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You can also read about the 1915Çanakkale Bridge in our previous editions of e-mosty

1915 Çanakkale Bridge
General Project and Bridge Information
Magdaléna Sobotková

Multi-Purpose & Modular Underwater Machinery (MUM) and its Use on the 1915 Çanakkale Bridge Project
A. Serkan Togay, Aras Marine Construction

Photo on the Front Cover: Credit ÇOK A S
Photo on the Back Cover: Credit: Muhammed Ilyas Özer, Era

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

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Dear Readers

This special issue of the magazine e-mosty is dedicated to the 1915Çanakkale Bridge in Türkiye. This bridge is with its 2,023m long mid-span the longest suspension bridge in the world. The bridge opened to traffic on 18 March 2022, more than one year before the scheduled date.

In this special issue, we present various aspects of its design and construction intending to bring you technical information about it and at the same time celebrate the achievements of the people and companies involved in this project.

I would like to thank our Editorial Board, especially Richard Cooke for the review and assistance with the content; the 1915Çanakkale Communications Team, ÇOK AS and DLSY for their assistance; and all authors, people and companies that have been helping me to put the content together.

We also thank our partners for their continuous support.

We wish you a pleasant time reading this special edition, and as an introduction, you may like to watch the teaser below:

Click on the image to play the video.

Credit: FilmGenetik
www.filmgenetik.com

The next e-mosty magazine will be released on 20 September 2022.

Magdaléna Sobotková
Chief Editor
The magazine e-mosty (“e-bridges”) is an international, interactive, peer-reviewed magazine about bridges.

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

It is published quarterly: 20 March, 20 June, 20 September and 20 December. The magazines stay available online on our website as pdf.

The magazine brings original articles about bridges and bridge engineers from around the world. Its electronic form enables the 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 mainly 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.

ISSN: E-MOSTY 2336-8179
In August 2021 we established a new magazine, e-BrIM, which focuses on Bridge Information Modelling. Its first regular issue was released on 20 February 2022. The September 2021 edition of e-mosty was also a “zero” edition of e-BrIM.

We follow the concept of the e-mosty magazine; e-BrIM is also an international, peer-reviewed magazine with open access and the possibility to subscribe. Our plan is to publish it three times a year (20 February, 20 May and 20 October); we believe that with the current development of BIM, there will be plenty of interesting and useful content to share.

Let us introduce and welcome our Editorial Board Members. Thank you all for accepting our invitation. We all do our best to prepare technical, educational and informative content for our readers. We would like to invite you to contribute with your articles to this newly established magazine e-BrIM:

**CALL FOR PAPERS**

**20 October 2022 Edition:**

**Deadline for first drafts: 20 September 2022**

*(please contact us to confirm and reserve space for your article)*

**20 February 2023 Edition:**

**Deadline for first drafts: 20 November 2022**

The text shall be in MS Word, 3 – 5 pages plus relevant images, drawings, 3D models, links and videos and shall be sent to our email address. You may also send an abstract before starting work on the article or contact us to discuss other options. All abstracts and articles will be peer-reviewed and also subject to approval by the Editorial Board.

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The magazine e-BrIM is an international, interactive, peer-reviewed magazine about bridge information modelling.

It is published at www.e-brim.com and can be read free of charge (open access) with the possibility to subscribe.

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20 February, 20 May and 20 October.
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The readers are mainly bridge leaders, project owners, bridge managers and inspectors, bridge engineers and designers, contractors, BIM experts and managers, university lecturers and students, or people who just love bridges.

ISSN: 2788-0540
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The Partnership can be arranged for either magazine separately, or for both magazines – for a discounted price.

Both the price and the extent of cooperation are fully negotiable.

Please contact us for more details and partnership arrangement.
First of all, please accept our congratulations on the successful completion of the 1915Çanakkale Bridge and its opening to traffic on 18 March 2022, one year ahead of the originally planned date. The project and your achievements have already gained international acclaim.

Thank you also for your time and cooperation on this interview.

You have been a CEO of a company that has been appointed to design, finance, construct and operate the Bridge. In your CEO’s message, you state that you aim to honour the glorious history of Çanakkale and crown the 100th anniversary of the foundation of the Republic of Türkiye. So, our first question is: What is your relationship to mega-scale projects in general and 1915Çanakkale Project in particular?

