e-mosty

ISSUE 01 / 2019 March

Long Span and Multiple Span Bridges

1915 Çanakkale Bridge   Chacao Bridge   Maputo - Katembe Bridge

Chacao Bridge, Chile

Front Cover: Chacao Bridge, Chile. Photo Credit: MOP Chile
Back Cover: 1915 Çanakkale Bridge, Turkey. Photo Credit: COWI

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Dear Readers

First article of this issue brings an overview of design of the ***1915 Çanakkale Bridge*** *which is a suspension bridge under construction in Turkey. When complete it is going to be the longest suspension bridge in the world.*

Next part of the magazine focuses on the ***Chacao Bridge*** *in Chile. It is a multi-span suspension bridge under construction. We have prepared a general overview of the project. It is followed by an article written by Alvaro F. Alrruiz Fajuri describing design of the bridge accompanied by drawings and a photo gallery.*

Design and Construction of the ***Maputo – Katembe Suspension Bridge*** *in Africa is briefly described by Konstantinos Papanikolaou. The article is also accompanied by drawings and a photo gallery.*

Last article of this issue was written by David Collings. He provides an overview of ***multi-span suspension bridges.***

*We agreed with Lawrence Shackman that we will continue in our cooperation - we are happy to provide continuous support to his initiative "****Bridge to the Future to help beat Cancer****".*

We also go on with supporting Bridges to Prosperity and Bridging the Gap Africa. And we are a medial partner of the ARCH 2019 – 9th Conference on Arch Bridges.

I am happy to announce that the company ***Rúbrica*** *will be our partner in 2019 again. Together with* ***ARUP***, ***COWI*** *and* ***BERD***, *four companies have already confirmed partnership for 2019. Thank you all very much for your support.*

Let me announce that first Issue of our new magazine ***e-maritime*** *will be published on 30 March on www.e-maritime.cz. It will focus on specialized vessels. The magazine is with open access, similarly to e-mosty, and you can also subscribe here.*

We have established separate LinkedIn pages for both magazines, and we invite you to follow us. We will mostly share information on the content of the magazines, editorial plan, details of the projects and articles, and their photos. We will also promote some specific projects (conferences, books, charities etc.).

I would very much like to thank all people and companies who have helped me prepare this issue, to all the authors and also to our partners.

Magdaléna Sobotková

e-mosty e-maritime

e-mosty

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

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

It is published quarterly: 20 March, 20 June, 20 September and 20 December. The magazines stay **available on-line** on our website. It is also possible to download them as **pdf**.

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

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

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

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

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

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e-maritime

The magazine **e-maritime is an international, interactive, peer-reviewed magazine about vessels, ports, docks and maritime equipment**.

It is published on www.e-maritime.cz **three times a year:**
30 March, 30 June and 30 November.

September Issue is shared with the magazine e-mosty ("e-bridges"):
"Vessels and Equipment for Bridge Construction"
which is published on 20 September on www.e-mosty.cz.

It can be read **free of charge** (open access) with possibility to subscribe.
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We aim to include all important and technical information
and show the grace and beauty of the vessels and structures as well.

SUBSCRIBE

Acknowledgement

We would like to thank the following people and companies for cooperation on preparation of the articles in this issue; thank you very much for your time and assistance.

1915 Çanakkale Bridge

Mark Page, Head of UK Communications and Marketing, COWI

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Chacao Bridge

Alvaro F. Alrruiz Fajuri, Inspector Fiscal Puente Chacao, MOP Chile

Eduardo Fernandez de la Pradilla Hernaiz, Construction Manager for the Supervision Team, COWI

Arturo Galvez, General Manager for the Supervision Team, RyQ Ingeniería

Joe Showers, Engineering Manager for the Supervision Team, COWI NA

Maputo – Katembe Suspension Bridge

Konstantinos Papanikolaou, CEO at INSTAT SA

Multiple-Span Suspension Bridges

David Collings, Technical Director, Arcadis; Researcher and Associate Lecturer, University of Surrey

Special thanks to Members of our Editorial Board:

Richard Cooke, David Collings, Juan C. Gray, Ken Wheeler and Derya Thompson.

1915 ÇANAKKALE SUSPENSION BRIDGE

Magdaléna Sobotková

Figure 1: Rendering of the bridge
Source: 1915canakkale.com

Commencement of works: 2017

Planned opening of the bridge to traffic: 2022/3

Type of the bridge: Steel Suspension Bridge

Main span: 2,023m

Total length: 4,608m (including 4 viaducts)

Location: Çanakkale, between Gallipoli and Lapseki, Turkey

1915 ÇANAKKALE

Client: The General Directorate of Highways (KGM)

Concessionaire: ÇOK İYİ A.Ş

Engineering Consultants for KGM:

Parsons in JV with Tekfen Engineering

T Engineering for Parsons

Contractor: Consortium DLSY - Daelim, Limak, SK E&C, Yapı Merkezi

Contractor´s Design Team:

COWI with sub consultant PEC

Independent Design Verifier: Arup with sub consultant Aas-Jakobsen

INTRODUCTION

Turkey serves as an important crossing between Asia and Europe. Its rapid economic growth together with increased number of tourists, agriculture and transit transport has led to chronic traffic congestion.

The existing transportation network cannot accommodate all demands arising from the traffic growth.

To address these problems, the Turkish Government announced the Vision 2023 programme, which aims to increase the road, rail and sea transport capacities.

Part of the programme is a new suspension bridge across the Dardanelles which is expected to improve the transportation network on the west side of the country, promote socio-economic growth and tourism.

In particular it will provide an alternative route for European traffic to and from Izmir, Turkey's 3rd largest city, avoiding Istanbul.

The bridge with its main span of 2,023m is going to be the longest span suspension bridge in the world when it opens to traffic.

LOCATION OF THE BRIDGE

The 1915 Çanakkale Bridge (in Turkish 1915 Çanakkale Köprüsü) is located 200km southwest of Istanbul, spanning the Dardanelles Strait, which connects Lapseki District to the Gelibolu District (Gallipoli).

The strait forms a natural division between Europe and Asia and it connects the Marmara Sea with the Aegean and Mediterranean seas, as can be seen in Figures 2 and 3.

The bridge forms central part of the 321km long Kınalı -Balıkesir Highway, which will connect the O-3 and O-6 highways in East Thrace to the O-5 highway in Anatolia.

The 1915 Çanakkale Bridge is part of the programme, which expands earlier major transportation projects such as the Gebze-Orhangazi-Izmir Highway with the Osmangazi Bridge.

The project is expected to increase capacity, improve traffic flow and ease the present and future congestion problems.

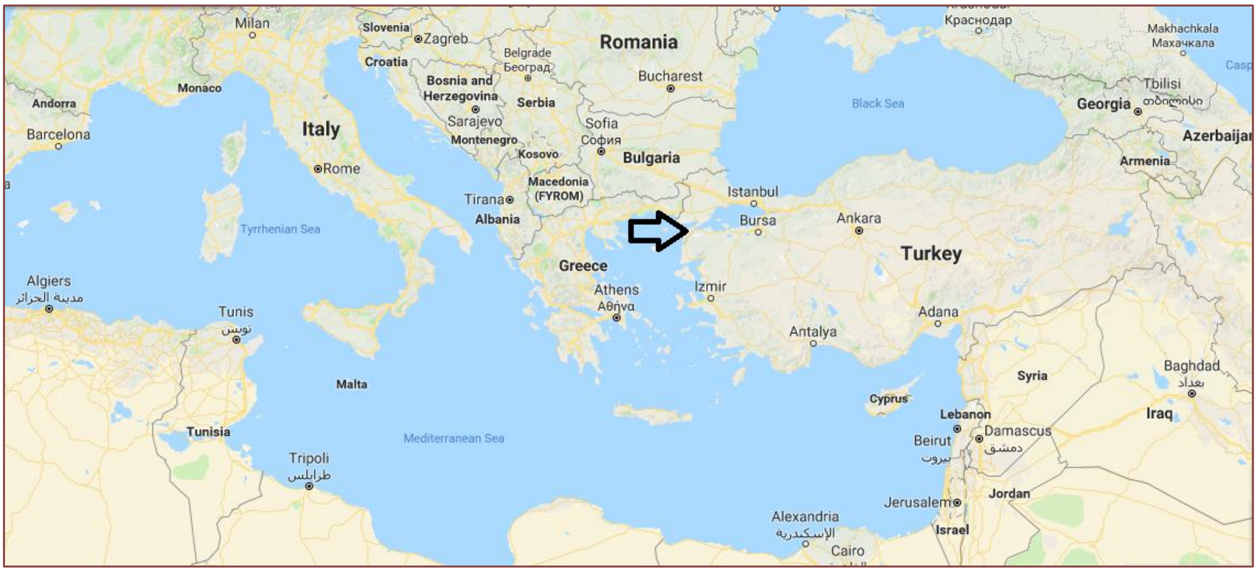


Figure 2: Location of the bridge on the map

Source: Google Maps

Figure 3: Overview of the whole project
Source: 1915canakkale.com

BRIDGE PROJECT DESCRIPTION

A consortium made up of South Korea´s Daelim and SK E&C, Turkey´s Limak and Yapı Merkezi won the tender for the construction of the bridge on 26th January 2017 by offering the shortest concession period of just over 16 years, which includes a Minimum Revenue Guarantee once the bridge is opened to traffic.

The General Directorate of Highways (KGM) awarded the 1915 Çanakkale Bridge and Highway Project within the framework of a Public Private Partnership model to the consortium, which subsequently established a joint-venture company (Commissioned Company), Çanakkale Otoyol Köprüsü İnşaat Yatırım İşletme A.Ş. (Çanakkale Motorway Bridge Construction Investment Management Inc.).

The EPC contract for the bridge was signed in an official ceremony on 16th March 2017.

The consortium will build, manage and operate the completed bridge for 16 years and two months under BOT basis.

The four companies each have an equal share of 25% in the project.

The bridge will be handed over to the Turkish Government after completion of the operation period.

The bridge is expected to be built at a cost of around 2 billion USD. Another 0.8 billion USD covers the cost of the motorway.

The ground-breaking Ceremony took place on 18th March 2017. Opening of the bridge is planned in 2022, in advance of the centenary anniversary of the declaration of the Republic of Turkey in 1923.

GENERAL DESIGN

The main structure will be 3-span steel suspension bridge. The bridge length will be 3,563m and together with two approach viaducts the total length will be 4,608 m.

The main span of the bridge will be 2,023m with 770m side spans. The Gallipoli approach viaduct will be 900m long and the Lapseki approach viaduct will be 650m long.

Towers and Sea Foundations

The towers will be 318m high, making the bridge the second tallest in Turkey, just 4m shorter than the Yavuz Sultan Selim Bridge. Each tower is founded on a cellular concrete caisson measuring 83m by 74m in plan.

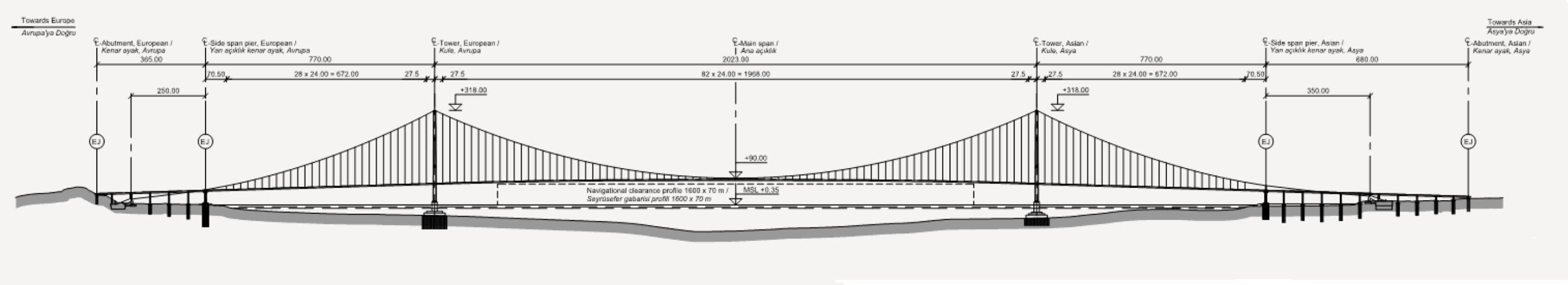


Figure 4: Elevation of the bridge

Each caisson was initially built in a dry dock that had been prepared on the European side of the strait.

After the main sections were built, the caissons were floated by controlled flooding of the dry dock and moved to deeper water.

Construction continues with the installation of the steel shafts that will support the tower legs. This is done in the ‘wet dock’ as the structure sinks deeper under the increased weight.

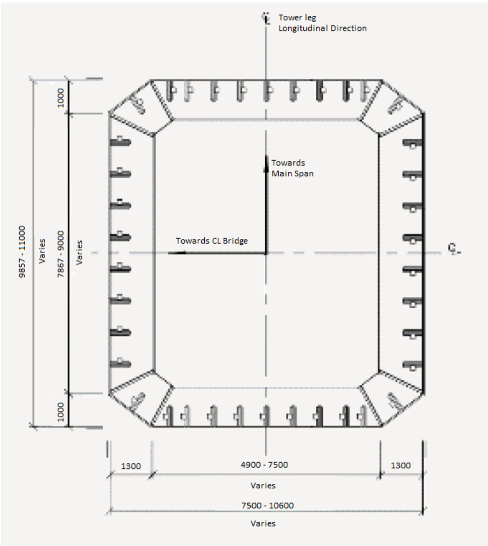


Figure 5: Plan of tower segment

After installation of the caissons at the site the steel shafts are filled with concrete and solid 10 m high plinths connected with a tie-beam are cast.

At the same time the sea-bed, which comprises Miocene mudstone, was prepared by dredging to get a level platform.

Then 2.5m diameter open ended steel inclusion piles were driven into the mudstone. There are 192 piles below the European tower with lengths up to 46 m and 165 piles below the Asian tower with lengths of 21 m.

The piles reduce tower settlement by about 80% and increase the lateral resistance of the foundation in the event of ship impact or seismic action.

However the piles are not directly connected to the caisson foundation. Instead a 3m thick gravel bed is placed around the head of the piles on which the caisson is placed after controlled immersion in water up to 45m deep.

This arrangement allows the tower to articulate by sliding during a major seismic event.

Steel towers were selected for fast erection. They comprise tapered box sections with a chamfered corner.

Figures 6 - 8: Renderings of the bridge. Source: 1915canakkale.com

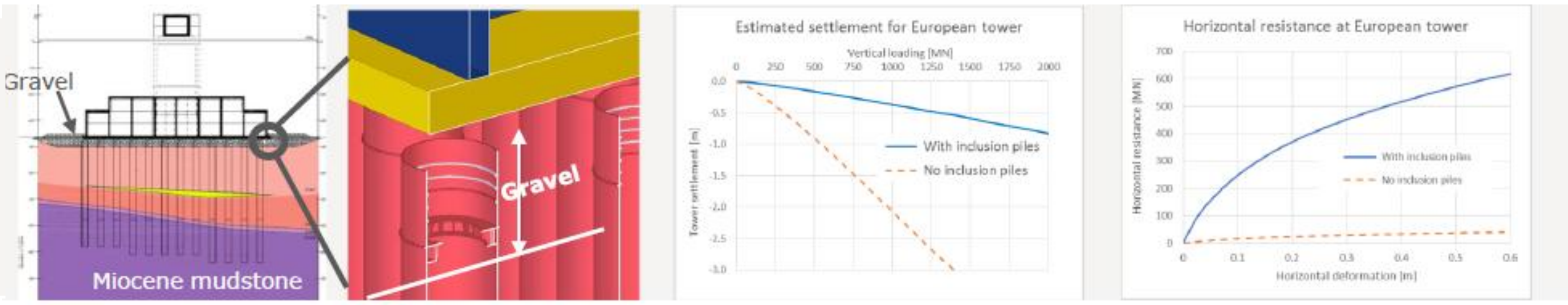


Figure 9: Ground improvement for tower foundations

Wall panels are pre-assembled and lifted into position. They are connected with horizontal block joints, welded skin plates and bolted splice connections of the longitudinal stiffeners.

This method enables fast construction with the possibility to erect further blocks above before finalising welding works.

Anchorages and Cables

The ground conditions for the anchorages are critical in order to resist the massive forces from the suspension cables.

There is weak soil on both the European and Asian shorelines, so the side spans were increased to take advantage of founding the anchor blocks within the Miocene rock further from the shore.

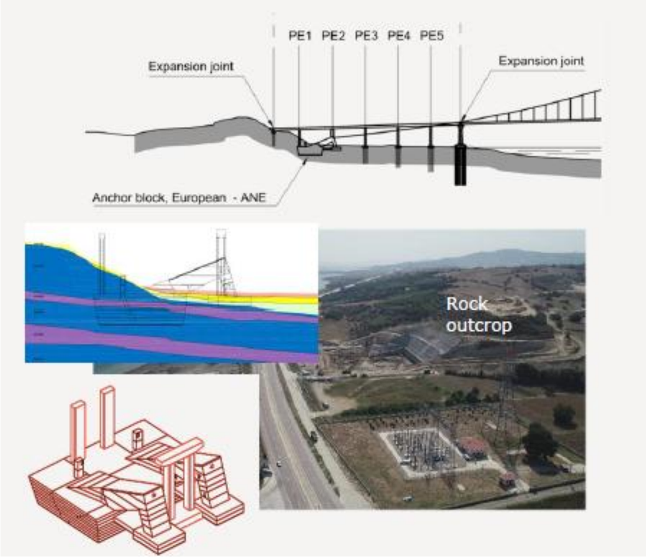
Like the Osmangazi Bridge, the anchorages are designed to minimise their height so that the tension forces are transmitted directly to the foundation blocks, reducing the over-turning moment. The anchorages are positioned below the decks of the approach viaducts at each end. This means that they are set back from the end of the 770m suspension bridge side spans.

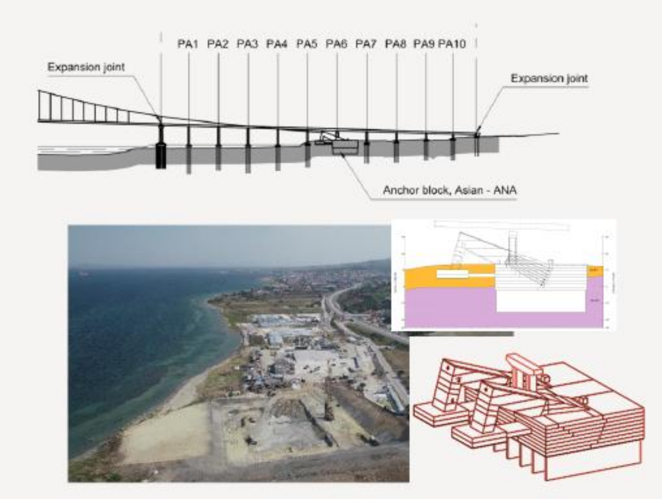
The suspension cables are formed of PPWS – Prefabricated Parallel Wire Strand – which are continuous between the anchorages. The tie-down, each comprising 4 No. tensioned bars, is clamped to the main cable and transfers load directly to the piled foundation of the side span pier.

