust and well communicated arguments set out to ensure that sufficient funds are made available.

Apart from inspection and routine maintenance work, major preservation or improvement work on the major suspension bridges in the US has focused mainly on:

- Deck rehabilitation or replacement
- Suspender replacement
- Cable Band Bolt tightening/replacement
- Painting steelwork
- Anchorage rehabilitation
- Bearing and joint replacement

This article will look briefly at the first three of these tasks; deck rehabilitation or replacement, suspender replacement, and cable band bolt tightening/ replacement.

In addition, the introduction of main cable dehumidification in the US will also be examined.

2. DECK REHABILITATION OR REPLACEMENT

There is a notable difference in the approach to the expected service life of the decks of suspension bridges in the US. Most of the major suspension bridges are in the North Eastern states where winters can be severe. As a consequence road salts are used extensively in severe winters. In the UK and Scandinavia other forms of deicing are used instead of road salts. The authors are not aware of any major suspension bridges in the US where alternatives to road salts are used.

Consequently, it is not uncommon for owners to expect a reduced life of 50 years for the deck, compared to over a 100 year service life for the other major components of the structure. The use of grid infill rather than orthotropic decks makes replacement less onerous. Perhaps this thinking is one of the reasons that cable stayed bridges, with high deck compression loads being integral to the form of the structure, have until relatively recently been slow to have been adopted in the US.

Figure 3 shows the replacement grid deck being constructed on the Walt Whitman Bridge in Philadelphia. AECOM designed this project on behalf of the Delaware River and Port Authority, which was carried out by American Bridge, between 2010 and 2014.

3. SUSPENDER REPLACEMENT

In the US, engineering rope is typically used in suspenders and has an inner wire core with outer strands at a specific lay wound round the core. A typical 7 x19 construction is shown in Figure 4.

The two elements connected by the suspenders, the deck and the main cables, have a different stiffness and move relative to each other both laterally and longitudinally due to transient loadings.

This movement can cause the most severe effect on the short hangers and the wires at the socket

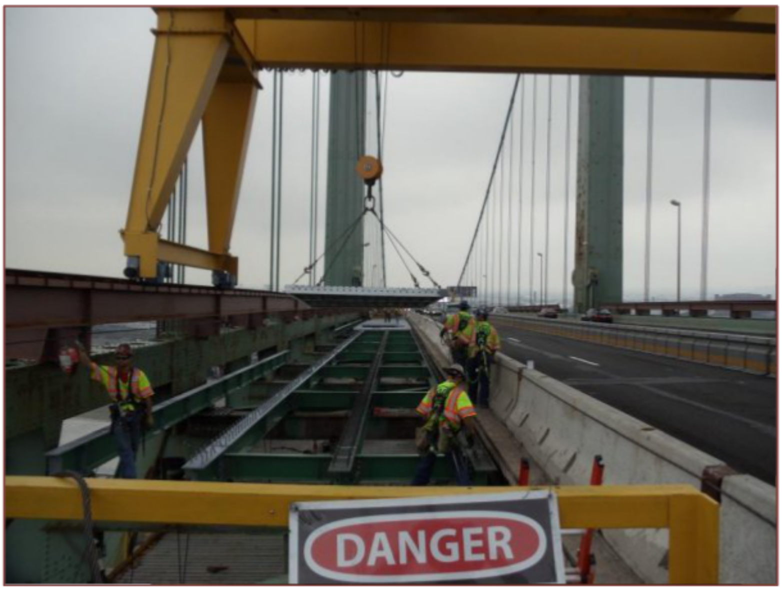


Figure 3: Deck Replacement on Walt Whitman Bridge

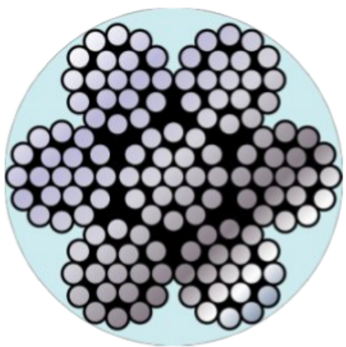


Figure 4: Typical 7 x 19 Rope Cross Section

interface are prone to fatigue damage at this point. In addition, experience has shown that no matter how diligently the suspenders are painted, because of their construction, water will find a way into the ropes, and collect at the socket. When dirt and road salts are added to this mix, the result can be accelerated corrosion, broken wires and a loss of strength. The typical end bearing socket detail is usually below deck level in a confined area as shown in Figure 5, which can cause water and dirt to be trapped and make inspection and maintenance difficult. Making sure these sockets are washed down regularly to remove dirt and salt is extremely important.

Figure 5: Typical suspender socket detail on a US suspension bridge

It is unfortunate that there appears to be no effective method of testing suspenders for wire breaks at the most critical area - the socket interface. Removal and testing or unwrapping of this type of rope appears to be the only sure way of determining whether failure has occurred within the inner wire core.

Protective coatings to suspenders have been another maintenance issue for bridge owners. In the USA, Noxide is used on a number of bridges. Some owners have had issues with coatings bulging and water retention at the bottom of the suspenders and have used a thinner coating over a short length of the suspender immediately above the socket. It does seem somewhat counterintuitive given the aforementioned problems at the socket level but allowing trapped water to get out from inside the rope is more important at this location.

As a consequence of all the concentration of issues at the socket level of suspenders it is recommended that owners consider removing a number of short suspenders for examination and testing if the suspenders have been in service for more than 25 years, even if there are no external signs of damage.

A typical suspender replacement frame used in the US is shown in Figure 6.

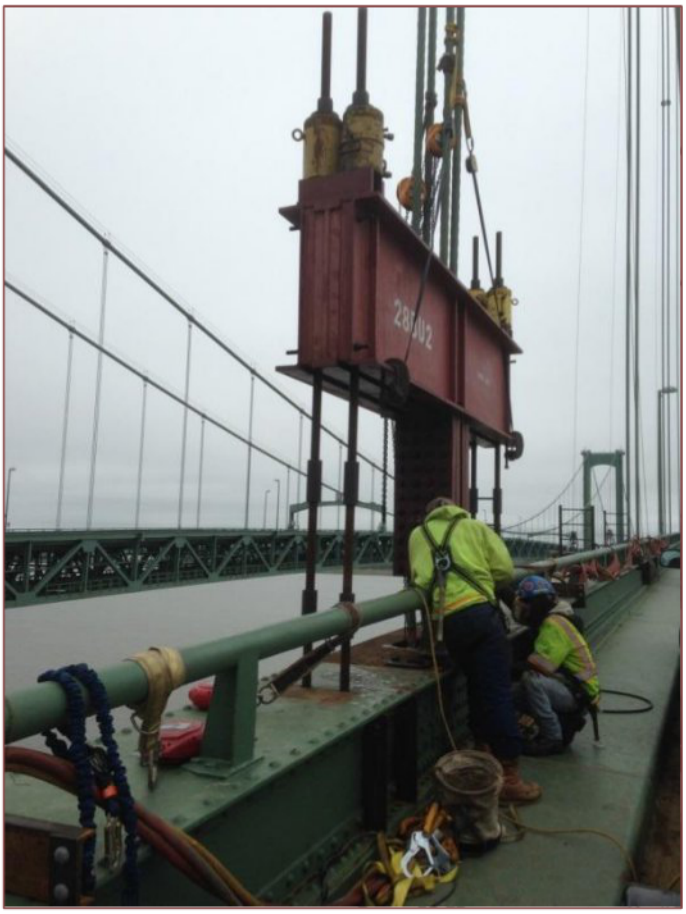


Figure 6: Typical suspender replacement temporary jacking frame

4. CABLE BAND BOLT RE-TENSIONING / REPLACEMENT

On US bridges typically the cable bands are steel castings that support the suspenders which loop over the bands. They consist of two cylindrical castings bolted together over the circumference of the cable.