Superstructure

The deck of the bridge will be at a maximum height of 72.8m creating a clearance of 70 x 1600 m, and will have a total width of 45.06m and an overall depth of 3.5m. It will carry six lanes (three in each direction), together with a maintenance walkways on each side.

The bridge deck comprises two stiffened steel box girders spaced 9m apart, connected by 3.5m deep cross-girders every 24m.





Figures 10 and 11: Ground conditions – anchor blocks

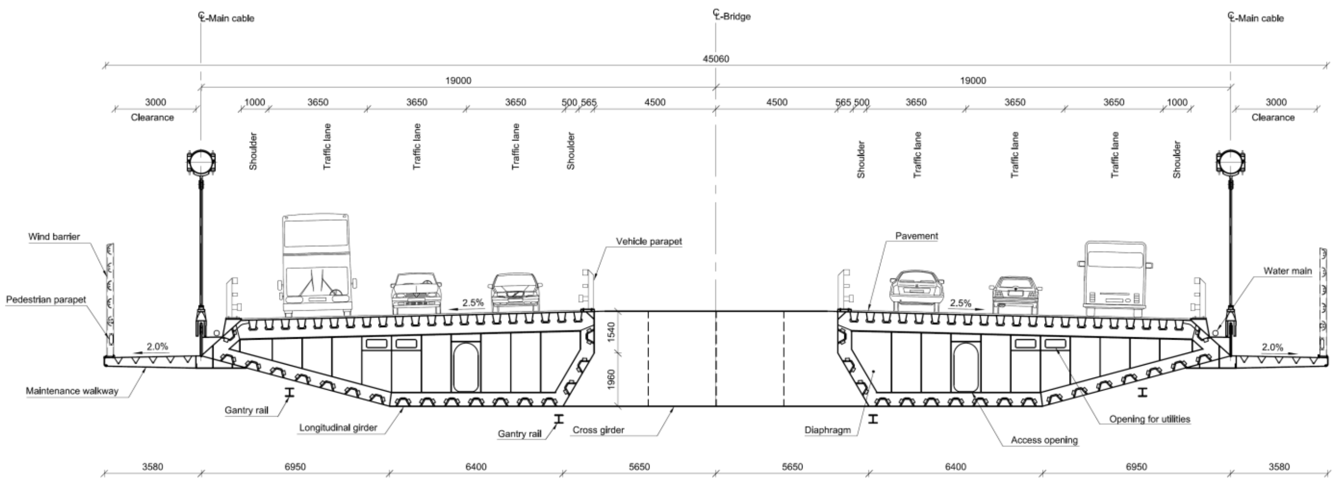


Figure 12: Deck section

The twin section steel box section deck reflects the technology recently used on other long span bridges.

The design considers traffic loading as follows:

- Loaded lengths < 200 m UDL = 81.8 kN/m (6 lanes) based on Eurocode 1991-2 load model 1, 2 and 3
- Loaded lengths > 200 m UDL = 58.8 kN/m (6 lanes) EN 1991-2 SE-NA taking effect of long loaded length into account

The approach span sections at each end are of prestressed concrete box section construction.

AERODYNAMIC TESTING

Aerodynamic modelling and testing of long-span bridges is essential to understand the response of the structure to the dynamic effects of wind and to optimise the design to achieve stability. Analysing of local wind data gave a basic wind speed of Vb=29 m/s, giving V=46 m/s at deck level (+86.0).

Wind tunnel testing was carried out in three locations, looking at specific characteristics:

- Deck section model at 1:60 scale in Canada
- Tower section model (1:80 scale), full tower model (1:225) and tower erection stages (1:225) in Denmark
- Full bridge model (1:190) and deck erection stages (1:190) in China.

Aerodynamic stability was verified (with additionally damping of the towers) through wind tunnel tests of the full aeroelastic model of the bridge.

Each box is shaped to minimise the effects of wind forces and to maintain aerodynamic stability. A number of different profiles were tested to optimise the behaviour with variations to the geometry of the inner web, gap width and the use of different heights of wind screens.

Flutter stability is dependent on mean twist angle of bridge girder due to mean wind loading and to ensure stability the models must prove that the deck remains stable with a wind speed of about 70m/s.

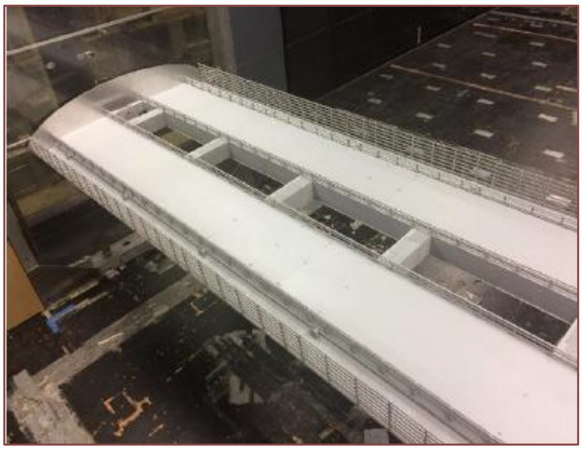
SHIP IMPACT

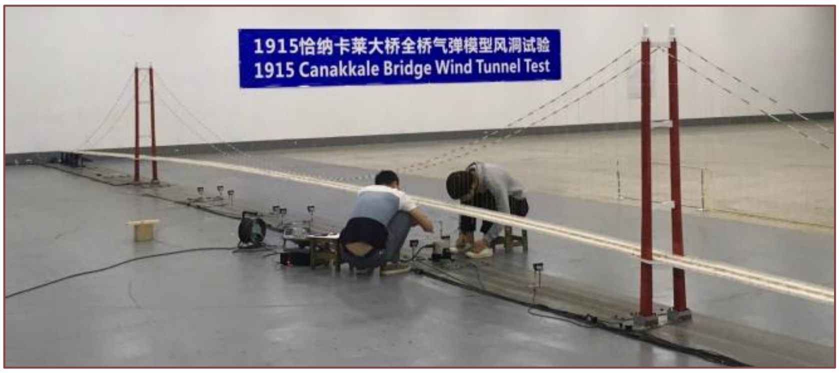
The navigation clearance envelope for the bridge is 1600m wide by 70m high, centred on the main span. However the design needs to consider potential impact by shipping, and the lower sections of the towers, up to 29.5m above sea-level, are exposed to ship impact.

The design requirement is for a 180,000 DWT ship, 370m long and 52m wide, impacting at an angle of up to 30 degrees and imparting a global impact force of 370 MN. These loads are then transmitted through the composite shafts and caissons.

Semi-local and local impact governs the steel tower leg design up to +29.5m. The box sections are stiffened with horizontal diaphragms and skin plate thickness has been increased to deal with these actions. Horizontal stiffeners are also added to increase local bending resistance of the skin plates.

Strict design criteria have been introduced to achieve minimal damage of non-accessible parts of foundations under accidental load.





Figures 13 and 14: Wind tunnel testing

This has resulted in specific design challenges and detailing of reinforcement, e.g. diagonal bars in some walls and slabs.

SEISMIC ANALYSIS

The bridge is located relatively close to the North Anatolian Fault but does not cross it directly. The design criteria consider 3 potential events:

- Functional Evaluation Earthquake (FEE) – 125 year return period
- Safety Evaluation Earthquake (SEE) – 975 year return and
- No Collapse Earthquake (NCE) – 2475 year return

The analysis applies displacements in three directions and these are applied at the six main supports – two anchorages, two end supports and two towers. Seven sets of time-displacement actions are applied to the dynamic finite element model to understand the non-linear element behaviour. This included the influence of using hydraulic buffers at the towers, wind bearings and soil-structure interaction.

PROJECT BENEFITS

The bridge will provide direct access from Europe to the south-western part of Turkey, while boosting economic development in the western region.

By providing a direct link to the south-west region, the bridge will also reduce traffic congestion in Istanbul, which witnesses high-traffic inflow from Europe.

The project will also help in improving traffic safety by reducing the number of intersections, which are a major cause for accidents.

Source:

www.1915canakkale.com

Presentation "1915 Canakkale Bridge design – meeting the challenge". COWI. Istanbul Bridge Conference, 5 – 6 November 2018

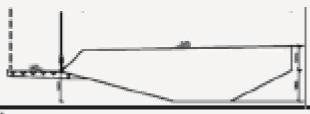
Deck no	Deck configuration	a [°]	V_{cr} [m/s]	Comment
A1	9m gap, inner web 1 4m wind screens 	-1.5 0.0 +1.5	53 66 >71	Failed
B3	9m gap, inner web 2 5m wind screens 	-1.5 0.0 +1.5	64 >78 >69	OK
C3	9m gap, inner web 3 4m wind screens 	-1.5 0.0 +1.5	65 >77 >69	OK - preferred

Figure 15: Testing of various profiles

CHACAO BRIDGE

General Overview

Magdaléna Sobotková

Figure 1: View of the Bridge Rendering: Courtesy of MOP Chile

Commencement of works: 2014

Planned Opening of the bridge to traffic: 2023

Type of the bridge: Multi-Span Suspension Bridge

Main spans: 1,055m + 1,155m

Total length: 2750 m

Location: Chacao Strait, Chile

Client: MOP (Ministry of Public Works of Chile)

Contractor: CPC (Consorcio Puente Chacao)

The Consortium comprises Hyundai Engineering & Construction, OAS, Aas-Jakobsen and Systra

Detailed Design: Aas-Jakobsen AS, SYSTRA

Supervision and Design Review:

JV COWI and RyQ Ingeniería

I. DESCRIPTION OF THE PROJECT

The Chacao Channel Bridge is a bridge currently under construction to link the Isla Grande de Chiloe with mainland Chile by crossing the Chacao Channel in Southern Chile, about 600 miles south of Santiago.

At present, the only way to reach Chiloé is by a 25 to 45-minute ferry trip.

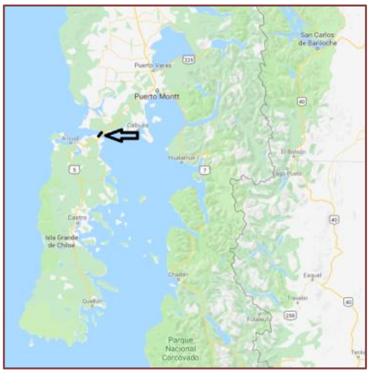
With the bridge, the time would be reduced to less than three minutes.

The project consists of a 2,750km long double suspension bridge with two main spans of 1050m and 1150m, an orthotropic steel box girder deck, four lanes, one central and two exterior shoulders and a central tower of an inverted Y-shape supported on rock of Roca Remolinos.

Although its construction was scheduled to start in 2007, the project was cancelled and then re-launched in 2012 when the Chilean government decided to issue an international tender for the re-design and construction of the bridge.

The Design-Build project comprises of three different public works projects: the suspension bridge, the access roads, and a service area with maintenance and visitor buildings.

Opening of the bridge is planned for 2023.



Figures 2 - 4: Location of the bridge on the map

Source: Maps Google

II. HISTORY

In 2005 Consorcio Puente Bicentenario was awarded a 35-year concession contract from the Chilean Ministry of Public Works for the design, financing, construction, operation and maintenance of a suspension bridge across the Chacao Channel.

The consortium consisted of Hochtief, Vinci Construction Grand Projets, American Bridge, Besalco and Tecsa. Hochtief, Vinci and American Bridge each owned 27% of the venture, and Besalco and Tecsa owned 9% each.

Hochtief was a leader, Vinci as technical lead and American Bridge to contribute with cable spinning and deck erection technology.

The construction project costs were estimated at USD 410,000,000.

The construction was supposed to commence in 2007 and terminate in 2012.

In 2006 it was announced that the estimated cost was above the limit and it was decided not to continue with the project.

In 2009 revival of the project was commenced and in 2012 an open international bidding process to present the best solution for the construction of the bridge was started.

The total investment limit was set up at 740 million USD.

III. RECENT PROJECT

The engineering, procurement and construction (EPC) contract for the project was awarded in 2014 to the consortium of Hyundai Engineering & Construction, OAS, Aas-Jakobsen and Systra.

The consortium is also funding the project.

Aas-Jakobsen and SYSTRA are responsible for the detailed design; SYSTRA is specifically responsible for producing geological, geotechnical and seismic studies, detailed designs for the foundations and designs for the central tower, the steel deck and anchoring systems.

The key technical challenges on this project are associated with the definition of the loads applied (impact of boats, wind and seismic activities) and the particularly complex design models.

The 84-month schedule has required rapid evaluation of design alternatives, streamlined design studies, highly collaborative workflows, and accelerated reviews.

Louis Berger delivers technical advisory services, including the seismic and aerodynamic analysis and evaluation during the tendering phase of the project.

The Project was awarded on 17th February 2014 for 360,134,000,000 Chilean pesos, which, at the exchange rate of the time fluctuated but they were roughly equivalent to approximately US$ 658M. At today´s exchange rate that would be US$ 546M.

The US$ 740M figure is the total government investment on the project and it includes other items and not only this contract.

When construction is complete, MOP will assume responsibility for operations and maintenance of the bridge.

MOP instructed the project team to consider operations and maintenance efficiency and economy in the bridge design, so the Ministry anticipates that the lifecycle costs of this infrastructure asset will be optimized.

Overall, MOP credits the high-quality design for this multi-span suspension bridge to the team's using the most advanced bridge engineering applications available.

Figures 5 – 7 : Renderings Courtesy of MOP Chile

IV. DESIGN

The bridge is a multi-span suspension bridge. It will be 2,750 long, with two main spans of 1,055m (south span) and 1,150m (north span), one suspended side span of 324m and one viaduct of 220m.

The bridge will have the capacity to accommodate four traffic lanes. The rock formation in the middle of the 125m-deep channel provides a base for the mid-channel.

The new bridge is designed to have a lifespan of more than 100 years.

The bridge will feature three concrete towers, with an inverted Y-shaped central tower measuring 175m-high.

The remaining two towers will be 157m and 199m-high respectively. The central tower is designed as an inverted Y to increase the stiffness of the system and provide a fixed point to the main cable.

Because the bridge is asymmetrical, with two spans of different lengths, the three pylons carry the burden of balancing the uneven loads.

The central, 175-meter tower became the focus of intense mitigation efforts when subsidence of the mid-channel rock formation created a construction challenge. The problem was solved performing 3D computational analysis aided in evaluating alternatives and improving the design of the central tower.

The deck is an orthotropic steel box girder with a total steel weight of 20,700 tonnes. The bridge girder is continuous from the South pylon to the North abutment.

The main cables will be 561mm in diameter with total weight of 8,900 tonnes, and are expected to be erected by the PPWS (pre-fabricated parallel wire strand) method. Preformed wire strands will be delivered to site in spools, unwound, and installed on site.

The Chacao Bridge will have a vertical clearance of 50 meters, plus a 2.5-meter 'safety space.' The navigation channel for the 2.8-kilometer bridge will be 600 meters wide.

When work began in 2014, the project team confronted several extreme challenges in designing the multi-span suspension bridge across Chacao Channel. The project site is in a remote area of the Los Lagos region, 1,100 kilometers south of Santiago.

The channel separates the 200-kilometer-long island from the mainland, but both land masses are part of the coastal range noted for high seismicity.

The bridge is just 80 kilometers from the fault zone where a disastrous 9.5 magnitude earthquake struck Valdivia, Chile, in 1960. In 2010, an earthquake of 8.8 magnitude struck offshore of Concepción, about 650 kilometers north. Seismicity was the most challenging design criteria for the team.

Additionally, the channel is prone to critical winds of up to 208 kilometers per hour, and ocean currents reach 9.7 knots or 18 kilometers per hour, with 8 meter waves.

The deep channel plunges 120 meters to the sea floor.

Mid-channel, rock protrudes enough to provide a base for the central support tower, but it presented problems with subsidence.



Figures 8 – 10: Renderings of the Bridge. Courtesy of MOP Chile

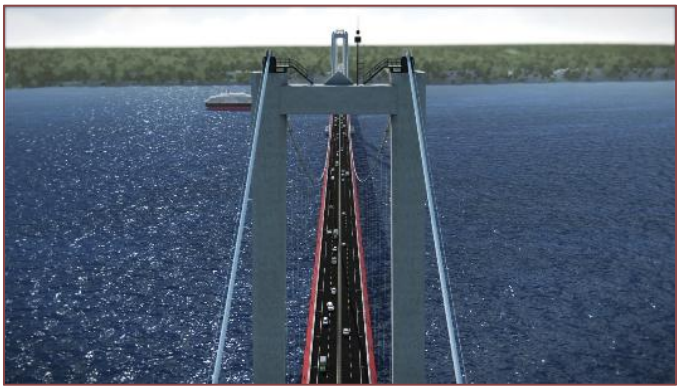


Figure 11: Renderings of the bridge   Courtesy of MOP Chile

V. STUDIES AND ANALYSES

To ensure the safety and serviceability of the bridge under these conditions, and adhere to strict environmental qualifications that protect local flora and fauna, archeological zones, and aboriginal communities, the project team performed global analysis and time-history analysis in addition to multiple engineering studies.

The analyses investigated factors influencing linear, non-linear, static, and dynamic behaviours, and the studies included bathymetric, geodesic, geologic, geotechnical, seismic, topographic, and wind climate investigations.

The bridge is located in a highly seismic region. One of the largest earthquakes in the world was in 1960 in Valdivia which is located between Talca and Chiloé Island.

The structural design of Chacao Bridge was guided by seismic design criteria according to AASHTO LRFD Bridge Design Specifications (2012), in conjunction with Chilean Standards (*NCh*).

The seismic analysis focused on specific response criteria for both bedrock and soil behavior. The effects of wave impacts in the event of a tsunami also had to be considered. This comprehensive probabilistic seismic hazard analysis (PSHA) defined the structural response to seismic activity.

Quite extensive aerodynamic studies have been carried out; they are fundamental to guarantee the stability of the bridge. They are also distinct from the wind studies, which were just used to determine the wind parameters for the bridge design and the aerodynamic studies.

Wind tunnel analysis studied the bridge's aerodynamic stability both in parts (deck, towers, suspension cables) and as a whole.

VI. CONCLUSION

With a 100-year design life, the Chacao Bridge will improve quality of life, commerce, and tourism for the Island of Chiloe and the port city of Puerto Montt.

The bridge will replace the ferry service across the rough channel and shorten the trip to minutes. Improved access and mobility between the mainland and the island will encourage an influx of professionals to live and work in the area, creating the opportunity for new development.

Ultimately, Chacao Bridge will connect the Island of Chiloe to Chile's highway system, uniting the island community with the rest of the country.

The Chilean government estimates the advent of improved commerce will result in a 6 percent social return on investment in the region.

The Chacao Bridge is an emblematic project, as the first long-span suspension bridge in Chile.

It represents an opportunity for the exchange of technological know-how among MOP and the partners participating in the consortium, and demonstrates that Chile provides a favourable business climate for developing large-scale projects.

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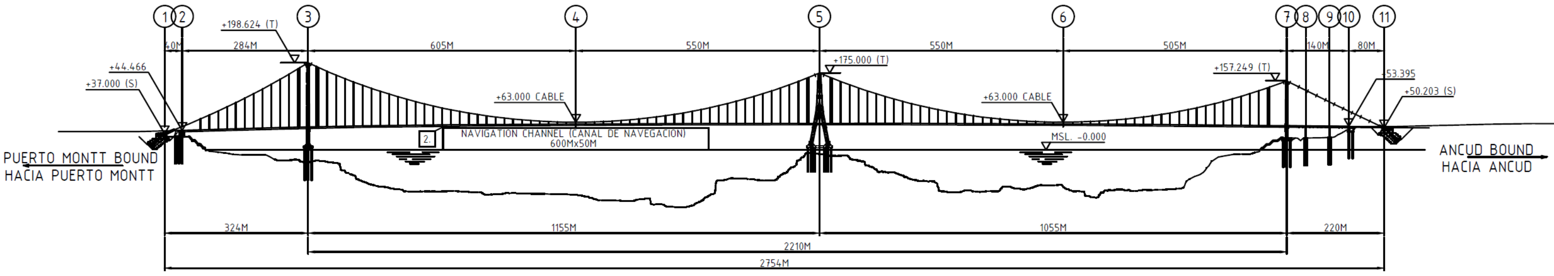
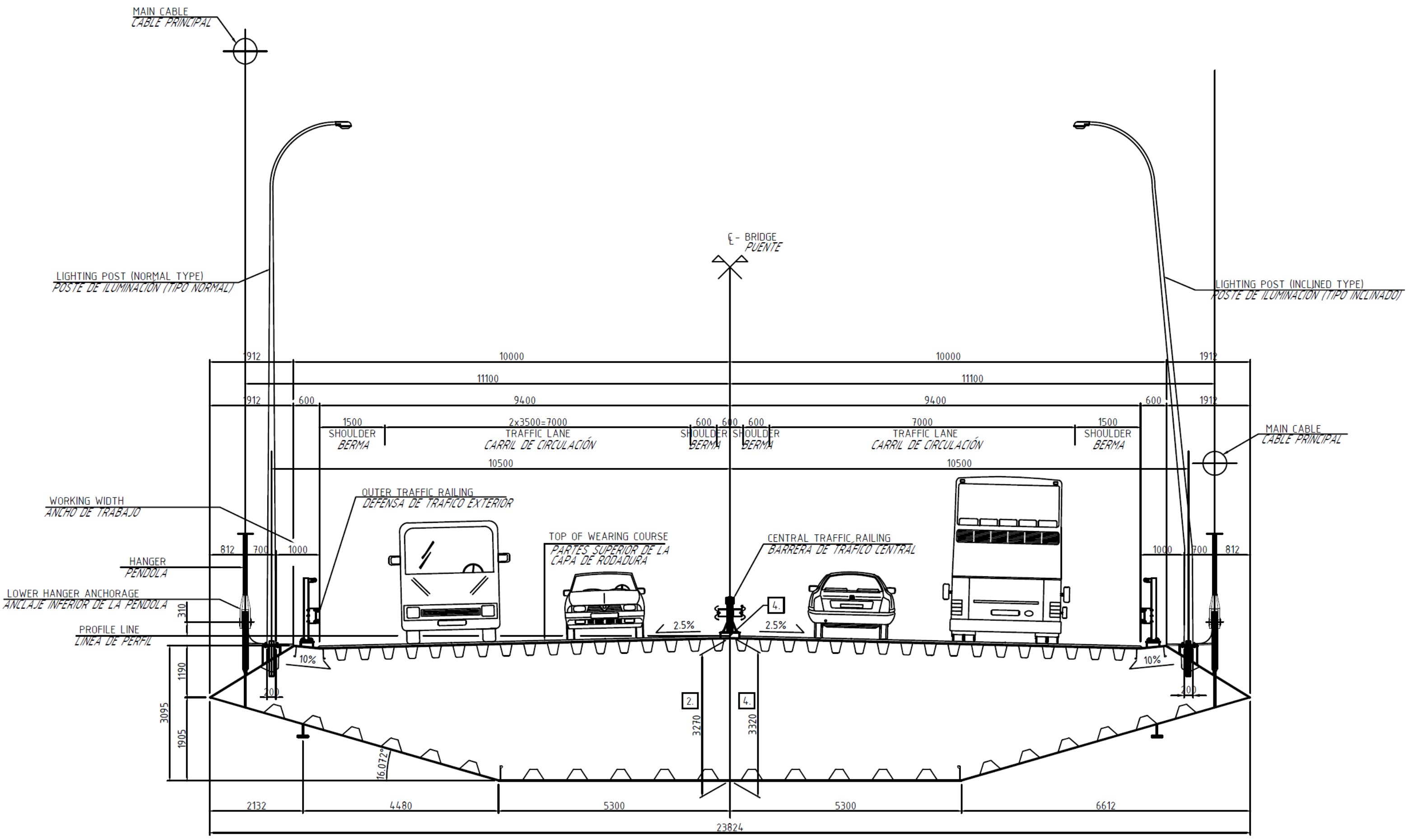
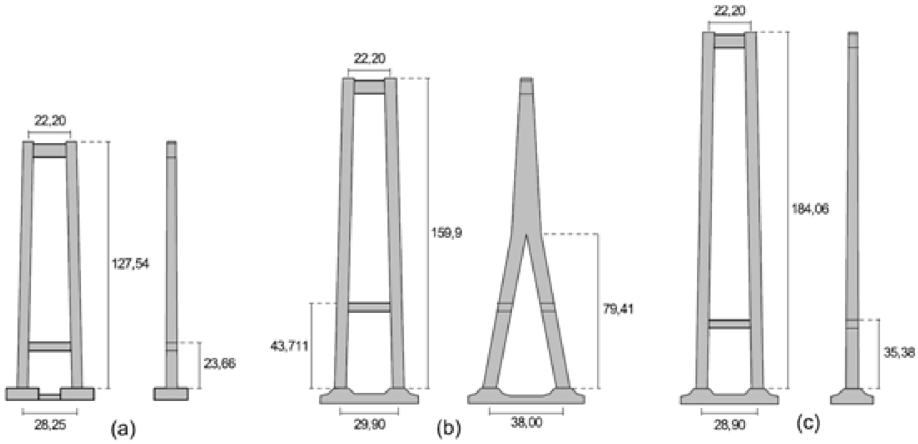
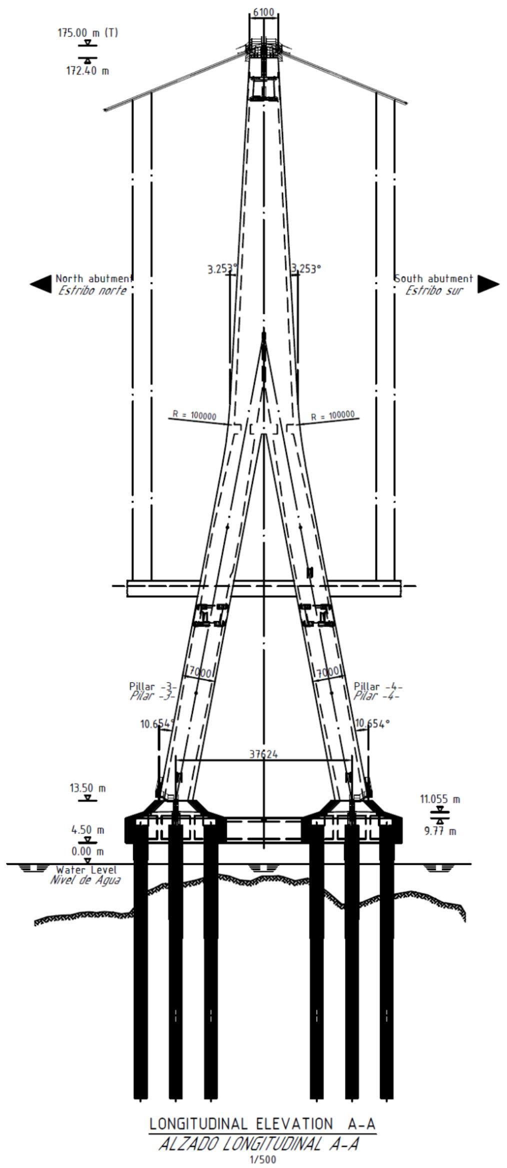


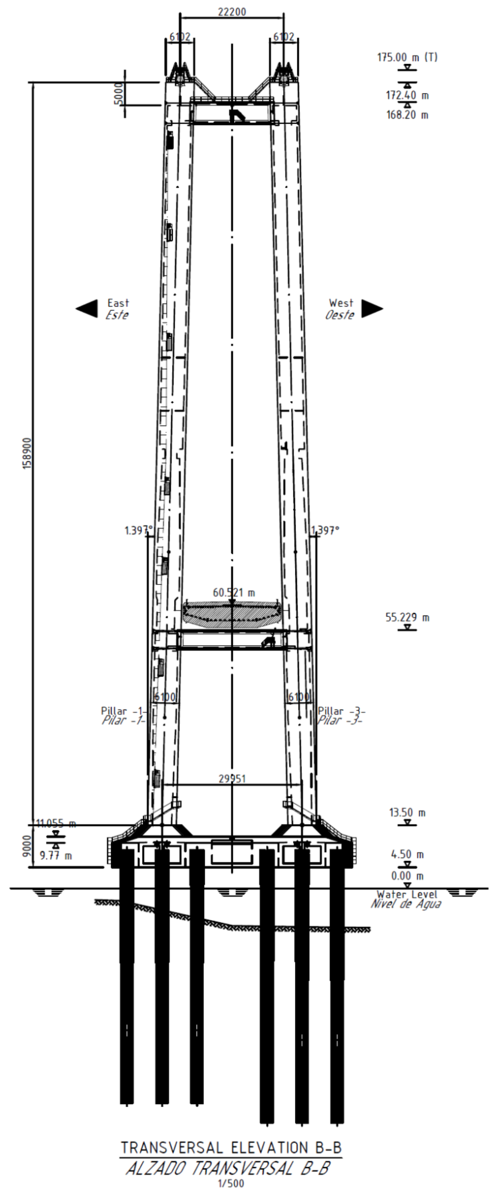
PUERTO MONTT BOUND
HACIA PUERTO MONTT
ANCUD BOUND
HACIA ANCUD
NAVIGATION CHANNEL (CANAL DE NAVEGACION)
600Mx50M
+198.624 (T)
+175.000 (T)
+157.249 (T)
+63.000 CABLE
MSL. ±0.000
324M
1155M
1055M
220M
2210M
2754M



MAIN CABLE
CABLE PRINCIPAL
LIGHTING POST (NORMAL TYPE)
POSTE DE ILUMINACIÓN (TIPO NORMAL)
LIGHTING POST (INCLINED TYPE)
POSTE DE ILUMINACIÓN (TIPO INCLINADO)
℄ - BRIDGE
PUENTE
SHOULDER
BERMA
TRAFFIC LANE
CARRIL DE CIRCULACIÓN
WORKING WIDTH
ANCHO DE TRABAJO
OUTER TRAFFIC RAILING
DEFENSA DE TRÁFICO EXTERIOR
TOP OF WEARING COURSE
PARTES SUPERIOR DE LA CAPA DE RODADURA
CENTRAL TRAFFIC RAILING
BARRERA DE TRÁFICO CENTRAL
HANGER
PÉNDOLA
LOWER HANGER ANCHORAGE
ANCLAJE INFERIOR DE LA PÉNDOLA
PROFILE LINE
LÍNEA DE PERFIL
23824







Drawings Courtesy of MOP Chile

DESIGN OF THE PUENTE CHACAO PROJECT

Alvaro F. Alrruiz Fajuri

Inspector Fiscal Puente Chacao

INTRODUCTION

Because of its location, communications with the Isla Grande de Chiloe (Chiloe Island), located at the northern end of the Chilean archipelago of Chiloe, have been problematic since early Spanish settlement in the 16th century.

The natural beauty and unique cultural heritage, represented by the UNECSO World Heritage designation for many of the island's wooden churches, have made Chiloe a destination for national and international tourism.

However, the island's connectivity issues have long presented challenges for economic development and access to many essential services.

A ferry system across the Chacao Channel between the communities of Chacao and Pargua is the primary access to the mainland for nearly all of the island's approximately 150,000 residents.

Crossing times of 45 minutes or more are not uncommon, with long delays frequently resulting from weather, sea conditions, and seasonal traffic demands. In recognition of the local and national benefits of a more rapid and reliable connection, the Chilean Government committed to construction of a fixed crossing to Chiloe.

When completed, the Chacao Bridge (Puente Chacao) project will provide residents and tourists with an all-weather connection to Route 5, the major north-south national trunk highway, as well as Puerto Montt, the largest regional population center.

The Puente Chacao project has been in development for the past two decades. Initial studies by the Chile Ministero de Obras Publicas (MOP) began in the late 1990s resulting in a 1997 investment study and a technical feasibility study in 2001. Preliminary geotechnical investigations began in 2000. The Public Private Partnership (PPP) procurement was terminated in June 2006, when the consortium indicated that the bridge cost would be greater than the financial limit imposed by the Government of Chile. The project restarted in 2012 when a Design Build (DB) contract was adopted.

The Contract was awarded to the Consorcio Puente Chacao (CPC) in February of 2014. The international DB consortia members include Brazilian company OAS, South Korean Hyundai, French Systra and Norwegian Aas-Jakobsen.

The owner's engineering team is a joint venture of COWI and Chilean firm RyQ. Final design began early in 2014, and construction of portions of the bridge pylon foundations began in early 2018. The completed final design was accepted by MOP in late 2018.

PROJECT ELEMENTS AND GENERAL BRIDGE ARRANGEMENT

Major project elements include a 2,754-meter long suspension bridge consisting of two suspended main spans of 1055 and 1155 meters; a 324-meter long suspended North Side Span; a 140-meter-long three span South Approach Viaduct; three reinforced concrete pylons, and two main cable anchorages.

The deck profile provides for a 600 meter-wide by 50-meter high main navigation envelope under the north main span.

Pylon top elevations are between +157.2 and +198.6 meters. With the exception for the anchorages, all major bridge elements are supported on deep pile foundations.

Other project elements include four lane roadways to connect the bridge to existing Route 5 sections at both project limits; and buildings that accommodate bridge services and a public interpretive center.

One distinctive feature of the Puente Chacao is the use of continuous cables over three pylons to support two main spans, which results from unique site features.

The 2.5-kilometer-wide Chacao Channel has water depths of up to 125 meters at the crossing location. However, one notable exception is a rock mass extending upward from the seafloor to nearly sea level at Roca Remolinos (Whirlpool Rock) at the middle of the channel.

Results of a preliminary exploration program indicated that the geology of Roca Remolinos could feasibly support construction of a major bridge foundation.

Preliminary studies also identified that a continuous, multi-span suspension bridge would be more economical than a more conventional suspension bridge design with two pylons and a single main span. Similar studies of single and two span cable stayed bridge alternatives reached the same conclusion.

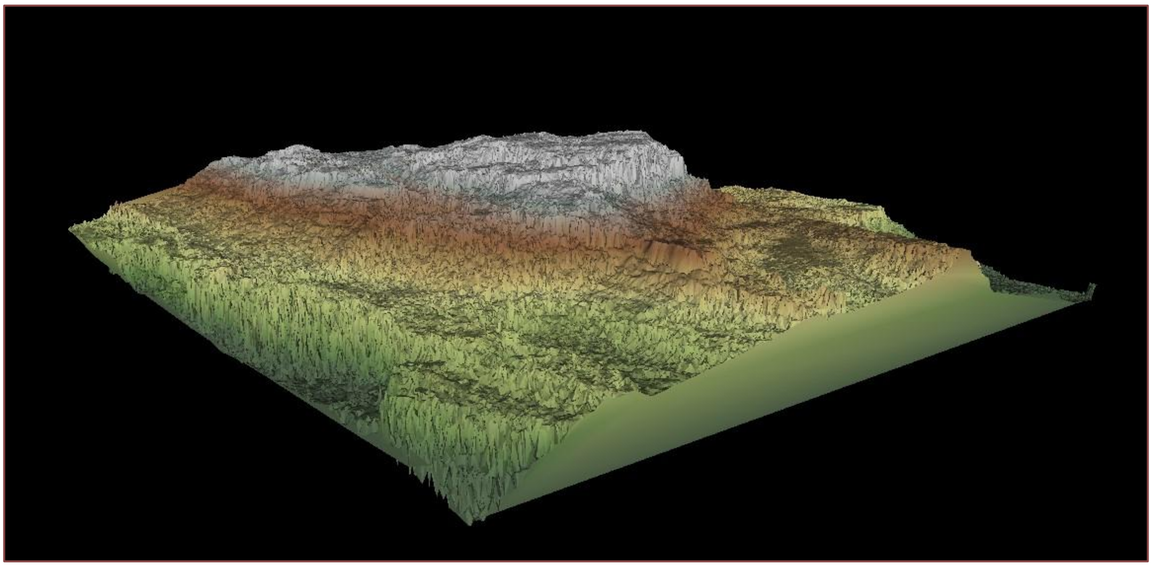


Figure 1: Roca Remolinos

Subsequent geotechnical exploration conducted by CPC, the Contractor, confirmed the feasibility of a suspension bridge with two main spans and a center pylon founded on Roca Remolinos.

As a result of all of these studies, CPC's final design arrangement includes two spans suspended by continuous cables. Few continuous, multi-span suspension bridges exist in the world and Puente Chacao will be the first in the Western Hemisphere.

In addition, the Puente Chacao's suspended span lengths will be the longest in Latin America.

Another unique feature of the Puente Chacao is the Central Pylon arrangement. While the North and South Pylons have relatively conventional arrangements of straight, vertical columns, the Central Pylon has an inverted wishbone frame arrangement with two longitudinally inclined lower columns intersecting above the deck elevation.

The intersecting lower columns are topped by variable-width pylon columns extending upward to the cable saddles. This arrangement is required by unbalanced loadings on the Central Pylon, as well as seismic and wind loads, which must be transferred to the foundations.

A notable feature of the Puente Chacao results from the site topography. Steep banks between 30 and 50 meters tall allow the bridge abutments to be located close to the tops of both banks.

Grade adjustments at either end of the bridge are accommodated by use of cuts and embankments, eliminating the need to construct long approach viaducts to connect with the approach roadways.