The number of bolts in each cable band is dependent on the slope of the cable. The friction from clamping against the cable provides the force that prevents the band from sliding down the cable. The steeper the cable, the more bolts are needed to prevent this sliding.

Over time due to continuing compaction of the cable, and due to creep of the zinc coating on the wires, the tension in the bolts deceases. This is a well-established occurrence and on some bridges significant drops in bolt tensions have been measured.

There is some debate about how often cable band bolts should be checked for this loss of tension. However, it is considered good practice to carry out a check every 15 to 25 years.

To establish a new load the bolts have to be de-tensioned in turn and past experience has shown that it is prudent to allow for some bolt replacement.

Figure 7 shows measuring load by extension and Figure 8 cable band bolt tensioning.

5. DEHUMIDIFICATION OF MAIN CABLES

5.1 History

As early as 1968, corrosion was found in the outer wires of the cables on the Golden Gate Bridge, and in 1978 the U.S. Grant Bridge over the Ohio River was closed after severe corrosion was detected in the main cables. In the 1980s, broken wires prompted rehabilitation efforts on the main cables of the Bear Mountain and Mid-Hudson Bridges in NY.

In 1990, corrosion was discovered on the outer main cable wires of a bridge in Japan that was just seven years old. Further inspections revealed corrosion in the main cables of other suspension bridges in Japan that were even younger. Investigations ensued, and accelerated testing led engineers to conclude that, even with improved wrapping and sealing, it was not possible to make a cable completely watertight. The idea was born that if a suitable dry-state environment was maintained by some artificial means, it would be a promising way to protect the cable against the spread of corrosion. The development of main cable dehumidification stemmed from this work.

5.2 The Process

Main cable dehumidification involves injecting dried-air into the cable microenvironment and allowing the air to permeate into the interstitial spaces (voids) between the individual cable-wires. The dried-air collects the trapped water before releasing the moisture-laden air through exhaust ports (Figure 9).

Figure 7

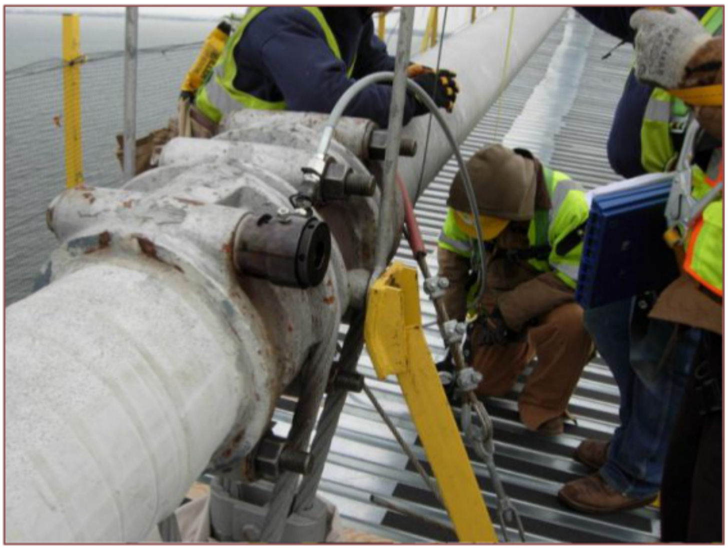


Figure 8

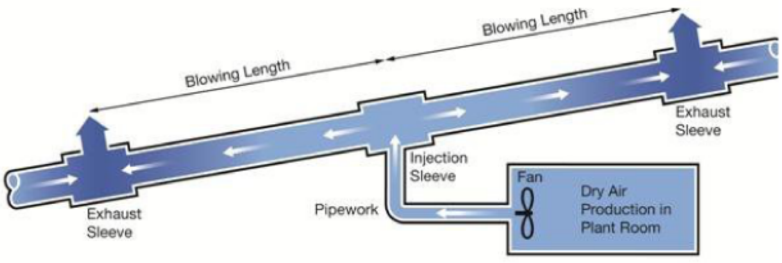


Figure 9. Cable dehumidification process

The premise of cable dehumidification is to protect the individual cable wires through the control of humidity within the cable. This is a long-proven technique dating back to the first half of the twentieth century, where work was carried out by W.H.J. Vernon and later by H.H. Uhlig of the MIT Corrosion Laboratory. The results of corrosion studies indicate that if the relative humidity (RH) is kept below 60%, the corrosion rate dramatically decreases, and below 40% corrosion practically ceases (Figure 10).

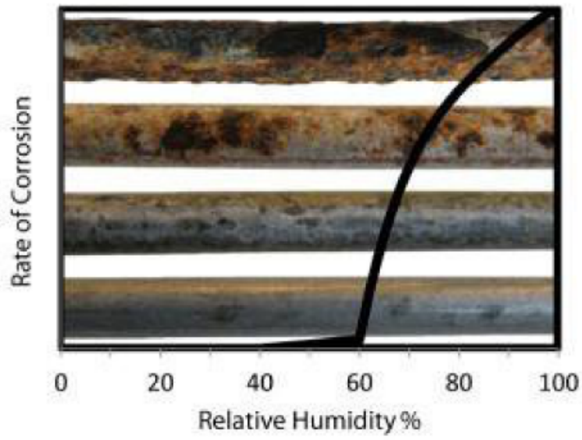


Figure 10: Rate of corrosion vs. relative humidity (background: 4 stages of cable wire corrosion)

The implementation of a series of injection and exhaust sleeves along the length of the cable, supported by a system of dehumidified air maintained below the threshold 40% RH, supplies a continuous lifeline of dried-air to combat corrosion. This can be contrasted with the original passive system of protection for most main cables, which typically included galvanized cable wires with a layer of red lead or zinc paste below a soft-annealed galvanized wire wrapping and paint system.

Dehumidification also contrasts the historic approach to retrofitting cables with the added protection of oiling – an expensive process of unwrapping and wedging the cable wires apart and pouring in specially formulated oil in the hopes of protecting the cable against continued corrosion.

5.3 Fracture Mechanics of Cable Wires

Cable wires are usually about 0.196 inch in diameter and in the US have a range of tensile strength from 1000 to 1600 Mpa. The wires are usually galvanized, pulled across the spans, and then compacted together to form a near circular cable cross-section, comprised of thousands of individual wires, or tens-of-thousands in longer-span bridges.

There are many contributing factors to cable corrosion and loss of strength. However, it is the initiation and propagation of cracks that ultimately cause cable wires to break. This process starts with the water that has collected within the cable reacting with atmospheric pollutants leading to zinc depletion – the degradation of the galvanized coating on the cable wires. Once the zinc protection is depleted, corrosion pitting will occur; some of the pits develop cracks, which then grow into the cable wire cross-section. The very high strength of the steel used in cable wire makes it more brittle in nature and more susceptible to hydrogen embrittlement and associated cracking. Hydrogen embrittlement is a result of hydrogen at the subatomic level migrating into the steel matrix, causing the cable wire to become brittle and prone to wire cracking and fracture at normal levels of working stress.

Historical data on existing bridge cables that have been retrofitted with a dehumidification system demonstrate a marked reduction and near-cessation of wire breaks over time (Figure 11), illustrating the effectiveness of main cable dehumidification on the overall health of the cables.

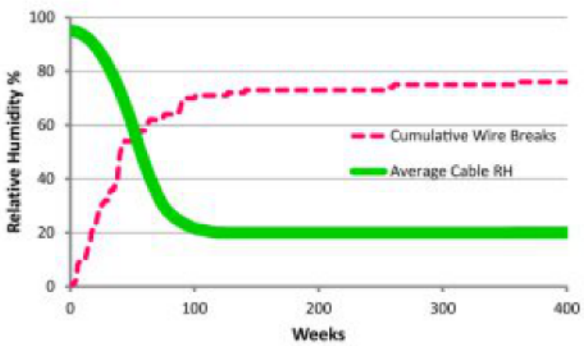


Figure 11. Reduction in cumulative wires breaks on dehumified cables

5.4 Monitoring the Vital Signs of the Cable

Assessing the condition of the cables by visual and hands-on inspections can be supplemented by acoustic monitoring. Depending on the condition of the cable, internal cable inspections typically occur but once a decade and focus on just a few locations along the cable. The estimated strength of the cables therefore requires statistical extrapolation from the relatively small amount of data collected. Cable wires gradually deteriorate through corrosion, crack initiation, and crack growth, culminating in a sudden break. This releases energy which can be detected through a network of acoustic sensors.

Some bridge owners have installed acoustic monitoring systems that listen 24/7 to the whole length of the cables for breaking wires. This provides valuable and in some cases crucial important long-term information on the structural health of main cables.

Two key pieces of data are generated by the acoustic monitoring – hotspots indicating significant wire-break activity and the long-term trend of cumulative wire breaks. This data enables the bridge owner to have an increased knowledge and confidence in the actual health of the cables.

Cable strength and durability are influenced by many complex interrelated factors including construction quality, long-term performance of constituent materials, and human responses to these. As main cables are the primary load carrying elements of the structure, it is important that their condition is known and closely monitored. Diminishing tensile strength factor of safety is the main concern for suspension bridge owners and generally drives the implementation of preservation strategies.

Cable corrosion on suspension bridges is insidious. Corrosion will begin slowly and may not be readily apparent through external examination of the cables. Unfortunately, cable corrosion cannot be reversed. By the time the cables are opened for internal inspection, significant corrosion may have already occurred. Of even greater concern is that wires may have already cracked and a number may already be broken, leading to reduced cable reliability and strength.

5.5 Implementation

Following the successful implementation of main cable dehumidification to the Forth Road, Severn and Humber Bridges in the UK, AECOM designed the first main cable dehumidification system in the United States on the twin suspension bridges making up the William Preston Lane Jr. Memorial (Bay) Bridges in Maryland.

Dehumidification was programmed for installation following internal cable investigations, which revealed the existing cable protection strategies were less than effective. The design of the system was initiated in 2010 and the Westbound Bridge dehumidification system was commissioned in 2014, while the Eastbound Bridge was commissioned in 2015.

Following the Bay Bridge, AECOM designed the cable dehumidification on the twin suspension bridges making up the Delaware Memorial Bridges between Delaware and New Jersey. Construction began in early 2016 and the cable dehumidification systems are anticipated to be completed by late 2017 to early 2018.

Since 2010, eight bridges are now in various stages of project development or delivery (Table 1), equating to nearly 25% of the US major cable suspension bridge inventory.

Bridge	Owner
WB Bay Bridge	MDTA
EB Bay Bridge	MDTA
NB Delaware Memorial	DRBA
SB Delaware Memorial	DRBA
Philip Murray	Allegheny Count
George Washington	PANYNJ
Ben Franklin	DRPA
Anthony Wayne	ODOT

Table 1: US cable dehumidification projects Known projects 2010-2017

It is likely that more of the US suspension bridges will have main cable dehumidification fitted as it is the most effective way of preventing further deterioration and strength loss in main cables.

6. CONCLUSION

There seems little doubt that spend on preserving and improving the existing infrastructure in the US is likely to increase and that more exciting and challenging projects lie ahead for those involved in maintaining long span bridges.

PRESERVING THE CABLES OF THE CHESAPEAKE BAY BRIDGE

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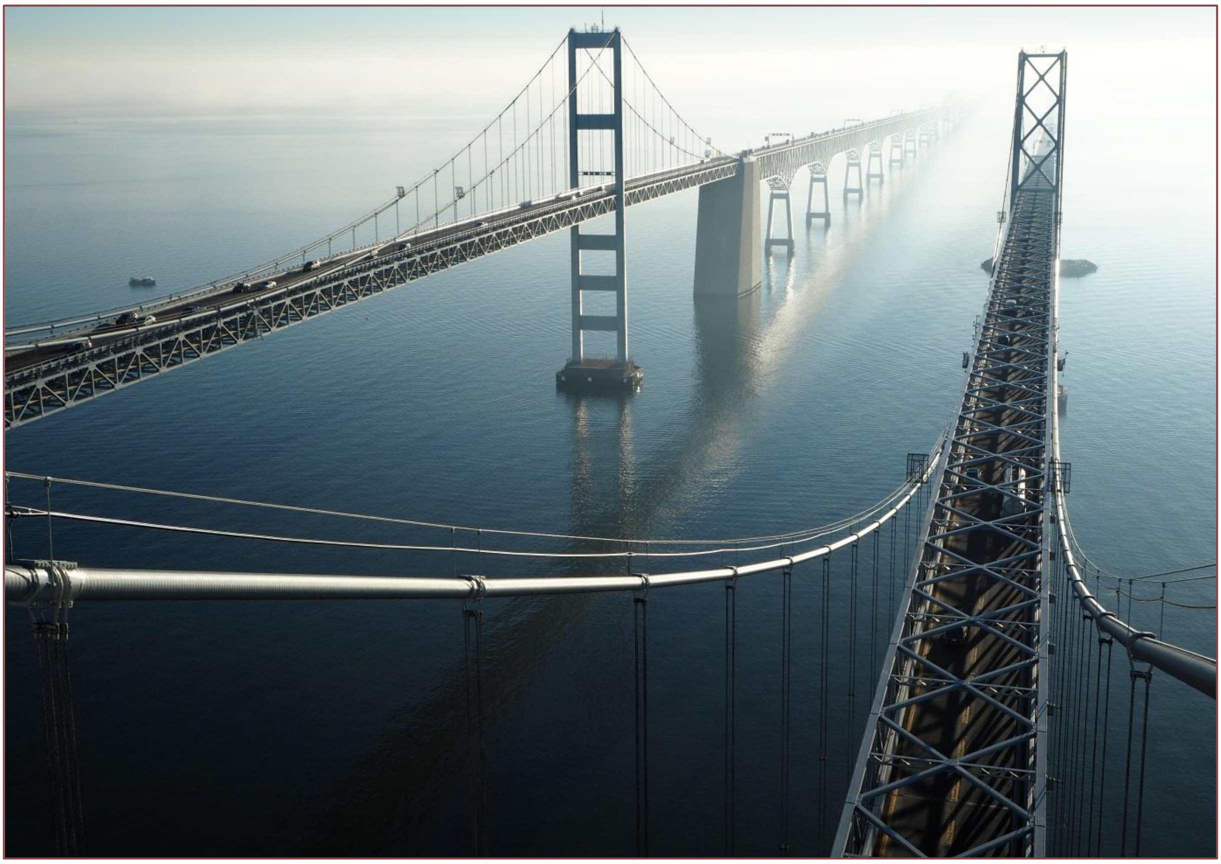

Chesapeake Bay Bridge, Maryland, USA (Photo Credit: Charles Cocksedge, AECOM)

1. INTRODUCTION

The William Preston Lane Jr. Memorial (Bay) Bridge, also known as the Chesapeake Bay Bridge, carries Eastbound and Westbound U.S. Route 50 and 301 over the Chesapeake Bay in Maryland, USA. The twin bridges are located east of Annapolis and serve to connect the Baltimore and Washington, D.C. metropolitan regions to the eastern shore of Maryland. The Bay Bridge is owned and operated by the Maryland Transportation Authority (MDTA) and is one of five signature toll bridges in Maryland.