DESIGN REQUIREMENTS

MOP developed the Instructions to Builders (ITB) which contained the contract administrative and technical basis, as well as project specific requirements. In addition, the ITB referenced standard codes, including the Manual de Carreterras, the Chilean roads design manual; the AASHTO LRFD Bridge Design Specifications, the highway bridge design code for the United States; and the AASHTO Guide Specifications for Seismic Bridge Design.

The contract permitted application of other design standards in cases where the identified standards did not address a specific design issue, provided that the design build contractor proposed and received acceptance for use of portions of these standards.

The ITB also contained requirements for the design build contractor to conduct surveys, tests and studies related to site conditions and loadings necessary for the project design. These included Bathymetry and Topographic Surveys; Geotechnical Field Investigation Program; Geological Studies; Scour and Erosion Studies; Maritime Studies (including currents and wave heights); Seismic Studies including a Seismic Risk Study Assessment and a Seismic Monitoring Program; Wind Measurement Studies and a Wind Tunnel Testing Program; Temperature Studies; Vessel Traffic; and studies of other specific risks. CPC summarized the project design requirements in a Design Manual. Additionally the ITB mandated the structure to be designed considering access, ease of inspection & maintenance and with a 100 year durability requirement under normal maintenance practices.

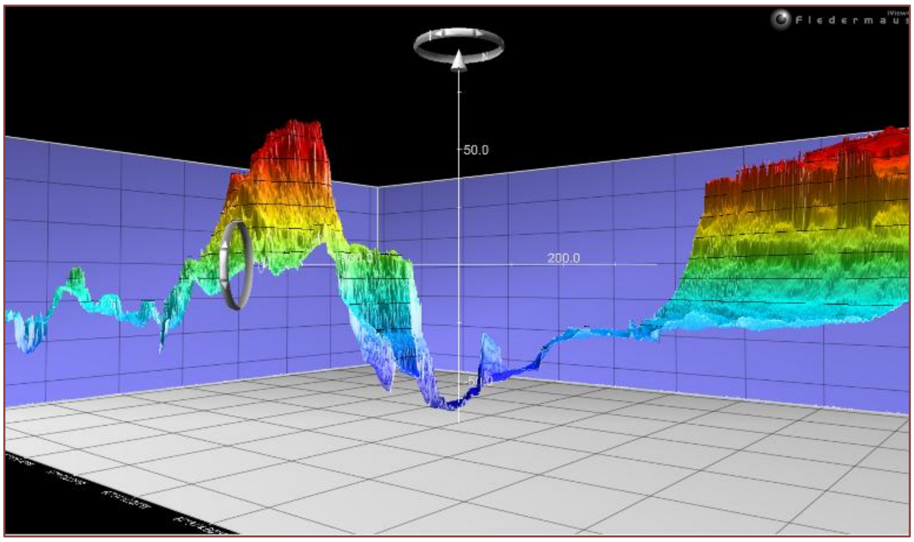


Figure 2: General Bathymetry

Chile is one of the most seismically active areas in the world with a history of major earthquakes, and the project site is near a boundary between the Nazca and South American plates.

The May 2, 1960 Valdivia Earthquake with a magnitude of 9.5, which was described as one of the largest earthquakes ever recorded worldwide, resulted in major damage to Valdivia, approximately 200 kilometers from the project location, as well as nearby Puerto Montt.

Aside from damage to structures, the 1960 event resulted in landslides.

In recognition of this and other major Chilean earthquakes, MOP required that the sole bridge connecting Chiloe with the remainder of the country be serviceable for emergency vehicle access following large major seismic events or tsunamis throughout its 100-year design service life.

In response, CPC developed a probabilistic seismic hazard analysis considering contributions from multiple subduction zone sources and shallow crustal sources. This analysis included two major recorded historical megathrust earthquakes: the 1960 Valdivia earthquake with a magnitude of 9.5 and the 2010 Maule earthquake with a magnitude of 8.8.

Bedrock response spectra were developed for the Maximum Probable Earthquake (MPE) with a 1000-year return period had a 10% chance of occurrence in 100 years (1000-year return period), and Construction Event Earthquake (CEE) with a 10% chance of occurrence in the expected construction duration of 4 years.

In addition, a deterministic seismic hazard analysis was performed for a potential local fault passing under the north main span of the bridge (the Gulf of Ancud fault).

The bridge was designed to accommodate a transverse permanent offset between the central and north pylon due to rupture of the potential Gulf of Ancud fault and a vertical settlement of the Roca Remolinos due to a major subduction earthquake.

Project requirements also included establishment of a site seismic monitoring program to provide an on-going record of ground motions.

Along with the strong ground motions, the 1960 Valdivia event produced tsunami waves with heights of up to 20 meters that resulted in major damage to coastal areas as far away as Hawaii and Japan.

The subsequent Maule Earthquake of 2010 with an 8.8 magnitude resulted in tsunami waves with heights of 15 meters.

The Puente Chacao's location at the narrowest section of the Chacao Channel between the Pacific Ocean and the Gulf of Ancud is at risk from tsunami waves.

As a result, the project was designed to resist a design tsunami equivalent to the tsunami resulting from the 1960 Valdivia earthquake.

A related issue is volcanic effects. Many volcanoes are located near the project site and some are active: Volcan Calbucco, approximately 100 km from the project site, had a significant eruption in 2015.

CPC's design studies concluded that volcanic eruptions were not a significant risk at the project location

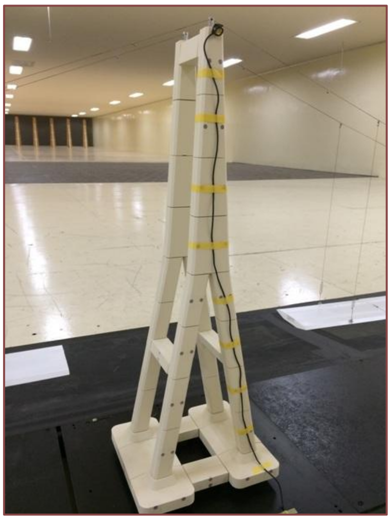
Other project location related design requirements were for tides, currents, and wind. The open site is subject to winds of over 200 kilometers per hour.

Currents through the channel reach nearly 10 knots, with 8-meter waves, sufficient to interrupt ferry service.

These conditions create major challenges for marine construction in the Chacao Channel, as well as demands on the long span bridge elements.

CPC established data collection programs and studies as part of the project Basic Engineering program which informed the development of Final Design criteria.

A CPC wind tunnel test program included sectional models and full bridge aeroelastic model tests to confirm design wind demands and evaluate stability of the structure.



Figures 3 and 4: Wind Tunnel Tests of the Central Pylon

Vessel impact was another significant design consideration. The ship collision study was carried out following the recommendations given in AASHTO LRFD Bridge Design Specification, 6th Edition, 2012.

The study included a detailed AIS (Automatic Identification System) traffic analysis, it addressed the most relevant accident scenarios and determined the probability of aberrancy (PA) based on an analysis of historical data. According to AASHTO LRFD, this is equivalent to conducting navigational simulations.

The results of the study confirmed that the return period of bridge collapse due to ship collision was greater than 10,000 years. In conclusion, the risk level under ship collision was found to be sufficiently low.

SITE GEOLOGY AND GEOTECHNICAL STUDIES

The project site geology is primarily the result of historic advances and retreats of glaciers from the nearby Andes Mountains.

Two different geomorphologies are present near the project site. The irregular topography of the Chiloe (South) side is consistent with a typical glacial geomorphology.

On the continental (North) side, the morphology is much regular with plateau-like aspects corresponding probably to quiet sedimentary deposits conditions (lacustrine /outwash).

Stratigraphy at the Pylon and Anchorage foundation locations on the North and South channel banks is characterized as follows:

- Soils from ground level to around El. 0 MSL are mainly silt, gravely sand and sandy silt.
- A cementitious soil layer called “cancagua” is only found in the south bank approximately from El. 0 MSL to around El. -10 MSL.
- The underlying soil layer is recognized as silty sand, silt or sand with silt, occasionally gravel and lean clay to around El. - 82.0 MSL.
- The lowest soil layer encountered down to the end of boreholes across the project site is silt or silty sand with isolated lean clay.

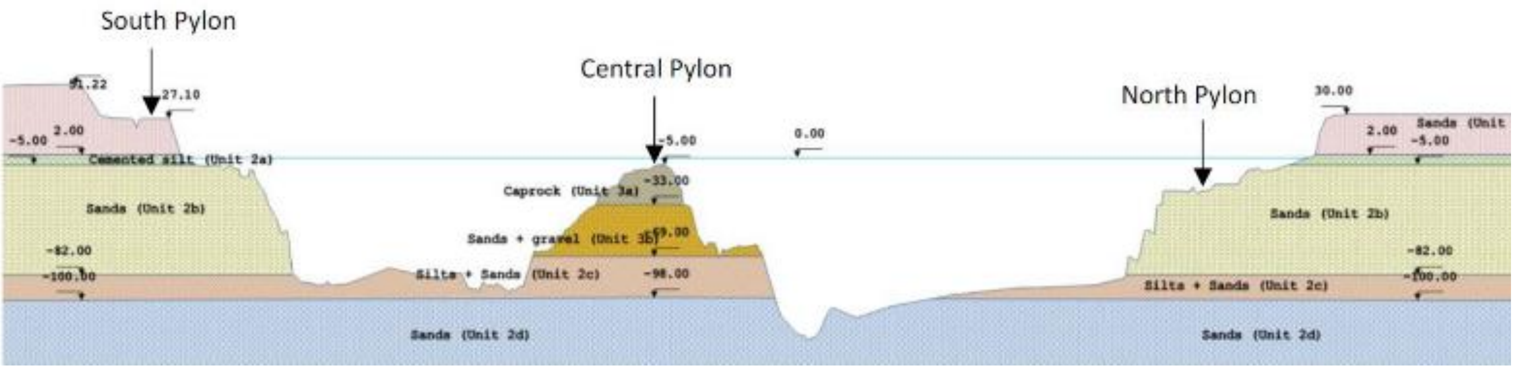


Figure 5: Geotechnical Strata

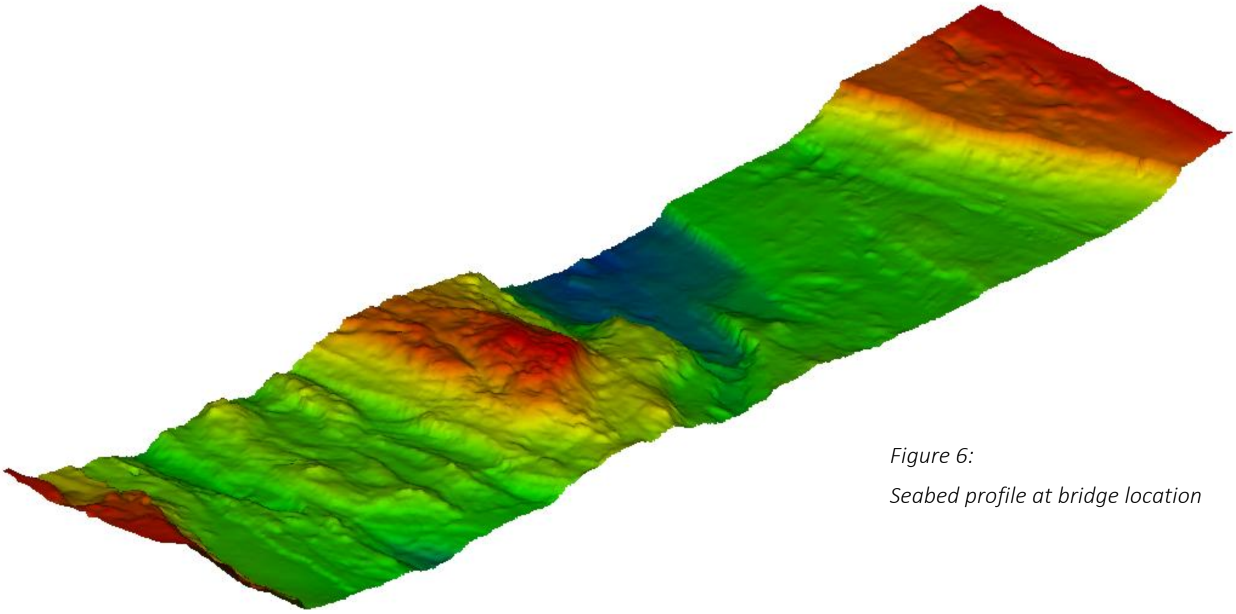


Figure 6:
Seabed profile at bridge location

At the Central Pylon location at Roca Remolinos, the top geo-unit termed as Caprock from ground level to around El. -39.0 MSL, is a volcano-sedimentary conglomerate with heterogeneous clast size and nature, and very variable clast/matrix proportion.

It is composed of brecciated quartz, highly silicic glass (with variable contents of alkalis), plagioclase components and small proportion of clay minerals in the interstitial fine-grained cement.

The geo-unit just below the Caprock formation, down to about El. -73.0 MSL is mainly composed of silty sand to sand with silt. The drilled shafts supporting the Central Pylon are tipped in this soil unit at El. -50.0 MSL approximately.

Bedrock was not encountered at the bridge site within the depths of the geotechnical drilling programs.

CPC conducted a geotechnical exploration program to develop final foundation design parameters. Three previous geotechnical campaigns were performed by the owner in 2000, 2001 and 2005 at South Bank, Central Pylon and North Bank locations.

CPC carried out a supplementary geotechnical campaign in 2015 for the detailed design phase, which included field drilling up to 100-meter depth, standard penetration tests (SPT) and pressuremeter tests (PMT), geophysical PS logging, piezometer installation, and a comprehensive laboratory testing program.

The laboratory tests included the index tests, unconfined compressive strength tests, triaxial tests, cyclic triaxial tests (seismic and fatigue), resonant column tests, oedometer tests, chemical tests and mineralogical analyses.

Following the geotechnical investigation program, CPC developed the design parameters for shear strength, soil deformation and consolidation, unconfined compressive strength, shear modulus and damping ratio, drilled shaft skin friction and end bearing resistance.

MAJOR PROJECT ELEMENTS

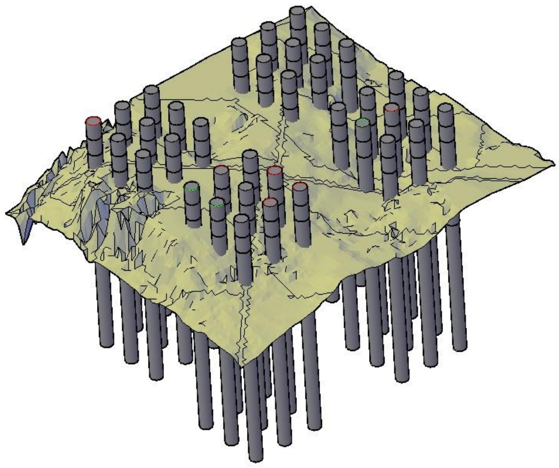
PYLON FOUNDATIONS

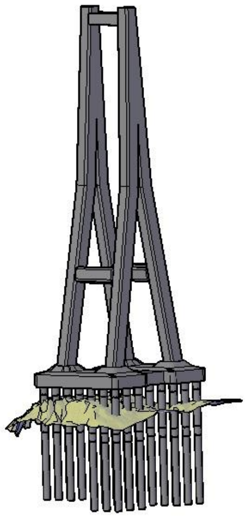
In-water foundations for the North and Central Pylons utilize 2.5 meter-diameter drilled shaft foundations along with permanent steel casings embedded at the top in the pile caps and extending into excavations drilled into the sea floor.

The pile casing participates with the longitudinal pile reinforcing steel cage to resist lateral loads resulting from seismic, vessel impact, and other design demands.

Casings thickness varies with design demands, and the casing segments are welded together at the site.

Aside from addressing structural demands, the steel casings allow construction of cast-in-place reinforced concrete piles in water depths of up to 25 meters.





Figures 7 and 8: Central Pylon foundations on piles

Pile lengths vary between 82.5 and 86 meters for the North Pylon, and between 50.5 meters and 54.7 meters for the Central Pylon.

The on-shore South Pylon pile foundations and the abutment pile foundations also use 2.5 meter-diameter drilled shaft foundations.

However, steel casings are not required for construction or to resist design demands.

Anticipated large soil movements during the MPE event resulted in concerns related to permanent displacements at the South Pylon foundation.

As a result, the South Pylon pile lengths are 60 meters long. Abutment pile lengths vary between 35 and 45 meters to resist design demands.

PYLON PILE CAPS

The North and South Pylon both use an 18-pile arrangement to support pile caps of similar dimensions.

An arrangement of 9 piles and a solid pile cap sections are located under each of the two pylon columns, and a voided section of the pile cap connects the two solid pile cap sections.

The North Pylon pile cap soffit is located above the tidal zone with a bottom elevation of +4.5 MSL, while the on-shore South Pylon pile cap has a bottom elevation of +21.0 MS.

In contrast, the Central Pylon pile cap consists of two linked pile caps, each cap having similar dimensions to the North Pylon and South Pylon pile caps.

Each of the two pile caps is supported by 18 piles to support two of the four inclined pylon columns.

Voided linkages connect the twin pile caps, resulting in a total of 36 piles under the Central Pylon. As with the North Pylon, the Central Pylon pile cap has a bottom elevation of +4.5 MSL

Connections between the piles and pile caps are critical in developing sufficient resistance to seismic and other design demands.

The connection design is based on a combination of pile casing embedment into the pile caps, welded studs on the pile casing exteriors, and reinforcing steel.

Pylon pile caps depths vary between 6.0 and 9.0 meters. Post-tensioning is used in addition to reinforcing steel to resist pile cap design demands.

PYLONS

The North and South Pylons have very similar arrangements of two reinforced concrete columns with a slight transverse inclination and two transverse cross beams connecting the columns.

One cross beam is located directly under the bridge deck and the other near the pylon top elevation.

The South Pylon column heights above the pile cap are 127.7 meters, while the North Column heights are 182.4 meters.

The column base dimensions are 5.8 meters x 5.5 meters for the South Pylon, and 7.5 meters x 6.0 meters for the North Pylon, while the top dimensions are 5.1 meters x 5.5 meters for the South Pylon, and 5.4 meters x 6.0 meters for the North Pylon.

Cross beam depths for the South Pylon are 4.5 and 5.0 meters, while cross beam depths for the North Pylon are 4.8 and 6.0 meters.

The horizontal dimension between the column centerlines at the saddle elevations is 22.2 meters. Column wall thicknesses vary between 500 mm and 1200 mm over their height.

The Central Pylon arrangement is far more complex when compared to the other two pylons. Twin, longitudinally inclined columns have a separation of 37.6 meters at the top of the pile cap and join at approximately 100 meters above the cap elevation.