The Bay Bridge is comprised of two parallel bridges, each spanning approximately 6.4km (Figure 1). The main features of the bridge are the twin suspended spans over the navigation channel, which accommodate the commercial and recreational ships accessing the Port of Baltimore from the Atlantic Ocean.

Figure 1: Bay Bridge – Aerial view (left) and suspended spans (right); photos courtesy of MDTA

The Eastbound Bridge was completed in July 1952 and the Westbound Bridge was completed in June 1973, just a little over two decades later.

Both of the suspension bridges were designed by the J.E. Greiner Company, a Maryland based engineering firm owned today by AECOM through the acquisition of URS Corporation. Although the bridges are similar in many ways, there are several distinguishing features between the two of them.

The Eastbound Bridge carries two lanes of traffic towards the eastern shore and is comprised of steel girder, steel truss and suspension spans. When the bridge was built, it was the world's longest continuous over-water steel structure.

The bridge provided a vital link that did not exist at the time when Marylanders were using a ferry service to traverse the Bay. After four decades of planning and under the leadership of Governor William Preston Lane, Jr., the first bridge was directed to be built.

By the early 1960s, the bridge traffic was near capacity. It was not long before the second bridge was commissioned and construction began in May 1969.

The second bridge was constructed 137m north of the existing crossing and would carry three lanes of traffic. This bridge would become the Westbound Bridge carrying traffic from the Eastern Shore of Maryland to the metropolitan regions of Baltimore and Washington.

The Westbound Bridge is generally similar in construction to the Eastbound Bridge with a combination of steel girder, steel truss, and suspension spans. However, the suspended spans of the bridges were slightly different in both the stiffening truss and main cables.

The eastbound and westbound suspended spans are each approximately 884m long with a 488m main span and 198m side spans. The eastbound suspended spans were supported by a through-truss with backstays and low-level anchorages; whereas, the westbound suspended spans were supported by a deck truss and taller anchorages, allowing the cables to be anchored at near-deck level without backstays.

In terms of the cables, each was similar in diameter but constructed differently, including the cable corrosion protection system.

The Eastbound Bridge used galvanized helical strands coated with zinc paste, galvanized wrapping wire and a neoprene overwrap.

In contrast, the Westbound Bridge main cables were comprised of galvanized prefabricated parallel wire strands (PPWS) with a neoprene overwrap. The wires of the Westbound Bridge were compacted and banded together but no zinc or lead paste or wrapping wire was used (Figure 2).

Each of the cable types was rather unique for their era of construction and different than the system first notably used on wire cables by John A. Roebling for the Brooklyn Bridge in 1883. This system included galvanized wire, red lead paste, galvanized wrapping wire and paint, and became a generally adopted cable corrosion protection system used around the world.

Figure 2: Helical strand cable, Eastbound Bridge (left); PPWS cable, Westbound Bridge (right)

Following internal cable inspections and a thorough evaluation of options, the Maryland Transportation Authority adopted a proactive approach to the preservation of the main cables, by deciding to implement a main cable dehumidification strategy.

Although cable dehumidification had been implemented in Asia and Europe, this would become the first application of main cable dehumidification in the United States and North America.

2. MAIN CABLE DEHUMIDIFICATION

The Maryland Transportation Authority engaged AECOM for the design and development of the contract documents for the main cable dehumidification, based on our international cable dehumidification expertise.

AECOM had previously performed the cable investigations, design, and supervision for the installation of main cable dehumidification systems on three signature bridges in the United Kingdom including Forth Road, M48 Severn and Humber (Figure 3).

All three bridges had parallel galvanized wire cables and a conventional corrosion protection system of red lead paste, galvanized wrapping wire and paint.

AECOM performed the internal cable inspections and strength evaluation of the main cables using the NCHRP 534 Guidelines (TRB 2004) for all three of the bridges between 2007 and 2010.

The extent of corrosion discovered was greater than originally anticipated, and it became evident that intervention was required.

It was determined that the exposure of the main cables in high levels of humidity and corrosive contaminants such as chlorides, carbon dioxide and noxious gases was resulting in a continuous oxidization process of the main cables, and the traditional protection systems adopted during their construction were not as effective as originally thought.

The main cable dehumidification system on Forth Road Bridge was installed and fully operational in 2009, while the systems on M48 Severn and Humber Bridges became fully operational in 2009 and 2010 respectively (Cocksedge & Bulmer, 2009; Cocksedge et al, 2011; Christodoulou et al. 2011).

The premise of cable dehumidification is to reduce the relative humidity (RH) inside the cables below 60% where corrosion becomes thermodynamically negligible (Figure 4). The relationship between corrosion rate of ferrous steel and humidity was investigated by Vernon in the 1930s (Vernon, 1935).



Figure 3: AECOM cable dehumidification projects in the UK – Forth Road ←, M48 Severn ↑, Humber →

The principle of dehumidification is applied to suspension bridge cables by developing dry air within mechanical plant rooms and then injecting the dried-air into the cables. The cables are wrapped with an elastomeric membrane and heat sealed to keep the dry air in and water out.

Once the dry air is in the cable, it travels through the voids between the cable wires or strands, resulting in a drying process with the residual moisture from within the cable removed at the exhaust points as moisture laden air (Figure 5).

When the dry air is first injected into the cables, the drying process begins. This is where any pre-existing condensate is removed from the cable.

As this occurs, the relative humidity is reduced until it is below the critical threshold where it is then sustained such that corrosion becomes practically negligible. The system operates on a continuous basis thereafter.

3. BAY BRIDGE DEHUMIDIFICATION PROJECT

3.1 Contract Overview

The design of the dehumidification systems was initiated in 2009/2010 with procurement of the construction contract in 2011.

Since cable dehumidification was new to the United States, the Maryland Transportation Authority decided to use a Design-Bid-Build (DBB) project delivery method, but combined it with a single-step Competitive Sealed Proposal (CSP) procurement method to incorporate both a technical and price component in the selection process.

The technical proposal required the prospective bidders to submit both qualifications and technical approach to perform the work.