These lower inclined columns have dimensions of 6.1 x 7 meters. A delta frame consisting of the pile cap with two inclined pylon column legs resists longitudinal loads applied to the pylon.

Single columns with longitudinal dimensions varying between 14.9 and 6.1 meters extend from the top of the delta frames to the top of the 158.9-meter tall Central Pylon columns.

Three cross beams transversely connect the pylon columns: two cross beams below the deck and one cross beam near the pylon top.

As with the other two pylons, the Central Pylon columns have a slight transverse inclination, the horizontal dimensions between the column centerlines at the saddle elevations is 22.2 meters, and the column wall thicknesses vary between 500 mm and 1400 mm over their height.

Seismic reinforcement detailing is provided in potential plastic hinge regions of pylon columns and cross beams.

Additional safety margin is provided in design of potential brittle failure modes including shear in pylon columns and cross beams.

Reinforcing steel in the column legs is detailed to accommodate seismic design demands in the column to crossbeams joints and column to pile cap joints.

Owner requirements include designing to the AASHTO Seismic Design Specification and detailing lower portions potential plastic hinge regions of pylon columns and cross beams consistent with the Japanese seismic detailing practices. Cross beams of the central pylon are transversely post-tensioned to resist demands in the column joints.

DECK SYSTEM

The suspended bridge deck section has a total width of 23.8 meters consisting of an 18.8-meter wide, four-lane motorway with and shoulders and a total width of 23.8 meters.

There are no sidewalks. Suspenders located 22.2 meters apart transversely and 20 meters longitudinally connect the suspended deck to the main cables.

The suspended bridge deck section is a trapezoidal, orthotropic steel box girder with longitudinal stiffeners on the top and bottom plates and a maximum depth of 3.72 meters.

The deck is longitudinally continuous for 2,494 meters between the expansion joints North Abutment and South Pylon.

Typical girded segment lengths are 20 meters, with other segment lengths occur near support locations and midspan areas.

Truss diaphragms are located at typical 4-meter intervals and at the suspenders. Plate diaphragms are located at the North Abutment and Pylons.

As it is normal with this type of decks, the details have been designed to minimize the effects of fatigue on the steel.

The interior of the deck will have a de-humidification system to eliminate the possibility of corrosion and extend its design life.

It will also be provided with both internal and external inspection gantries as well as access points at regular intervals.

SUPERSTRUCTURE ARTICULATION

Articulation of the suspension bridge consists of transverse bearings for the bridge deck at the three pylons and the north abutment; vertical pendulum bearings, end stoppers and expansion joints at two ends of the deck at the south pylon and the north abutment; and longitudinal dampers connecting the north end of the deck with the north abutment.

The transverse bearings transfer significant lateral wind or seismic reaction forces to the interfacing substructures and at the same time accommodate large longitudinal relative displacements of the deck.

The vertical pendulum bearings handle the combination of large longitudinal displacements and potential uplift forces at the two ends of the deck.

For a long span bridge, limiting the accumulated travels at the superstructure/substructure interfaces is essential in maintaining acceptable service life of all the mechanical units.

The longitudinal dampers are velocity dependent devices effectively restraining deck movements caused by transient load conditions while allowing slow thermal movements.

The dampers have a fuse or load limiter protecting the interfacing structures against overloading from rare events such as exceptionally high turbulent wind conditions or major seismic events.

The end stoppers limit the maximum longitudinal travels of the bridge deck, thus reducing the displacement capacity requirements for all the mechanical units.

Large swivel modular expansion joints are specified to accommodate significant movements (up to ±1.3 m longitudinal relative displacements) and meet the seismic performance requirements.

CABLES AND SUSPENSION SYSTEM

The main cables consist of 60 prefabricated strands each, with 127 wires per strand. 5.4 mm galvanized strand with a breaking strength of 1860 MPa is specified.

Each of the two cables has a total steel area of approximately 0.17 square meters. Wrapped cable diameters are approximately 0.52 meters.

Each cable is supported by saddles at the top of the three pylons and two saddles within the anchorage splay chambers.

Suspenders connect to the main cable with bolted cable clamps at a typical longitudinal spacing of 20 meters.

Zinc coated wire rope suspenders with a tensile strength of 1610 MPa are specified.

As it is the case with the deck, the cable will be provided with a state-of-the-art de-humidification system to prevent corrosion of the wires and extend its design life.

The system will inject dry air at regular intervals into the cable. A neoprene cover along its length will minimize air loss.

CABLE ANCHORAGES

Subterranean gravity type anchorages are located adjacent to both bridge abutments.

The massive reinforced concrete structures have lengths of 48 meters and heights of approximately 38 meters.

Connections of the main cables to each of the 18-meter long x 10-meter wide anchorage blocks utilizes grouted post-tensioning tendons anchored in the bottom of the blocks.

The anchorages bear directly on the underlying soil and do not require pile foundations. Bottom elevations of the anchorages are +14.1 for the North Anchorage and +2.3 for the South Abutment.

CONCLUSION

In summary, the design of this unique structure has overcome the difficult local conditions and tight technical requirements to produce a state-of-the-art structure which, once constructed, will hugely improve the communications between the Isla Grande de Chiloe and the continent.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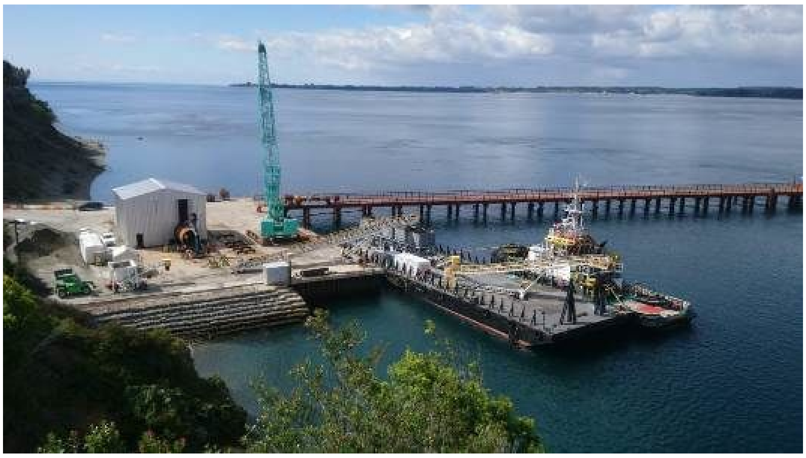


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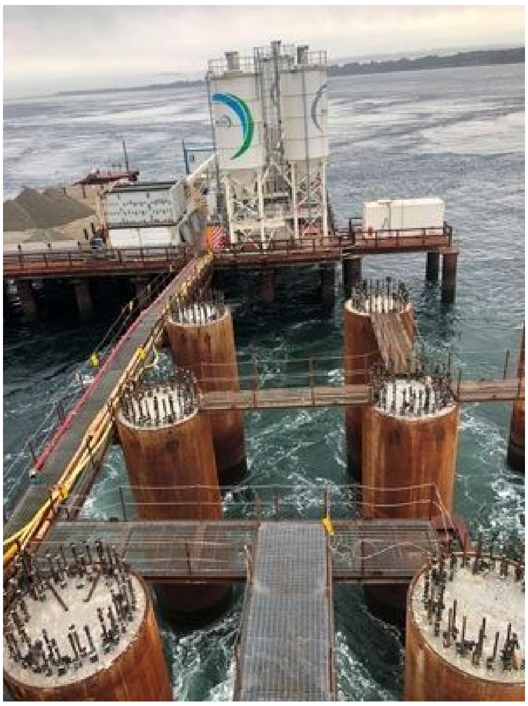

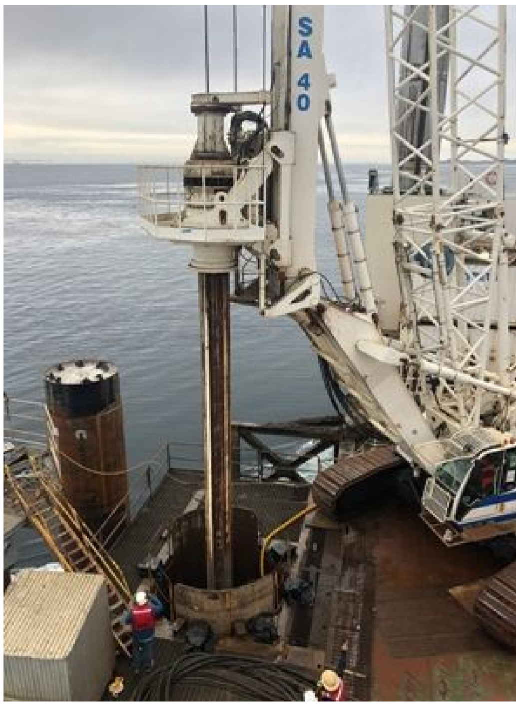
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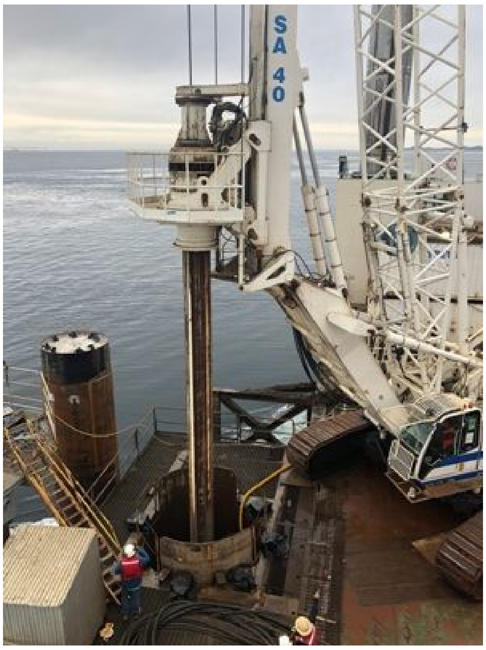
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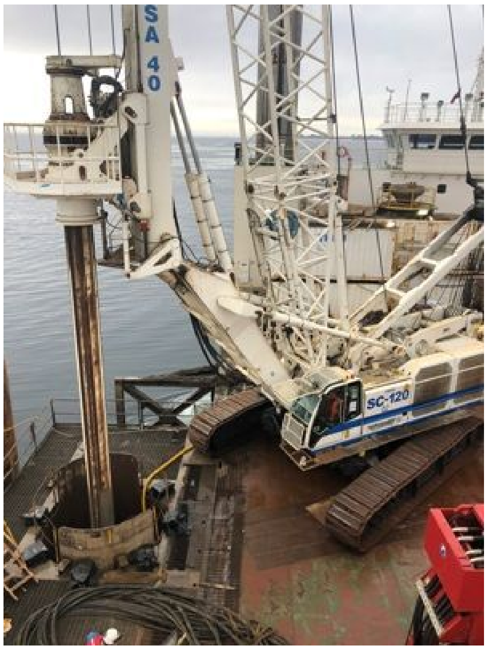
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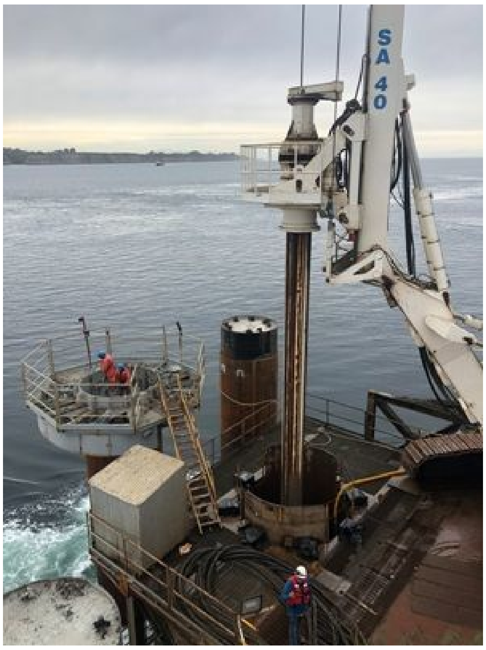
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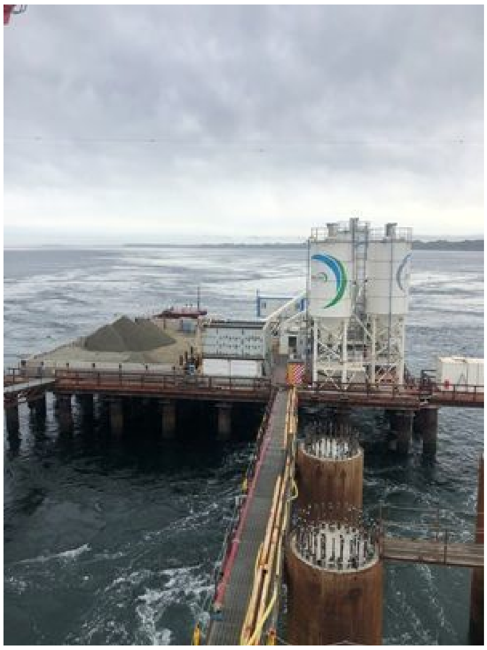
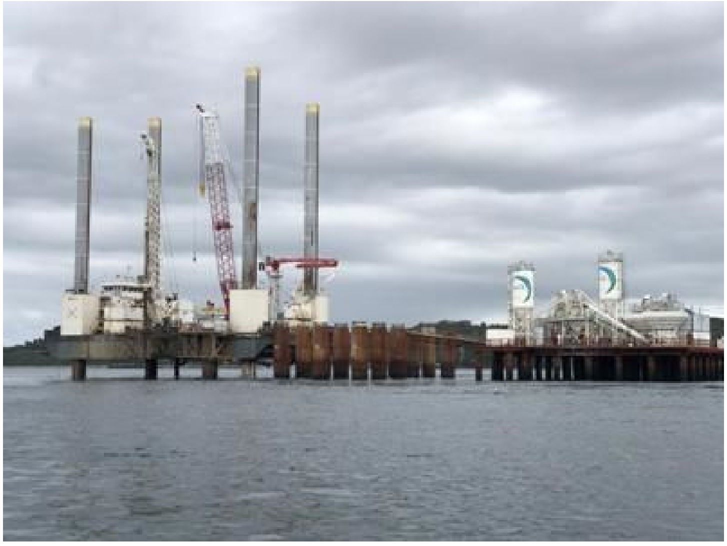
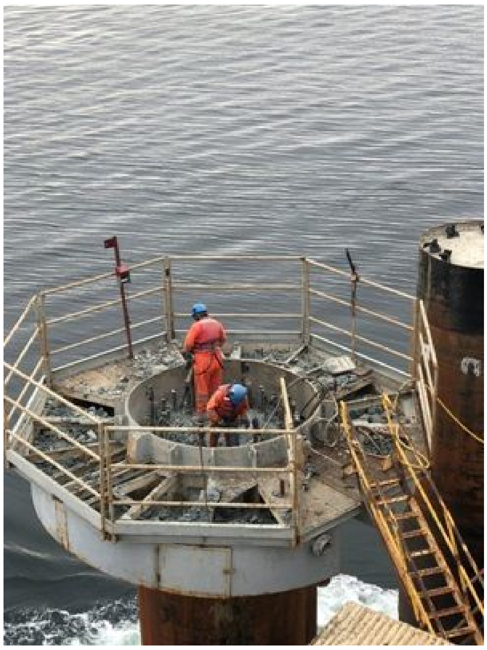









All photos Courtesy of MOP Chile

MAPUTO - KATEMBE SUSPENSION BRIDGE

Dipl.-Ing. Konstantinos Papanikolaou IWE

Figure 1: View of the Completed Bridge

INTRODUCTION

This article provides an informative synopsis of the design and construction of the longest suspension bridge in Africa. Not only for Africa but also for the rest of the world it represented a real challenge to ''tame'' the bridge because of the cyclone phenomenon loads - Mozambique is in an area in which cyclones originate (see below).

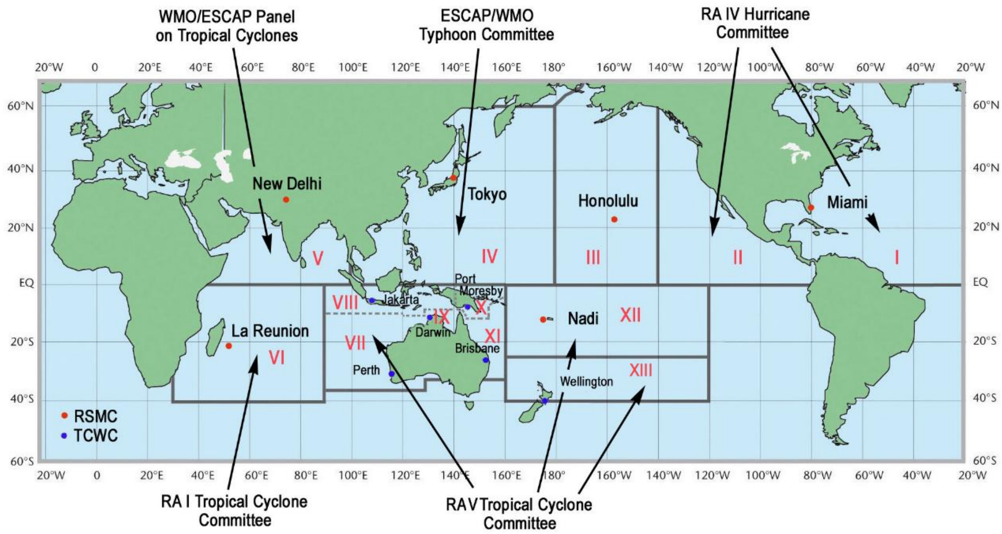
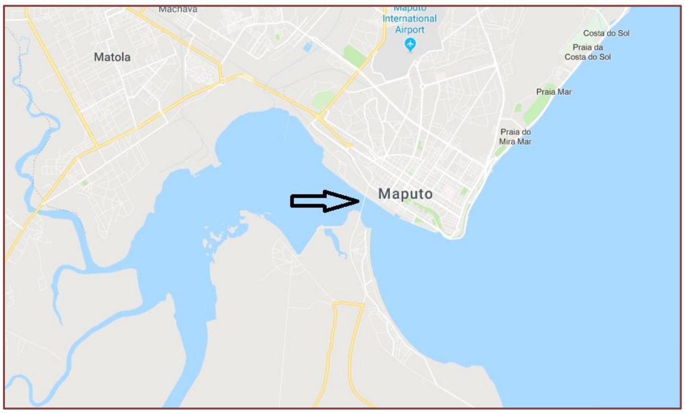


Figure 2: Map showing main cyclones origins



Figures 3 and 4: Location of the Bridge on the map
Source: Google maps

For hundreds of years the ferry route connected the City of Maputo with the opposite bank. The ferry services were operated by unseaworthy vessels or sometimes disrupted by cyclones.

A permanent link to replace the ferries became the source of debate for a number of decades until 2014 when the crossing became real with the proposed bridge solving forever the above mentioned problems.

With Pylons reaching up to a height of 143 metres the Suspension Bridge is without doubt an impressive landmark of the city Maputo, for Mozambique and for all Africa.

The Bridge was under construction for approximately 3.5 years. The Bridge has been in use since the end of 2018 when it was handed over to the Mozambican Government.

DESIGN AND CONSTRUCTION OF THE BRIDGE

LAYOUT OF THE BRIDGE

The total length of the whole crossing is 3,003m. The North Approach Bridge length is 1,093m, measured from the abutment to the Suspension Bridge North pylon.

The South Approach Bridge length is 1,230m, measured from the abutment to the South pylon. The main Suspension Bridge, the longest in Africa, has a total length of 1,224m between the anchorages and comprising a central span of 680m.

There is an overlap between the back spans of the suspension cables and the approach viaducts as shown in the layout.

The North Approach Bridge is made up of two different bridge types. Measured from the abutment the 8 No. spans were constructed as a Precast Beam Bridge. The maximum span is 30m.

It then continued with the construction of one of the most challenging bridge construction stages in the world, a Free Cantilever Bridge (FCB) with a total length of 853m and having a maximum span of 119m.

At the beginning of this section viewed in plan, the FCB alignment is highly curved and has a 6% cross slope. It then straightens briefly before a reverse curve leading up to the Suspension Bridge section.

Adjacent to this is the three span Suspension Bridge of which the spans are 260m + 680m + 284m = 1,224m.

The South Approach Bridge comprises a Precast Beam Bridge. T-beam precast beams lengths vary from 45m to 30m. The total length is 3 x 45m + 3 x 45m + 3 x 45m + 5 x 30m + 5 x 30m + 5 x 30m + 4 x 30m + 4 x 30m = 1,230m. Close to the abutment the bridge is also on a curved alignment (see below).

The South Approach Bridge was constructed conventionally with linked spans of Precast Beams with an in-situ deck, with movement joints every 3 to 5 spans.

Specific Details

Overall length of all bridges	L = 3,003m
Maximum height of the main pylons	H = 143.14m
Deck width of the Suspension Bridge	B = 25.60m
Deck thickness of the Suspension Bridge	d = 3.00m
Pile diameter of the foundation of the Suspension Bridge	Φ = 2.20m
Pile number of each pylon of the foundations	24 pieces
Pile lengths of the foundations of the Suspension Bridge	max. L = 110.00m
Anchorage, South: diameter	d = 50.00m
depth of the anchorage	h = 36.00m
Anchorage, North: diameter	d = 50.00m
depth of the anchorage	h = 11.35m

THE DECK

The proportions of the deck of the Suspension Bridge are shown in the following "Drawings Section" illustrating the symmetrical geometry.

The deck has a slender depth and contrasts well with the stockier towers.

Despite the aesthetic slenderness, this deck is designed to resist fluttering phenomenon caused by wind in an area where cyclone occurs.

PYLONS

The main Pylons are concrete and each consists of two hollow legs 7m x 5m in section, with horizontal bracing beams at 1/3 and 2/3 height and near the top.

WIND AND EARTHQUAKE LOADS FOR THE DESIGN OF THE SUSPENSION BRIDGE

The Bridge in Maputo is positioned at the end of an axis which is starting in Djibouti and ending in Mozambique, on the east of an active tectonic plate.

The axis is follows the path Djibouti-Ethiopia-Uganda-Rwanda-Burundi-Borderline Tanzania / Congo-Malawi-Mozambique.

Along this axis the tectonic plates move and the consequence is the risk of severe earthquakes.

Another major challenge was to design the bridge for wind loads which can achieve values up to 250km/h = 69.44m/s.

In the past many cyclones have hit the coast of Maputo Bay and other areas of Mozambique.

For this reason, data was collected and scrutinized very carefully with all the measured wind speeds since 1973.

The data were provided by "Instituto Nacional de Metereologia de Mocambique".

By statistical analysis of all these collected wind speeds, using the Gumbel Method the derived value of the basic wind speed was:

$$v = 35.77 m/s,$$

for 100yr return period, at a height of 10m above sea level (as recommended in the wind tunnel test Report as well).

The loading experienced by the deck was estimated in the wind tunnel report.

As the height of the Suspension Bridge above the sea level is approximately 64m, the design wind speed was evaluated to:

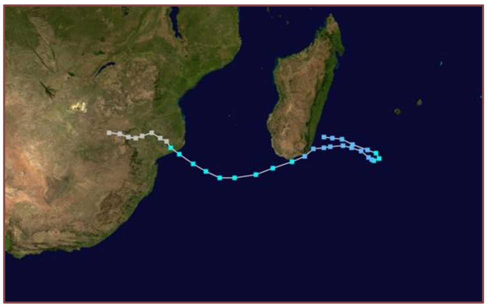
$$v = 49 m/s.$$

The wind tunnel test for the chosen deck of the Suspension Bridge resulted in a flutter wind speed:

$$v = 73 m/s.$$

Some significant cyclones which have hit Mozambique in the past include:

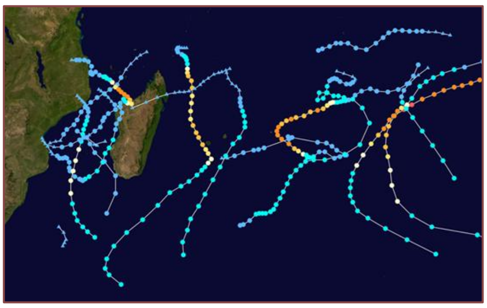
a) Dando in the year 2012



b) Leon-Eline in the year 2000

c) Domoina in the year 1984

Cyclones in the South West Indian Ocean for the period 2013 – 2014:



The orange points are wind speeds up to 350 km/h.

SUSPENSION BRIDGE´S DECK LIFTING AND POSITIONING

Lifting and positioning was done with the assistance of two separate sets of cables. They were supported at the pylons. On these two cables a crane was suspended with the ability to move vertically and perform a 90° vertical axis rotation.

57 deck segments were lifted and positioned over the waterway section of the bay. Seagoing Vessels then brought the 12m long and up to 150t deck segments one by one, each segment was lifted and before the crane approaches the final design elevation it rotates 90° and brought the segment to its final position. Each steel segment had a depth of 3m and a width of 25.6m.

SUMMARY

Despite the fact that the main span of the Suspension Bridge is only 680m and it is much shorter than the longest suspension bridges in the world such as the Xihoumen Bridge in China which is 1,650m (2nd longest) and the Akashi Kaikyo Bridge in Japan which is the longest span at 1991m, this Bridge brings Mozambique and the whole continent of Africa into the engineering community with the use of an advanced level of technology with regards to bridge construction, demonstrating the significant ambition and achievement of a historically unprogressive, poverty-stricken African state.

ACKNOWLEDGEMENT

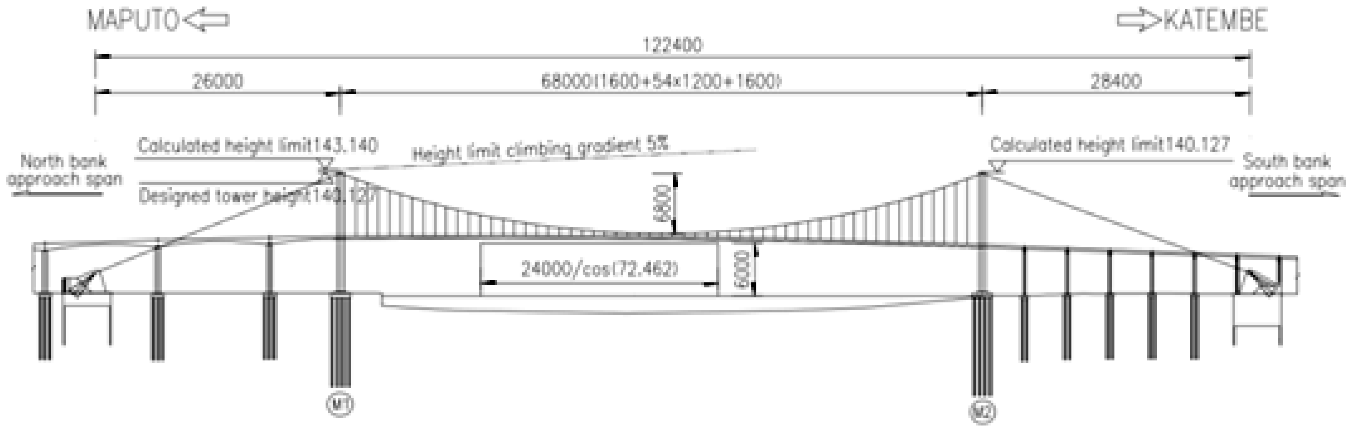
That this type of suspension bridge in Maputo - Katembe, Mozambique was feasible to design is thanks to a handful of international experts worldwide with this special knowledge.

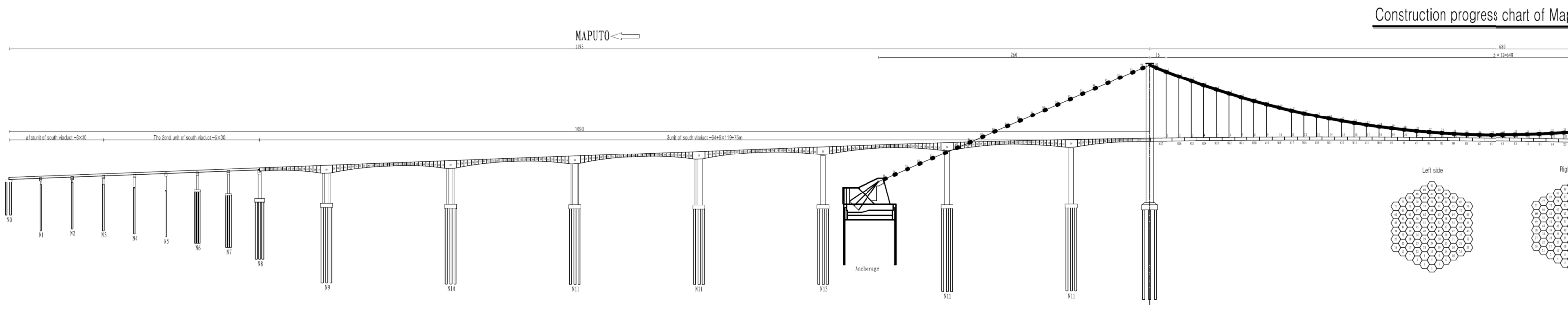
From the Chinese Construction Company CRBC the main contribution was provided by Design Leader Mr. Cai Jingwang.

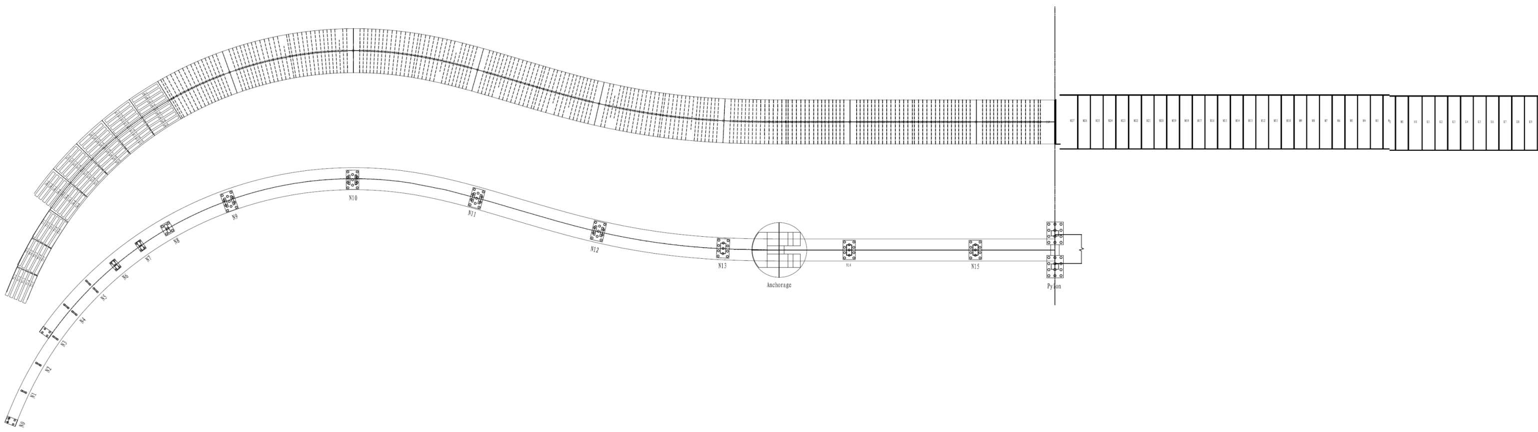
From the Mozambican Authorities (Maputo Sul) Mr. Vicente Miranda was instructive and supportive for the Design Team and later also Mr. Basilio Nzunga.

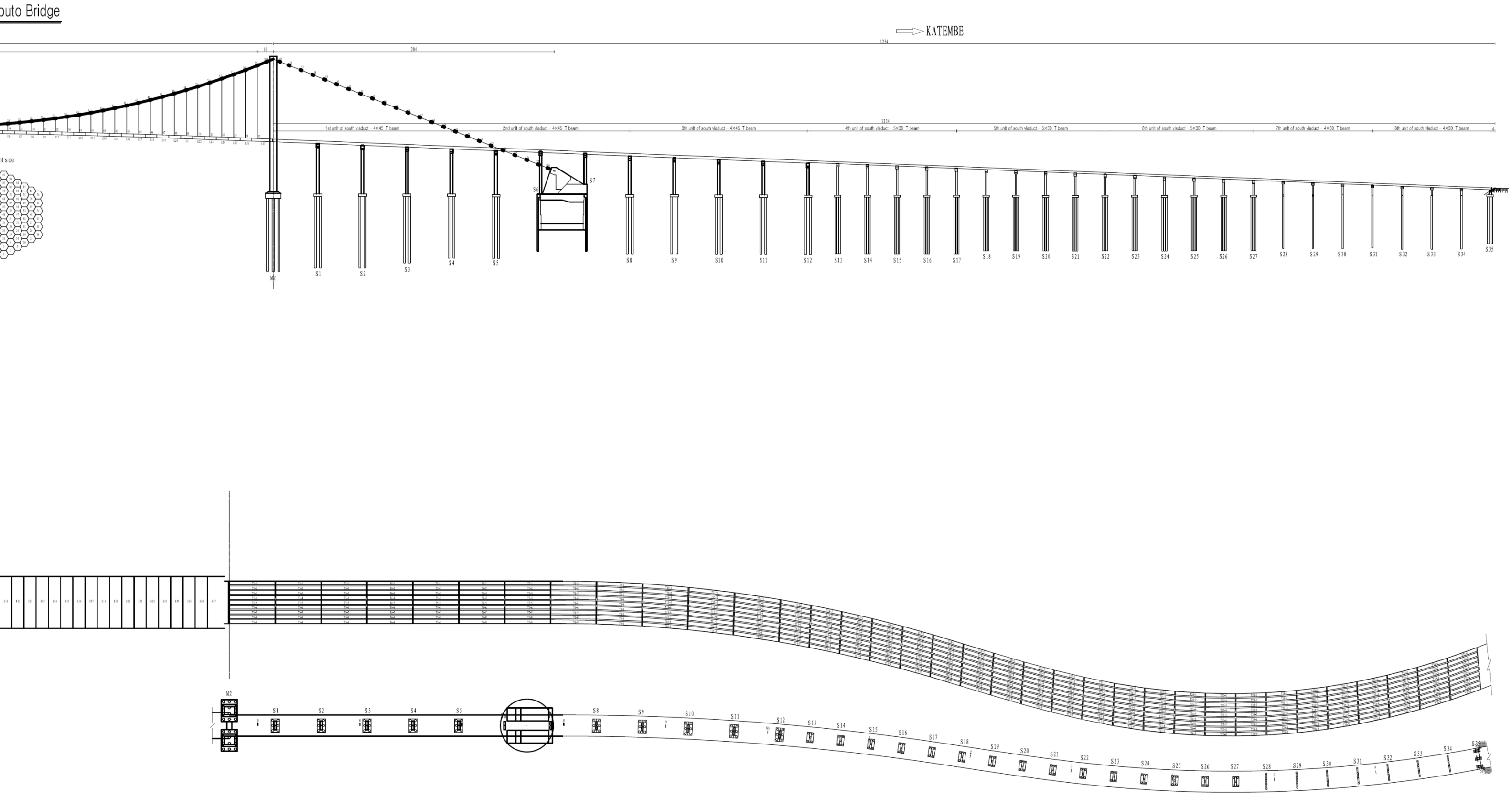
My honour was to be the Consultant, at the head of the above Design Team supported by my Greek Office Team (INSTAT SA), especially Mr. Dr.-Ing. Aristoteles Kakaliagkos.

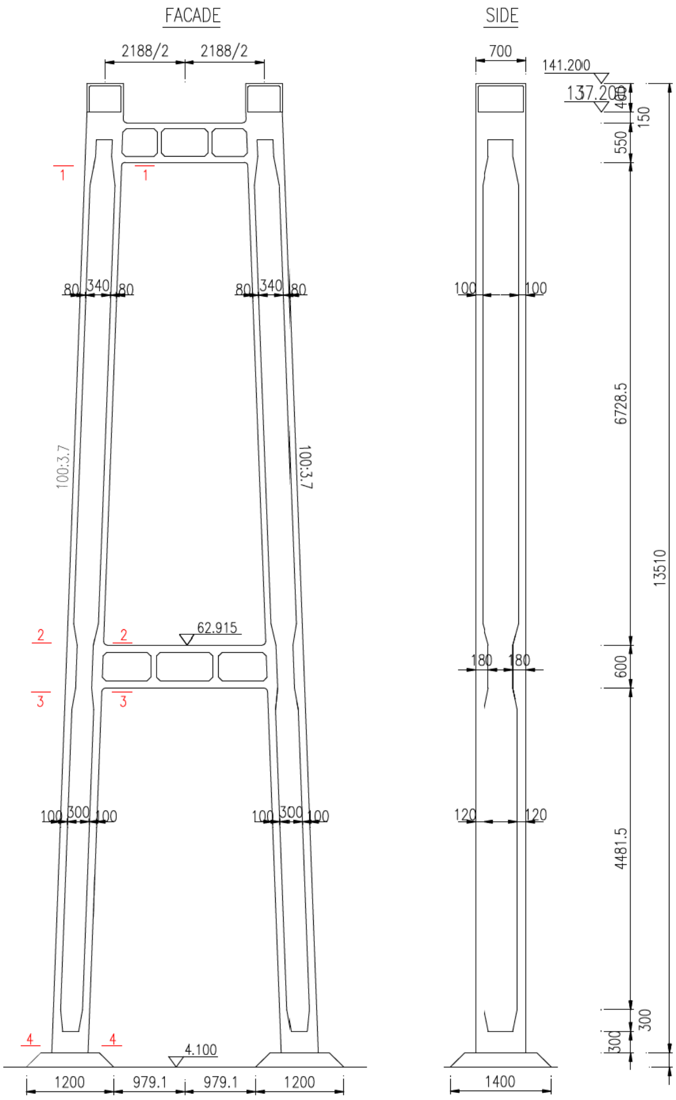
Finally, I want to thank GAUFF Nurnberg, especially Mr. Stefan Tavares Bollow and Mr. Bernhard Streit for giving me the opportunity to participate in this impressive project.