In accordance with Maryland regulations, the technical and price proposal were submitted concurrently and each was equal-weighted in the

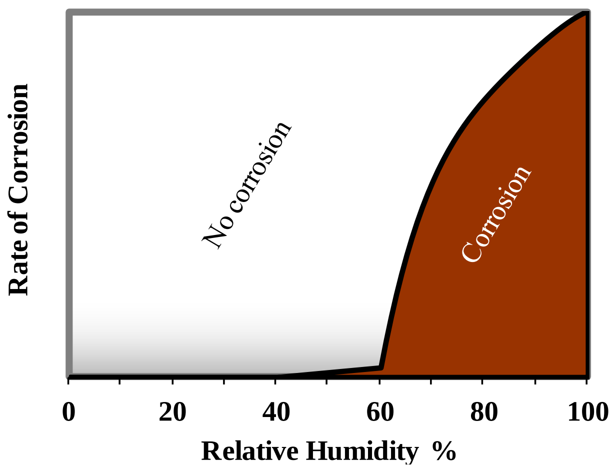

Figure 4: Relationship between corrosion and RH

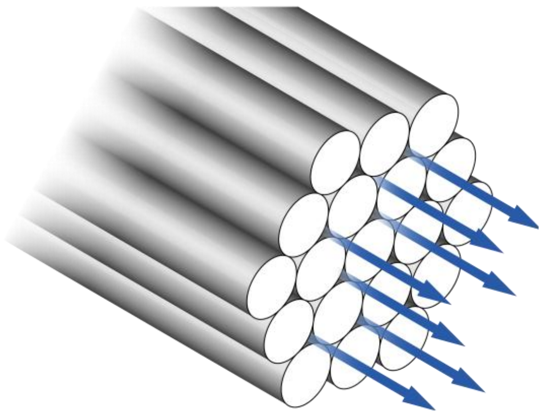

Figure 5: Cable voids used to inject dry air

overall ranking and selection process. The selection process included an interview with each prospective bidder and a Best-and-Final Offer (BAFO). The contracting method was lump sum. Kiewit Corporation was awarded the contract and notice-to-proceed was issued in 2012.

In terms of the contract documents, the drawings and specifications were modeled after the successful dehumidification systems AECOM designed for the three bridges in the UK. The documents were then adapted to US standards and further best practices were incorporated.

The contract documents included a combination of prescriptive and outline drawings and material, technical and performance specifications. This model best manages risk for all parties – owner, engineer, and contractor – as well as promotes high quality cable wrapping and sealing work required for a successful dehumidification system.

3.2 Dehumidification System Layout

AECOM designed the critical components of the systems including the location of the injection and exhaust sleeves, which established the blowing length in the cables.

The systems for both bridges were designed to dehumidify the entire length of the main cables, including the splayed strands and end sockets and anchor plates within the anchorages. The schematic layouts of the systems are shown in Figure 6.

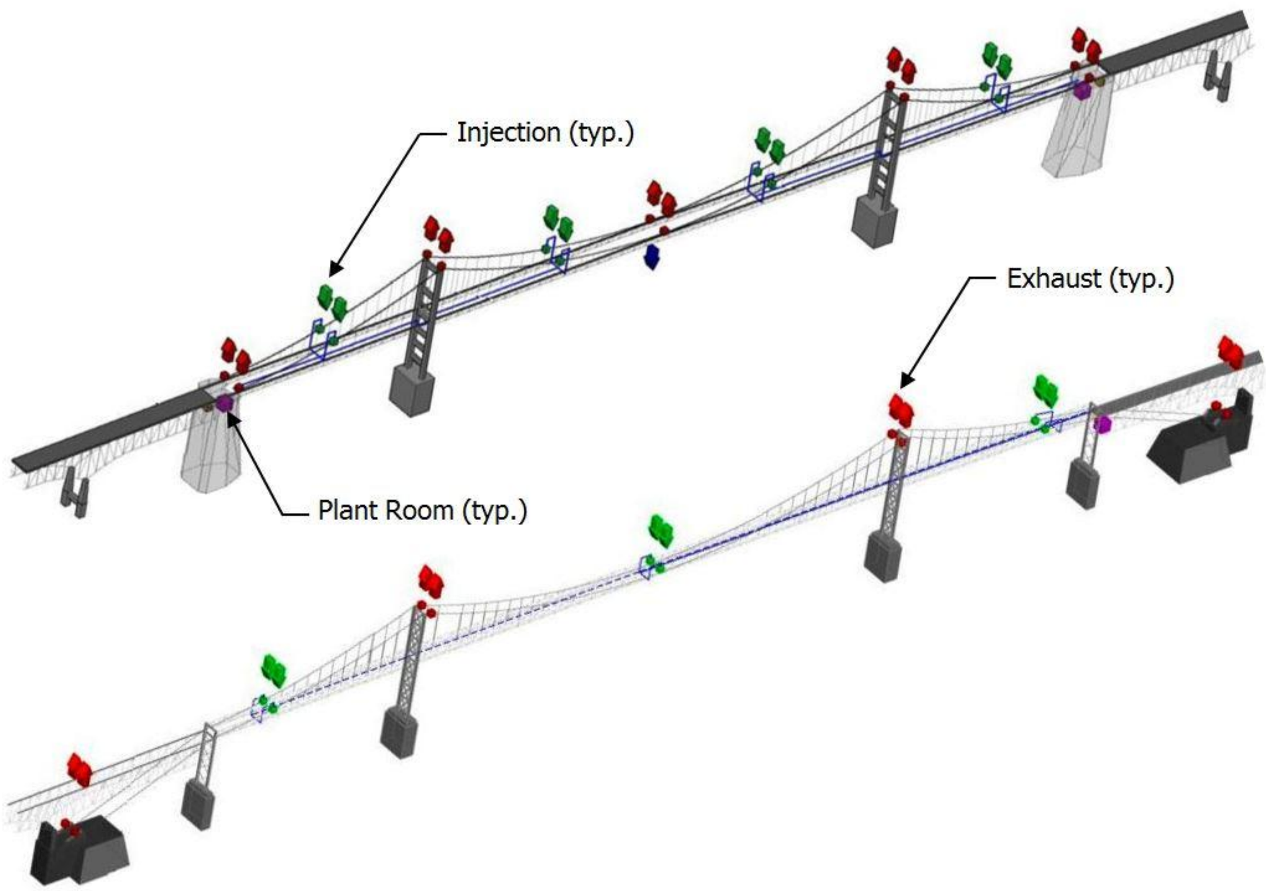

Figure 6: Dehumidification system layout – Eastbound Bridge (bottom), Westbound Bridge (top)

A different layout was used for each bridge since the cables were different. For the Eastbound Bridge, which has helical strand cables, the voids between the strands are larger than parallel wire cables, which results in lower airflow resistance.

For the Westbound Bridge, which has parallel wire strand cables with thousands of tiny voids between the wires, the airflow resistance is comparatively much higher. Therefore, a greater blowing length was used on the Eastbound Bridge cables in comparison to the Westbound Bridge to obtain efficiency and economy.

The tower tops were set as exhaust locations since these regions are more difficult to make airtight, as well as it would be difficult to install and maintain long vertical air pipe runs up the tower legs. The air from the cables was exhausted into the anchorages to dehumidify the splayed strands and cable anchor systems.

On the Eastbound Bridge, mid-main span was set for the injection point location, but on the Westbound Bridge it was considered more prudent to have shorter blowing lengths and inject at quarter-points given the higher air flow resistance of its parallel wire cables.

Potentially suitable plant room locations were limited on the Eastbound Bridge, since the cable anchorages were at water level. Having only 2-lanes, the Eastbound Bridge was also less accessible from lane closures in comparison to the Westbound Bridge. Therefore, a single plant room at the east end of the bridge under the approach span was considered to be most practical to facilitate future maintenance and reduce capital cost (Figure 7).