MAPUTO
KATEMBE
122400
26000
68000(1600+54×1200+1600)
28400
Calculated height limit143.140
Height limit climbing gradient 5%
Calculated height limit140.127
North bank approach span
South bank approach span
6800
24000/cos(72.462)
6000
M1
M2

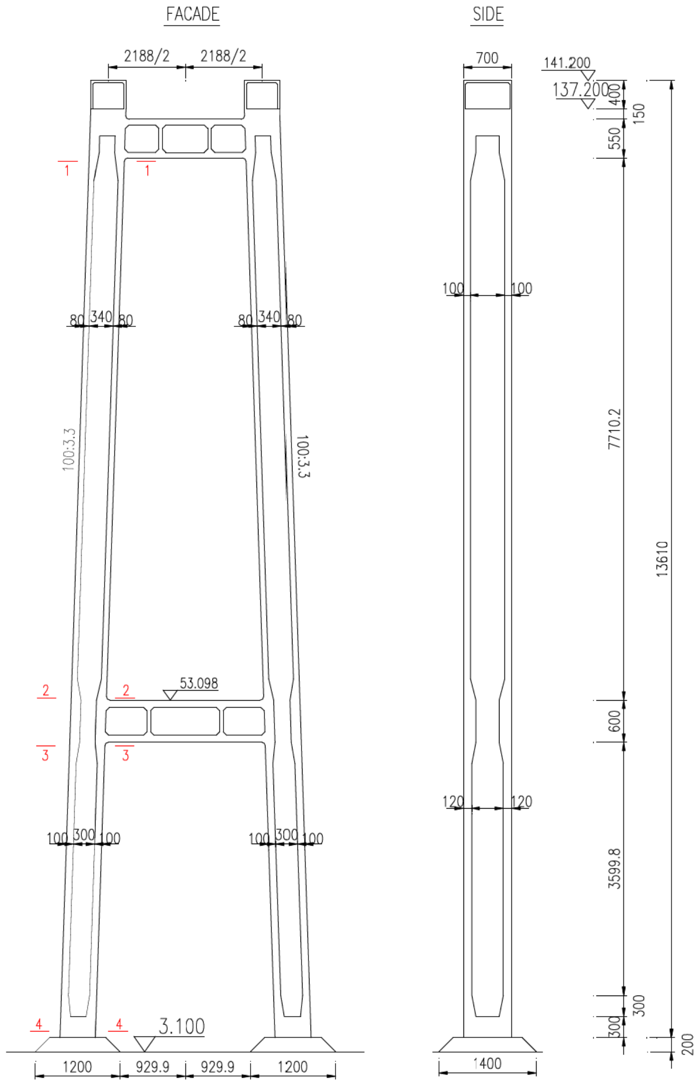

Construction progress chart of Map
MAPUTO
Anchorage


Anchorage
Pylon


puto Bridge
KATEMBE



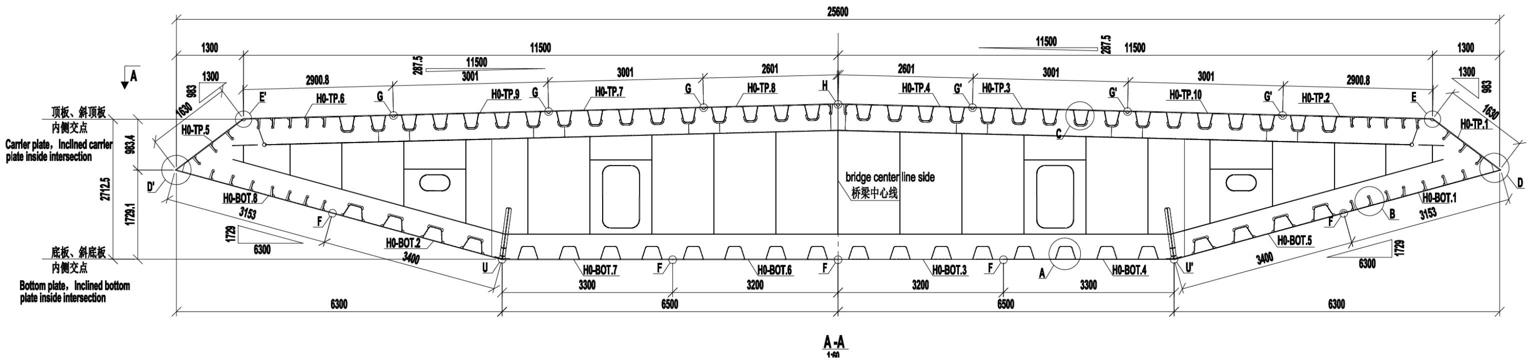
Units: Elevation in meter, others in centimeter.



Units: Elevation in meter, others in centimeter.

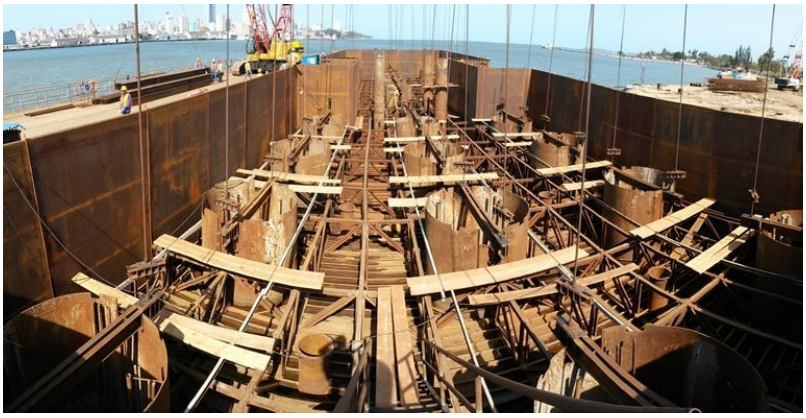
Pylon - Maputo Side

Pylon - Katembe Side



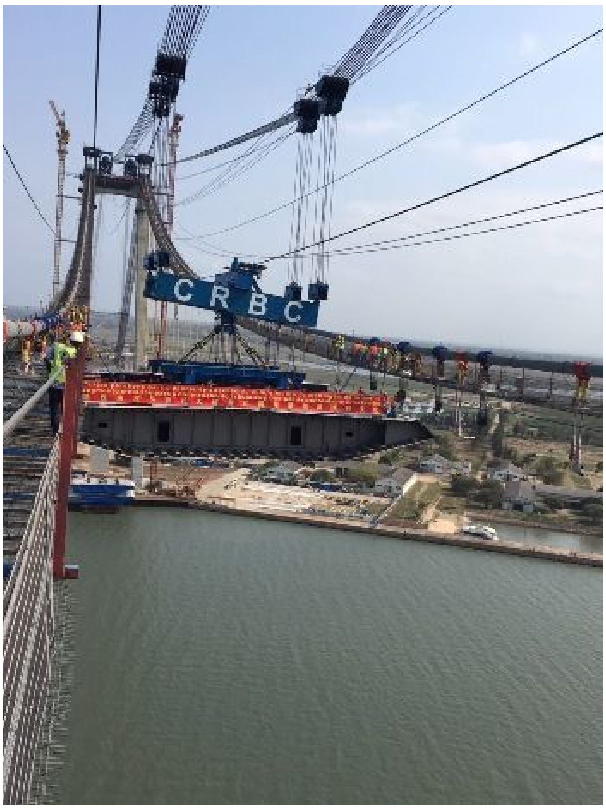
North Anchorage

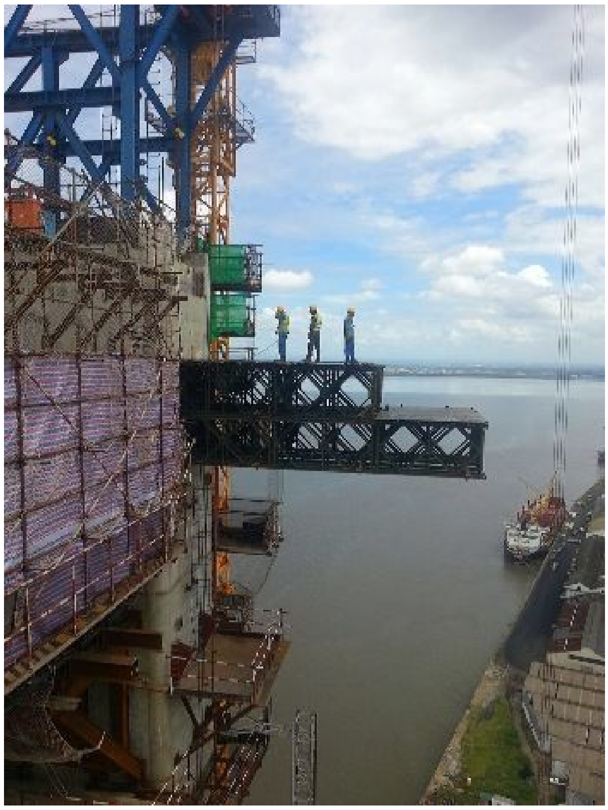
South Anchorage



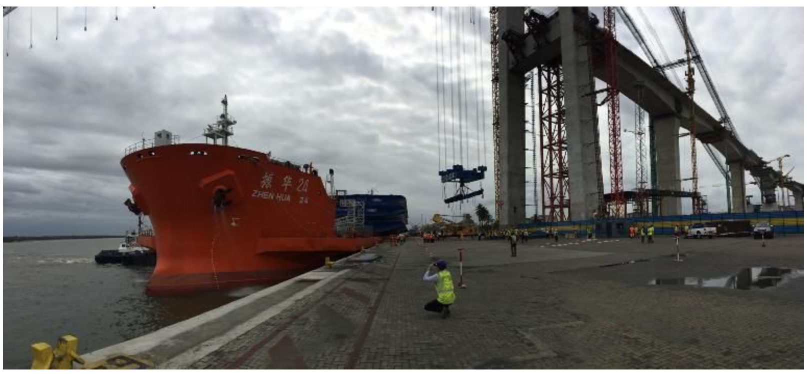
Piles of the South Pylon


CRB

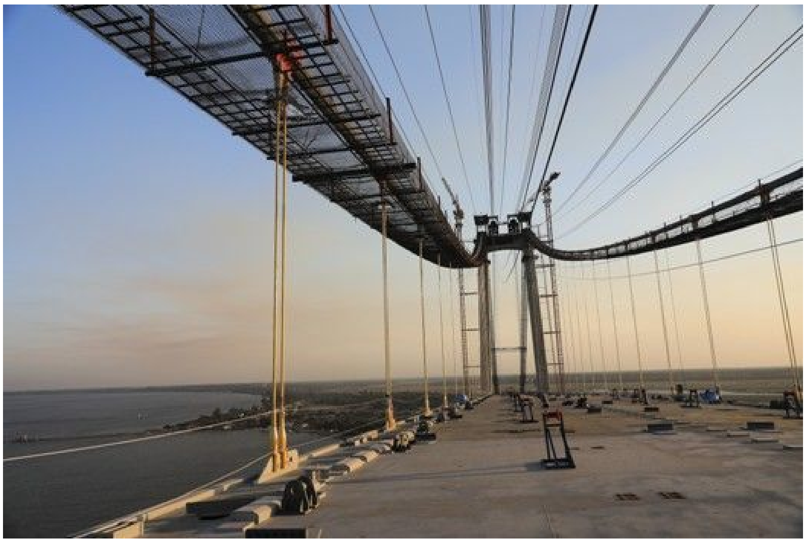




´Zhen Hua 24´ approaching berth 5



´Zhen Hua´24´ at berth 5 and bridge North approach



MULTIPLE-SPAN SUSPENSION BRIDGES

David Collings

Figure 1: Taizhou Yangtze River Highway Bridge [3]

This article provides a brief overview of multi-span suspension bridges for this issue of e-mosty magazine.

Multi-span suspension bridges are a form steeped in history, as many of the early suspension bridges were multiple span structures[1].

It is also a re-emerging form with significant advantages over more conventional very long span bridges. A form of bridge which I am sure we will see more examples of in the near future.

The traditional single span suspension bridge has been used for many of the world's longest spans; this arrangement is ideal for a single obstacle of reasonable size and gives the stiffest suspension bridge form.

Three span bridges with end spans of 20% to 40% of the main span can also be used for long spans; the shorter side spans do not adversely affect the overall behaviour of the bridge if kept within reasonable limits.

The recent Ozmangazi Bridge across the Izmit Bay in Turkey[2] or the current longest span of 1991m of the Akashi-Kaikyo Bridge completed in 1998 are good examples of this bridge form.

Other slightly longer conventional bridges such as Carnake at 2004m are being built.

Longer spans such as the 2700m span Messina Crossing or bridges over fjords in Norway have been seriously proposed but not built, they tend to be very expensive.

If the length of the side spans on these bridges is greater than 50% of the main span then the bridge becomes significantly more flexible and starts to behave as a multi-span structure.

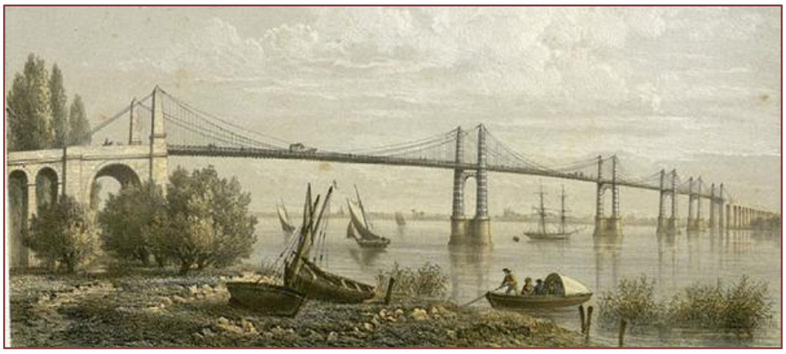


Figure 2: The Cuzbac Bridge, France

Figure 3: Loire River Bridge, France

The advantage of the multi span suspension bridges is in the ability to span long distances in water where conventional long-span bridges or shorter span viaduct construction is not economic.

Multi-span bridges were common in the early development of suspension bridges.

The 6-span St Nicholas Bridge (Figure 4) over the Dnieper (Dnepr) River in Kiev was the longest length suspension bridge until the construction of the more famous Brooklyn Bridge.

Twin span bridges (often called three tower bridges in China) can result in bridges that cover the same distance but are more economic to build.

With the construction of the Taizhou Bridge[3] and Maanshan Bridges in China and with others being constructed, there has recently been a renewed interest in this structural form.

If end spans are added the suspended length can be increased by a factor of 3 or more compared with a single span.

However, there can be a significant reduction in stiffness with this type of structure.

Most of the 20th century multi-span bridges such as San Francisco West Bay Bridge, USA, the Seto-Chuo Crossing and Kurushima-Kaikyo Bridges in Japan (see Figures 5 - 7) have used two conventional 3-span bridges placed end to end with a common anchorage to overcome the stiffness problem.

Figure 4: St Nicholas Bridge, Ukraine

Figure 5: San Francisco West Bay Bridge

Figure 6: The Seto-Chuo Crossing

Figure 7: Kurushima-Kaikyo Bridges

Over the years many ways of stiffening a multi span suspension bridge have been tried with varying degrees of success.

A number of these methods are shown in Figure 8. The first group of ways is to stiffen the cable system.

The range of modern cable span to sag ratio is from 7:1 to 14:1. Reducing the cable sag (or increasing the span-sag ratio) increases the cable stiffness.

Considering further the cable geometry, but exploring the use of twin cable systems: The use of twin separated cables with different sags helps stiffen the bridge (Figure 8b).

If pairs of cables are used, each supporting half of the bridge span (Figure 8c), a stiffer layout results, particularly if the cables are clamped together where they cross.

If additional cables are used to restrain the tower tops a similar appearance is generated (Figure 8d), the Cuzbac Bridge in Figure 2 has this form (although the cable arrangements could be as shown in Figure 8c).

To restrain the tower these inclined cables need sufficient strength to carry the live loads and stiffness to restrain the towers.

If additional cables are used tying the tops of the towers together (Figure 8e) a more efficient method results.

The method of tying the tower tops has been used on a number of multi-span bridges in France such as the Loire Bridge in Figure 3.

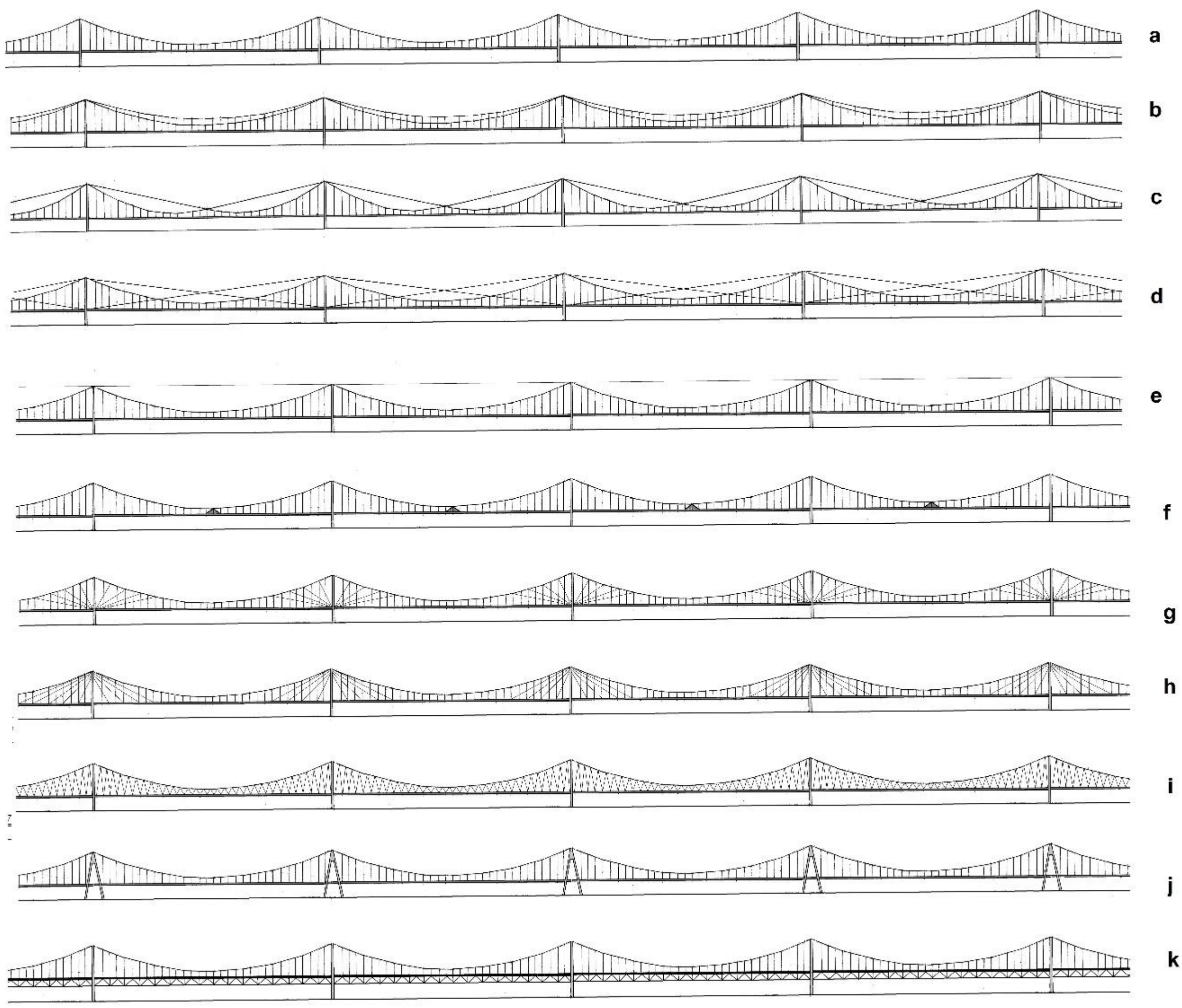


Figure 8: Methods of stiffening cables[1]

Part of the cable stiffness problem is due to the longitudinal movement of the cable, the same problem occurs on the single span suspension bridge at the mid span - with about half of the span loaded.

This is often solved by clamping the cable to the deck at mid-span (Figure 8f and Figure 9), thus limiting the longitudinal movement.

Cable clamps were used on the 3-tower Taizhou Bridge (Figure 1).

Negative stays clamped to the main cables at intervals along its length and anchored to the tower at deck level (Figure 8g) serve a similar purpose to the cable clamp.

Figure 9: Cable clamp on the Runyang Yantze Bridge[3]

Conventional stays radiating from the tower top (Figure 8h) were often used to stiffen early suspension bridges.

Roebling's bridges such as the Brooklyn Bridge are particularly noted for the use of additional stays.

The stays cannot extend far into the span unless the towers are made taller.

The optimum mix of stays and suspension structure is with stays covering 25% to 30% of the span from each tower.

Hybrid stay-suspension bridges have been proposed (Figure 10), particularly for long spans where the stays relieve the cables of a significant proportion of the dead load.

Most modern suspension bridges since the 1930's have been pure suspension structures. Recently the 1600m span Sultan Selim Bridge (3rd Bosphorus Bridge), using a hybrid cable stay-suspension form, was completed[4].

Another cable stiffening system is the use of inclined hangers to form a truss arrangement (Figure 8i) or a cable net if the hangers cross.

The inclined hangers working with the deck and cables to form a composite system carrying imposed loads and limiting deflection.

The amount of load that can be carried depends on the load in the hangers; the additional load should not be such that the hangers become slack.

These inclined hangers often have increased fatigue issues.

From the analysis of multi-span suspension bridges large movements of the towers are associated with the reduced stiffness.

Limiting the tower movement is key to stiffening a multi-span suspension bridge. Providing a more rigid tower (Figure 8j) significantly influences deflections.

A-shape towers or wide braced towers have been proposed. The A-shape tower is effective in limiting deflections.

However, research in China for the Taizhou and Maashaan bridges has shown the stiffness of the

Figure 10: A long span, deep-water, hybrid multi span suspension bridge proposal

tower can cause problems with slip at the cable saddles at the tower top.

The research indicates that an intermediate stiffness of tower is beneficial when used in combination with other methods of stiffening.

For the 3 tower Taizhou Bridge[3] only the central tower was stiffened, it was not a full A-shape but a λ-shape with the legs spread only from below deck level.

This partial tower stiffening was used in conjunction with cable clamps and a continuous deck fixed at the central tower.

The design development of the Chacao twin-span suspension Bridge (*see this issue*) has taken a similar form from early A frame to the current central tower form.

Truss girders have traditionally been used on suspension bridges and are often used today, they usually give a stiffer deck than a box girder.

With the increased cable flexibility of a multi span bridge the additional stiffness of the deck girder is relatively more important (Figure 8k).

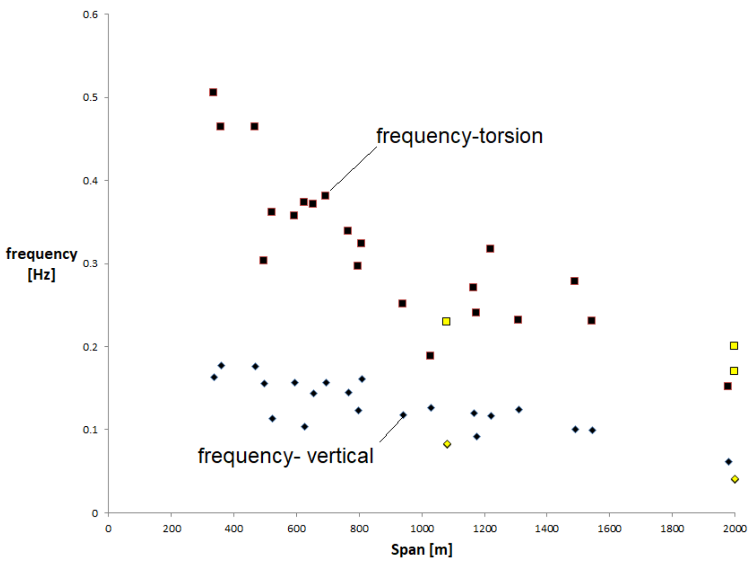


Figure 11: Suspension bridge vibration frequencies with multi-span bridges highlighted

The Oujiang River North Estuary Bridge, China, with twin 800m main spans is currently being built with truss girders.

Traditionally the deck girder articulation is a series of simple spans with expansion joints at each tower.

The continuous girder has more stiffness and reduces rotations.

The 3-tower Maanshan Bridge has a continuous deck that is also integral with the central tower.

The deck and cables of a multi-span bridge cannot in practice be infinite.

The effects of temperature need to be considered.

For the cables, temperature variations are accommodated by a small increase or reduction in cable sag.

For the bridge deck temperature will cause a change in length, the greater the length of the deck the greater the temperature movement and the larger the expansion joint.

A length of about 3km is the current practical limit for continuity.

The large expansion joints in current long span and multi span bridges are the main limiting factor when determining the length of a bridge.

Dynamic performance of the bridge is an important consideration in multi-span suspension bridges and is related to stiffness.

Since the dynamic failure of the Tacoma Narrows Bridge, due to wind induced torsional flutter instability, the knowledge of bridge dynamics and wind instability has increased significantly.

The dynamics of the 2-span Taizhou Bridge and the dynamic parameters of a 4-span suspension bridge with 2000m spans have been studied and are shown in figure 7 comparing them with more conventional suspension bridges.

Multi-span bridges are slightly more flexible dynamically than classic single span bridges, but the dynamic performance can be improved using similar stiffening techniques as used for static analysis i.e. increased tower stiffness, the use of cable clamps, etc.

Multi-span suspension bridges are appropriate for deeper water crossings, and can be more economic than very long spans.

The size of the foundation for the intermediate towers is a key aspect of this bridge form.

One of the largest bridge foundations constructed to date are the 80m diameter, 70m deep caissons of the 1991m span Akashi Kaikyō Bridge.

Slightly smaller multiple deep-water foundations were also used on the Rion Antiron multi span cable stay Bridge.

The large caissons required for the Taizhou Three-Tower Bridge are shown in Figure 12.

Gravity platforms for the offshore oil industry have developed from the Ekofisk platform in 96m of water to the Troll A platform in 305m of water. Proposals for their use with multi-span suspension bridges have been made (Figure 13).

The robustness of suspension bridges is a key criterion.

Conventional single or 3-span suspension bridges are often used to span major rivers, estuaries or fjords with the towers located on or as close as possible to the land.

For multi-span suspension bridges with one or more towers in the river or sea they will potentially have shipping lanes either side of one or more towers and so it is vital that the foundations and lower parts of the tower below the deck are protected against the possible ship impact.

Figure 12: River caisson for the Taizhou Bridge[3]

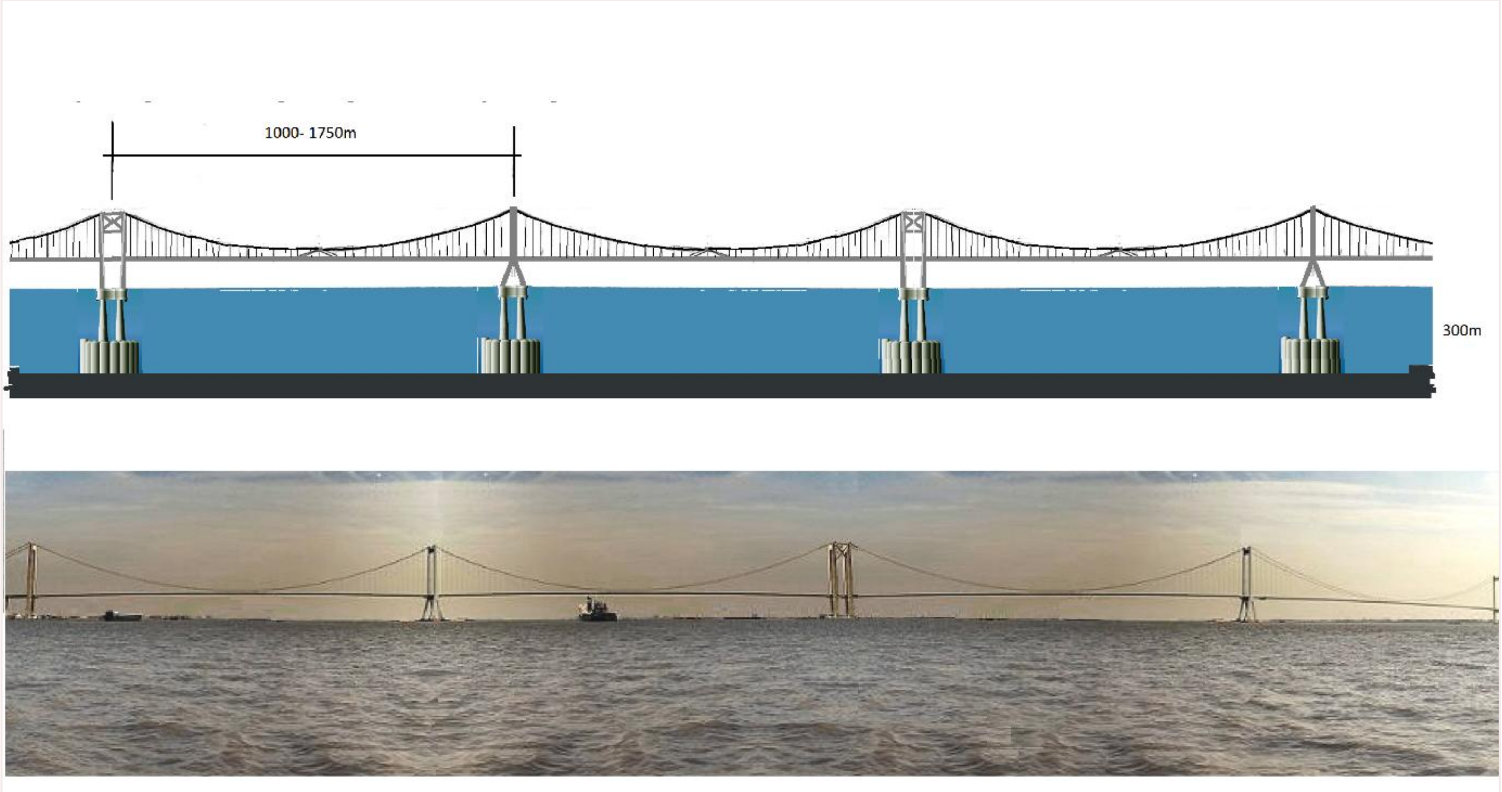


Figure 13: A long span, deep-water, multi span suspension bridge proposal, with gravity platform foundations

Much of the recent development in long span bridges and in particular multi-span suspension bridges (or multi-tower bridges 多塔的悬索桥) has taken place in China.

As outlined in this article regulating the bridge stiffness is key.

This technology is spreading, the Chacao Bridge, Chile, is an example of this.

The multi-span suspension bridge form has further potential and I am confident we will see further examples in the future.

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1 COLLINGS, David: (2015) Multiple-span suspension bridges: state of the art, Proceedings of the Institution of Civil Engineers. Bridge Engineering, Volume 169, Issue BE3. Pages 215 – 231. https://www.icevirtuallibrary.com/doi/10.1680/jbren.15.00035

2 https://e-mosty.cz/osmangazi-us-suspension-halogaland-bridge/

3 https://e-mosty.cz/asijske-mosty/

4 https://e-mosty.cz/3rd-bosphorus-bridge-michel-virlogeux-izmit-bay-bridge/

Bridge to the Future to help beat Cancer

Lawrence Shackman

View of the Queensferry Crossing

STORY

I was the Project Manager for the Queensferry Crossing Bridge which opened just over a year ago.

Sadly my mother passed away from cancer just a few weeks later. She was so impressed with the bridge and I suppose my efforts in getting it built but I would like to go further ....

I would like to help find a cure for this terrible disease which has claimed the lives of so many including my father, uncle and mother-in-law.

So, I have written and produced a song and video to celebrate the bridge construction and by watching the video I would then like people to donate to Cancer Research UK – any donation is very welcome!

See the video on my LinkedIN or Facebook pages.

Thank you for taking time to visit my JustGiving page.

JustGiving™

ABOUT THE CHARITY

CANCER RESEARCH UK

Cancer Research UK

Cancer Research UK is the world's leading charity dedicated to beating cancer through research. We are fighting cancer on all fronts, finding new ways to prevent, diagnose and treat it to save more lives. We are entirely funded by the public. With your help, we can ensure more people beat cancer.

Charity Registration No. in England and Wales 1089464, Scotland SC041666

ARCH 2019

9TH INTERNATIONAL CONFERENCE ON ARCH BRIDGES

PORTO
OCTOBER 2>4
2019

Under the theme **"Arch Bridges – Natural beauty for all time"**, the 9th **International Conference on Arch Bridges (ARCH 2019)**, will be held in Porto, Portugal, on **October 2 to 4, 2019**. The conference will be organized by the Civil Engineering Department of the Faculty of Engineering of the University of Porto.

Since the first ARCH Conference (UK 1995), seven subsequent editions took place (Italy 1998, France 2001, Spain 2004, Portugal 2007, China 2010, Croatia 2013 and Wroclaw 2016), all high quality and successful events. Stemming from such heritage, it is our pleasure to invite you to the next 2019 ARCH conference edition.

On behalf of the Organizing Committee we hope you consider accepting this invitation, as we are committing ourselves to provide the best possible for your overall satisfaction during and after the conference.

Sincerely yours,

António Arêde
Chairman of the Organizing Committee

António Adão da Fonseca
Chairman of the Scientific Committee

Rui Calçada
Co-Chairman of the Organizing Committee

Elsa Caetano
Co-Chairman of the Scientific Committee

CONFERENCE MAIN TOPICS

· Heritage arch bridges

· Analytic and numerical studies of arch structures

· Experimental studies of arch structures

· Design and construction of arch bridges

· Rehabilitation, maintenance and condition assessment of arch bridges

· New and future trends in a rch bridges

IMPORTANT DATES

Submission of abstracts:
November 2nd, 2018

Acceptance of abstracts:
December 17th, 2018

Submission of full papers:
March 16th, 2019

Acceptance of papers:
May 18th, 2019

Close of early registration:
June 16th, 2019

CONFERENCE VENUE

The conference will be held at the Faculty of Engineering of the University of Porto (FEUP), in one major campus of the University of Porto (UPorto) located at the north limit zone of Porto city (www.fe.up.pt).

CONFERENCE LANGUAGE

English will be the conference official language, including sessions, proceedings and general organization.

The conference website

www.fe.up.pt/arch19

provides more detailed information.

+INFO:

ARCH 2019 Secretariat
Department of Civil Engineering
Faculty of Engineering o
University of Porto

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arch19@fe.up.pt

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59%

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INCREASE IN LABOR MARKET INCOME

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BUSINESS OPPORTUNITIES IN THE CZECH REPUBLIC

The Czech Republic ranks among countries with a strong economy and good potential. According to recent data, industrial production in the Czech Republic has increased by 5.7% year-on-year, and the value of new orders has increased by 6.6% year-on-year. The employment rate has increased by 2% and the unemployment rate is currently around 2.5%

The economic situation of the Czech Republic is very good and gives opportunity to invest in both state and public sectors. State-run organizations are creditworthy and cooperation with them is sought-after.

In the area of public investment, there has been an obvious and long-term effort to open up the market as much as possible and to allow participation of entities with a registered office or place of business outside the Czech Republic. The basis of this trend is given both at the level of the European Union and at the level of national legislation where it is stipulated mainly by Act No. 134/2016 Sb., on Public Procurement.

Due to the simplification of participation in the tender procedure (introduction of a uniform European Certificate, the contracting authority's obligation to accept documents issued under foreign law), there is no restriction on participation in tenders in the Czech Republic provided the participant fulfils the conditions of the tender.

The market is open to companies from the whole world.
The participant shall be well acquainted with the legislation to be able to submit a perfect offer in compliance with any procedure given by the contracting authority – especially in the case of above-the-threshold public tenders which might be of interest due to their financial volume (supplies and services with an estimated value of more than 443,000 EUR or equivalent; construction works with an estimated value of more than 5.548,000 EUR or equivalent).
Due to the fact that the procedure in above-the-threshold public tenders is relatively rigid, and even the minor non-compliance with the conditions by the participant may lead to their disqualification, it is necessary to be familiar with this area or to contact a reliable partner.
To conclude, the Czech market offers many possibilities and is open to foreign investors. Czech legislation does not impose any significant restrictions on participation in public tenders, however, it is worthwhile to cooperate with a company which is familiar with the local market, legislation and local customs, and is able to find suitable opportunities.

In the case you are interested in the public tender market in the Czech Republic and intend to apply for public contracts, if you search for answers to your questions or for regular monitoring of relevant opportunities – our company KGS legal s.r.o. as a leading law firm with a focus on public procurement law is always at disposal for you.

e-mosty

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Long Span and Multiple Span Bridges

1915 Çanakkale Bridge

Chacao Bridge

Maputo - Katembe Bridge

1915 ÇANAKKALE