Figure 7: Eastbound plant room on platform; backstay and approach span on left, suspension span on right

Plant rooms on the Westbound Bridge were conveniently located inside each of the anchorages at deck level. This had several advantages including no traffic vibration, good maintenance access, shelter from the elements, more stable temperature conditions and lower cost lightweight plant room framing and wall components (Figure 8).

Figure 8: One of two plant rooms on Westbound Bridge within anchorages

On the Westbound Bridge, protective shroud walls were also erected to create exhaust chambers around the splayed strands and allow the dried-air from the main cables to keep the splayed regions dry. The shroud walls were constructed using a combination of a rigid wall system and a polyester fabric membrane for fitment to the top of the anchorage roof.

The Eastbound Bridge anchorages were smaller so the shroud enclosures were not required; instead, the dried-air from the cables exhausted into the anchorages to protect the strands and their anchor plates.

3.3 Wrapping and Sealing Works

For main cable dehumidification to be successful, air- and water-tight wrapping must be installed, including robust sealing at the cable bands and saddles. The elastomeric wrapping specified for the project was D.S. Brown's Cableguard™ wrap system.

The new cable wrapping was applied spirally over the bridge cable under tension using a Skewmaster™ wrapping device (Figure 9). The wrapping was performed uphill to create an overlapping shingle-effect so as to avoid water ingress from surface water running down the cable.

Figure 9: Cable wrap being spirally wound using a wrapping device (Skewmaster™)

To promote an air-tight seal, the wrapping was applied to create a triple overlap. The width of the triple overlap was set to a minimum and maximum width to provide a uniform appearance and promote heat sealing of the overlaps (Figure 10).

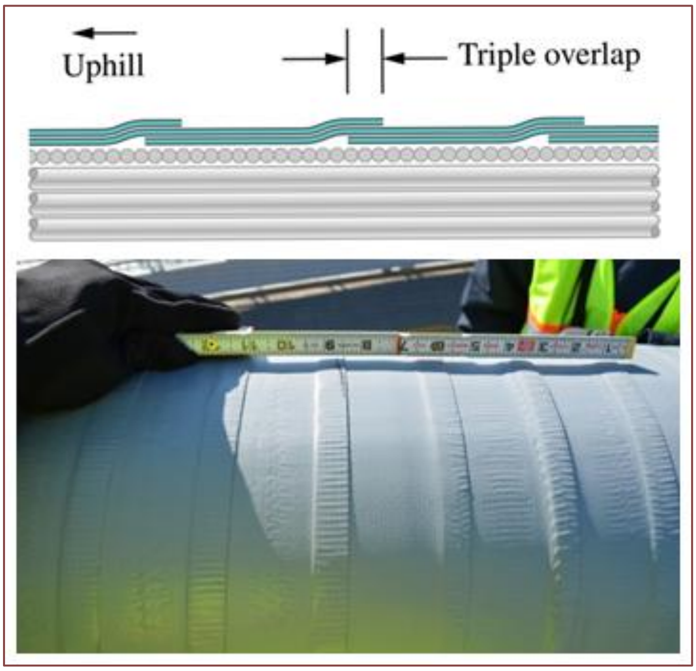

Figure 10: Schematic of triple overlap (top) and corresponding photo – (bottom)

The Cableguard™ was heat-sealed using inflatable heating blankets. The blankets were provided specifically for the project since they were dependent on the diameter of the cables. The blankets were inflated to press the flexible heating elements uniformly onto the cable surface and then heated to seal the wrapping (Figure 11).

Figure 11: Inflatable heating blankets used to seal the cable wrapping

Both the Westbound and Eastbound Bridge cables were entirely unwrapped and rewrapped with the Cableguard™ wrap system. Following the wrapping, an anti-skid surface paint and grit was applied to the top of the cable as part of the finish-work (Figure 12).

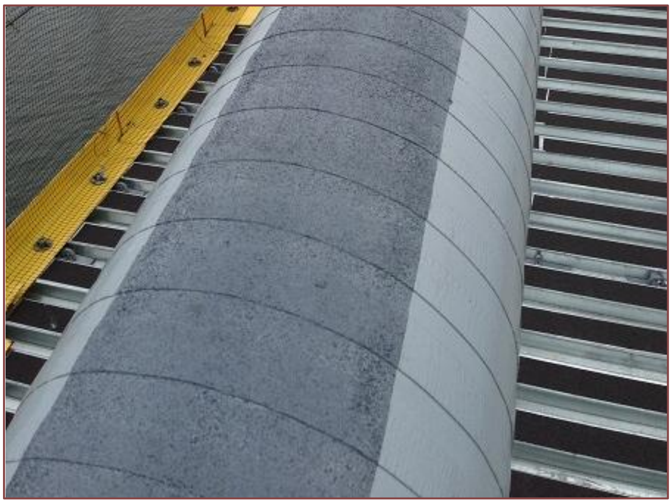

Figure 12: Finished cable with Cableguard™ wrap system

To achieve an airtight and watertight system, the termination and sealing of the wrapping at the cable bands and tower and anchorage saddles required specific sealing details. The details included a Cableguard™ neoprene wedge in combination with caulk sealant.

Once both were placed, a finishing strip of cable wrapping was installed and then completed with the installation of two additional stainless steel strap bands. The finishing strips provide a neat and durable detail and protect the underlying sealing materials from the environmental elements (Figure 13).

However, for the Eastbound Bridge, the cable band gaps were much narrower and ranged from 2mm to 6mm. The gaps were originally filled with a lead seal that proved difficult to remove due to the hardness of the sealant and the narrow width of the gap (Figure 15). While removal of the existing lead would allow the placement of modern sealants, it was believed that the removal process would have been overly intrusive and not beneficial to the overall sealing of the cable band.

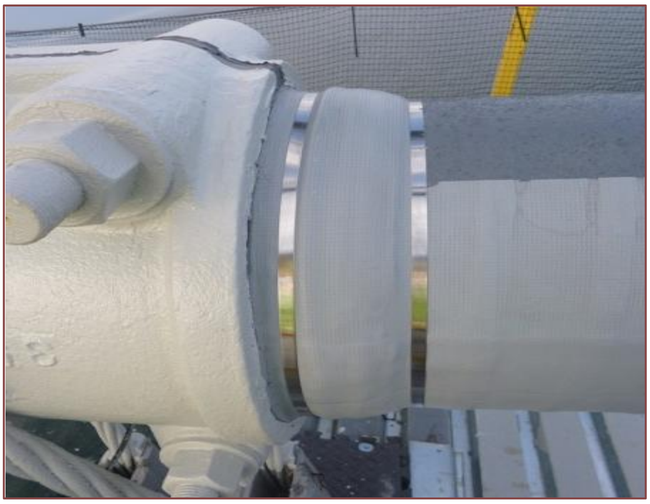

Figure 13: Finishing strip at cable band interface

Figure 15: Eastbound cable band gap filled with lead sealant

Both bridges had vertically split cable bands with longitudinal gaps top and bottom. However the width of the gap, and the manner in which they were originally sealed, was different.

For the Westbound Bridge the cable band gaps were approximately 19mm wide. The existing caulk sealant was removed and replaced with modern sealants, providing both a weather resistant and airtight seal (Figure 14).

Therefore, air trials were performed on a segment of the cable that had the new wrapping installed. An injection sleeve was installed on the cable and a temporary air blower was utilized to blow air into the sealed cables and test the in-situ lead sealant in the cable bands for air leaks.

Using an air pressure at the injection sleeve of 2000Pa, an air integrity test was performed which revealed only minor air leaks at the threads of the cable band bolts and through the suspender ropes; however, the in-situ lead caulking was air-tight (Figure 16).

Figure 14 ←: Westbound Bridge cable band longitudinal gap with new caulk sealant

Figure 16: Air trials with soapy water test on in-situ cable band (note bubbles detecting leaks around cable band bolts and suspender ropes)

Following the initial tests, suspender ropes were caulked within the cable band guides, and the cable band bolts were cleaned and coated with an elastomeric acrylic coating system for a subsequent air trail. These details were proven to be sufficiently airtight for the purposes of dehumidification and were therefore implemented on the remaining cable bands (Figure 17).

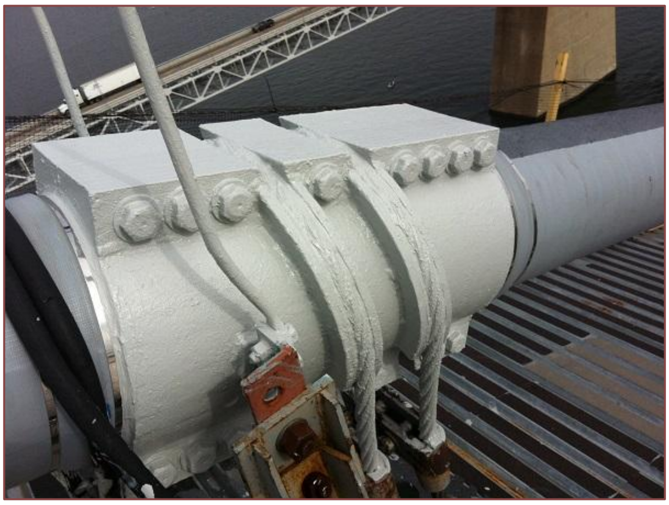

Figure 17: Eastbound cable band with new elastomeric acrylic coating system

The successful completion of the main cable wrapping and sealing began with contractually required shop trials. The contractor was required to demonstrate the ability to provide an airtight wrap, including the cable band seals, prior to applying the wrap and cable band sealing details on the bridge (Figure 18).

Figure 18: Shop test rig

The test rig was required to be constructed to allow pressure testing and detection of leaks along the wrap and interface with the cable bands through soapy water inspection (Figure 19).

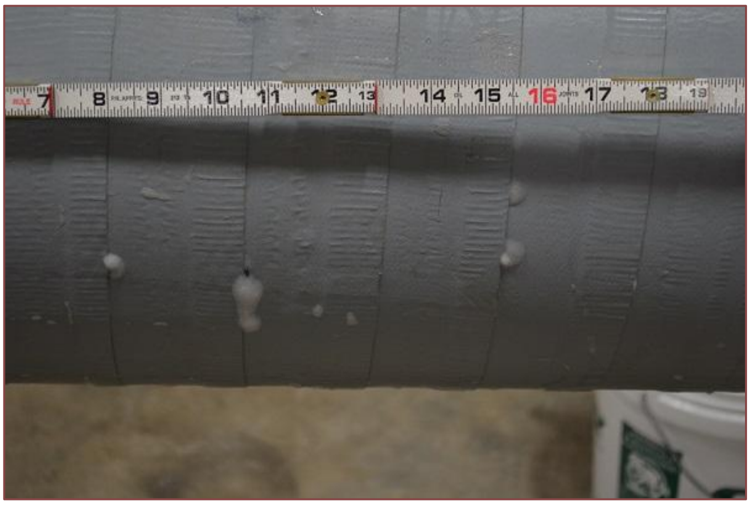

Figure 19. Soapy water inspection of cable wrap on shop test rig (note the bubbles indicating air leaks in the overlap areas)

Once the contractor successfully demonstrated the ability to wrap and seal the cable bands on the test rig, contractual provisions required two experimental panels on each bridge to be wrapped and heat sealed to the satisfaction of the construction management team. The purpose of the experimental panels was to demonstrate that the contractor could replicate the performance witnessed on the test rig while adapting to the actual cable and field conditions. This was particularly important for the heat sealing of the wrap, as field conditions such as ambient temperature affected the heating cycles required for proper sealing of the wrap.

3.4 Plant Rooms

The plant rooms house the mechanical systems for the development of a volume of stored dry air to be injected into the cables. Each plant room was required to be equipped with a desiccant wheel dehumidifier, plate heat exchanger and supply fans. The plant rooms were designed to function as insulated plenum chambers for the dehumidified air. This strategy allowed energy efficiency through passive heat recovery, close control of temperature and humidity and insulation against heat loss/heat gain. Standard off-the-shelf equipment was used to simplify future maintenance and reduce capital and long-term operational costs (Figure 20).

Figure 20: Injection fans with HEPA filters

The contract specifications provided the performance parameters for the plant rooms including the management of relative humidity, dew point, and internal pressure.

Moreover, to assist in reducing operational costs, the systems were required to be developed such that plant room relative humidity could be adjusted upwards and injection pressures/flows reduced, once the relative humidity at the exhaust points of the main cables was sustained below the target threshold.

The ability to adjust the system over time reduces energy consumption, electrical costs and long-term wear-and-tear on the equipment.

For the Westbound Bridge, the contract required two plant rooms, one in each of the concrete anchorages, to shield them from the harsh external environment. This provided the ability to specify lightweight modular construction such that all components could fit through the existing anchorage access doors. However, for the Eastbound Bridge, internal plant rooms were not feasible due to the location of the anchorages. Therefore, only one plant room was specified and located under the bridge on the approach-span deck truss.

This resulted in the plant room being exposed to harsh marine conditions including high wind speeds, solar gain, salt-laden marine air and low ambient winter temperatures. As such, it was required to be constructed of steel framework with twin-skinned insulated and vapor sealed stainless steel wall panels.

To facilitate system commissioning, the contract required the plant rooms and control systems to be preassembled in the shop and tested prior to delivery to the project (Figure 21).

Figure 21: Eastbound Bridge plant room preassembly and shop commissioning

Once the plant rooms and controls were witnessed by the construction management team and deemed functional, the contractor was authorized to ship them to site.

The requirement for shop testing was implemented to minimize field testing and troubleshooting, since the work could prove to be challenging with the remote location and limited access where the plant rooms were to be installed.

3.5 Dry Air Supply Piping and Injection/Exhaust Sleeves

The dry air developed in the plant rooms was required to be delivered to the cable by High-Density Polyethylene (HDPE) piping. The pipework was routed to the injection sleeves on the cable by messenger strands connected to the hand rope stanchions on the cable. The HDPE pipework was spirally lashed to the messenger strands for near-continuous support (Figure 22).

Figure 22. HDPE dry air supply pipework

The rigid HDPE pipework was transitioned to flexible stainless steel braided pipes where relative movement needed to be accommodated, such as at the injection sleeves on the cables (Figure 23).

Figure 23. Flexible stainless steel pipe transition to injection sleeve

The injection and exhaust sleeves are horizontally split stainless steel assemblies that accommodate either the injection pipe or exhaust port and integrate a network sensor box for data collection and monitoring purposes (Figure 24).

Figure 24. Cable injection sleeve (note sensor box on top)

Prior to installing the sleeves, the wrapping material and any existing wire wrapping was removed. The cable wires were wedged slightly open with zinc wedges to promote air ingress or egress. The two halves of the sleeves were then installed with specific circumferential and longitudinal gaskets and sealants. Similar to the cable bands, the objective is a robust, airtight and weather resistant seal.

3.6 Supervisory Control and Data Acquisition System

A supervisory control and data acquisition (SCADA) system was developed based on contract requirements to remotely monitor the plant rooms and cable sensors, as well as continuously collect the data from each. In addition, the SCADA network provides the feedback loop between the cable sensors and the plant room, as well as the plant room equipment and plant room program logic controller, such that the control system can adjust the system to maintain set-points for cable injection pressures and plant room relative humidity, respectively.

To monitor the dehumidification process, sensors are installed at the injection and exhaust sleeves on the cables in NEMA 4X boxes to protect them from the harsh atmospheric environment (Figure 25).

Figure 25: Sensors in NEMA 4X sensor box

The NEMA enclosure standards are defined in North America by the National Electrical Manufacturers Association (NEMA). For this application, the contract required an enclosure rating of 4X setting a standard for both corrosion protection, commonly used near salt water, and water tightness.

Flow, temperature, and humidity are monitored at injection and exhaust points, in addition to pressure at injection points. The injection pressure is both recorded and directly fed back to the dehumidification plant controllers to allow active control of the fan speed for a consistent injection pressure. A weather station is also installed to record weather data and the system feeds this data back to the plant room as well.

The system is accessed by either an operator interface terminal (OIT) in the plant rooms or remotely through the SCADA computer located in the MDTA administration building. The system is also accessible through a secure web-enabled interface.

3.7 System Commissioning and Operation

The system commissioning process included the evaluation of the mechanical, electrical and controls system in the field. Extensive checklists were used to evaluate the system and its performance. The process also included soapy water testing of the cable wrap and sealants to identify air leaks, as well as air flow trials to further evaluate system performance.

The Westbound Bridge dehumidification system was commissioned and operational in early 2014 while the Eastbound Bridge system was commissioned and operational by late 2015. The systems have remained in general operation since.

Data collected and analyzed from the SCADA systems on both bridges illustrate the systems are performing as intended. The graphs in Figure 26 demonstrate the efficacy of the Westbound System in two ways. The left graph plots the relative humidity over time for the first two years of operation to evaluate the cable drying process.

As can be seen, the relative humidity starts out quite high indicating the prevalence of moisture in the cable. However, within approximately the first nine months, the relative humidity has dropped and then sustained below 40% RH.

The graph on the right plots the cumulative water removed over time, which is not directly measured but calculated from the relative humidity and temperature data collected.

As can be seen again in the first two years, approximately 1,200 equivalent liters of water have been removed from the North Cable. Similar results have been observed for the South Cable and for the Eastbound Bridge.

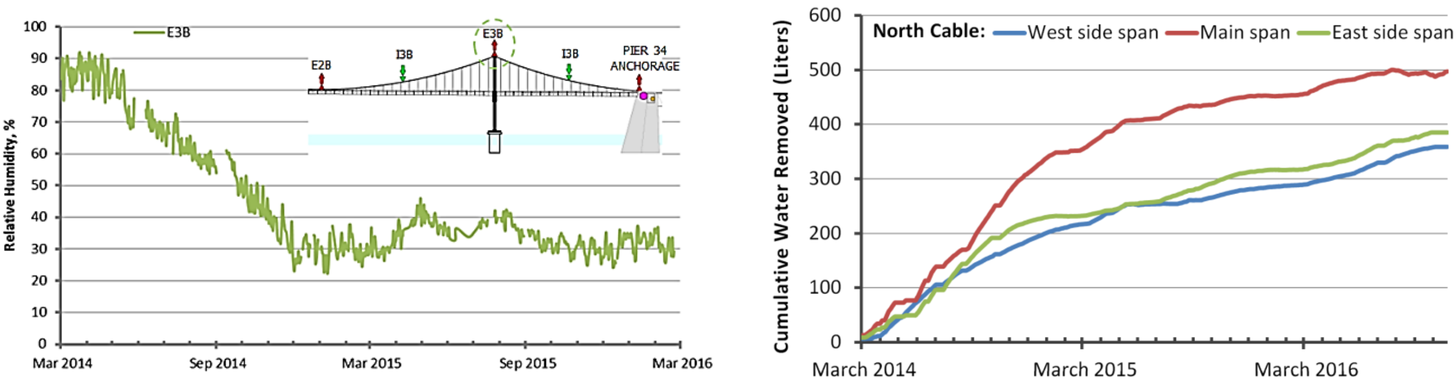

Figure 26: Westbound data – relative humidity over time (left); cumulative water removed over time (right)

3.8 Cable Access System

The contract documents required both low-level and high-level access to the main suspension cables; however the means and methods were left to the contractor. Specifications were developed to convey the constraints for cable access, including minimizing disruptions to traffic and sustained lane closures.

In response, the contractor implemented a temporary main cable access platform (catwalk) that ran continuously from one end of the cable to the other (Figure 27). The access platform allowed multiple tasks to occur on the cable simultaneously, such as removing the existing wrapping, installing new wrapping, sealing the cable bands and erecting the dry air piping. It was interesting to note that the method of access to the cable was different than the traveling gantries that had been used on the UK projects.

There are advantages and disadvantages to each, which the market and project constraints will dictate. However, since the Bay Bridge has been completed, similar full-length platforms have been used on other cable dehumidification projects in the US.

Figure 27: Main cable access platform; Westbound Bridge shown, Eastbound Similar (Photo Credit: Christian Christodoulou, AECOM)

4. CONCLUSION

The dehumidification of the cables on the Bay Bridge, as well as other structural and preservation work was completed in approximately 30 months. The project was the first-of-its-kind in North America and garnered a lot of attention in the industry, including five regional and national awards, and has since set the stage for the adoption of cable dehumidification as a preservation strategy on eight other bridges in the US.

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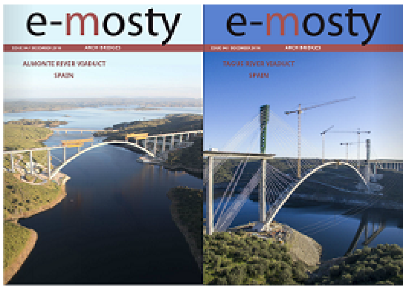

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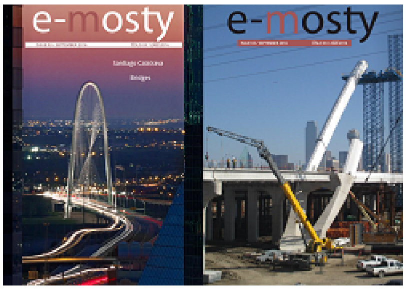

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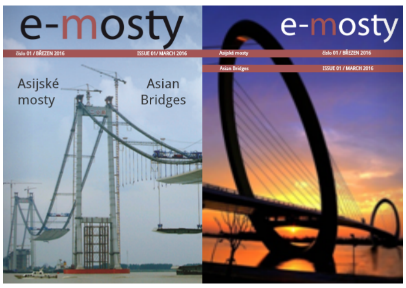

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