Everything happens for a reason. I practically started my career working on huge projects like dams and hydroelectric power plants at the General Directorate of State Hydraulic Works.

Later on, I had the good fortune to contribute to the Eurasia Tunnel also known as Istanbul Strait Road Tube Crossing Project. The tunnel is not only the first road tunnel connecting the Asian and European continents underneath the seafloor but also the first two-deck highway tunnel under the seabed in the world.

As the Deputy General Manager of the project, I have accumulated enormous experience. Realized by Yapı Merkezi and SK ecoplant - also partners of the 1915Çanakkale Joint Venture - the Eurasia Tunnel was one of the very first grand-scale Public Private Partnership (PPP) projects in Türkiye.

The project’s state-of-the-art technology and advanced engineering won many awards and received global attention.

I could have never imagined being able to work for a greater project, yet life is full of surprises.

Luckily, I have been in the right place at the right time and got involved in the 1915Çanakkale Bridge and Motorway Project.

Needless to say, 1915Çanakkale is a world-scale project with a much greater historical significance. In fact, realizing the dream of several centuries is once in a lifetime opportunity.

I will talk more about it in detail but suffice it to say that 1915Çanakkale will most probably be the jewel in the crown on my career journey.
The Bridge is the longest mid-span suspension bridge in the world. What does it mean for you?

From an engineering perspective, 1915 Çanakkale has been one of the world’s most challenging projects in recent times.

Both the 2,023 m long mid-span stretching between the tower foundations grounded on the seabed and its towers with a height of 318 m above the sea level are world-record breaking features. In other words, it is also the world’s tallest tower suspension bridge.

The tower foundations of the bridge are free-standing on the seabed at a depth of -45 m on the Asian side and -37 m on the European side.

One of the most crucial aspects of the Project is that the bridge had to be designed to withstand extraordinary challenges of heavy winds and seismic conditions.

Considering the fast wind speed which is characteristic of the Çanakkale region, an orthotropic twin box section steel deck with a total width of 45.06 m (including 9 m of gap connected by cross-boxes with a centre-to-centre spacing of 24 m) was determined for use on the bridge.

In terms of an earthquake risk, an immersed caisson type foundation positioned on the sea bed improved with steel inclusion piles was chosen for the tower foundations.

Let me also briefly comment on the cable fabrication.

The main cable comprises 144 strands in the main span and 148 strands in the side spans, with each strand consisting of 127 galvanized high-strength (1,960 MPa) wires with a diameter of 5.75 mm.

The total cable length reaches 162,000 kilometers. That is to say, the total length of the wires used in the main cable is equivalent to 4 times the circumference of the Earth.

Moreover, the Project also includes the Malkara-Çanakkale Motorway comprising of 88 km of motorway, 13 km of access roads, 2 viaducts and 12 junctions.

The fact that we could finish such a huge project in just four years, 1.5 years earlier than planned, is amazing.

And, what is more, we pretty much managed to stay on budget. We are indeed very proud of all these accomplishments.

You have a very strong technical and business education and background. How long have you personally been involved in the Project?

As a former member of Yapı Merkez family, I have always been aware of the fact that the chairperson of our group, Dr. Ersin Arıoğlu had the lifelong dream of building a bridge on the Çanakkale Strait.
So, the news of the tender caused great excitement within the group. I was especially interested since I saw this as a great opportunity to capitalize on my experience in the Eurasia Tunnel and step it up to the next level.

I believe that both my background and enthusiasm had been the main contributing factors for me being offered the position of Chief Executive Officer at ÇOK A.Ş.

No doubt, it was a role that would put my management philosophy to the test. Because of the complex structure of the Project, my appointment process went through several phases.

I am very grateful for both Sponsors’ and Administration’s undiminished confidence and continuous support.

After finishing the construction of the bridge and motorway successfully, we entered into the operation period and our working relationships continue in the same way smoothly.

**What have been the most challenging aspects of the Project in your role as the CEO?**

Let me first state that my position considerably differs from the classical job description of a CEO. Our Executive Board and the Board of Directors have a strong involvement in the day-to-day operations.

Their commitment and guidance have certainly facilitated my decision-making.

My previous experience with regard to the synchronous management of multiple stakeholders have also been quite beneficial.

I think I have managed to build a platform of extensive coordination and broad consensus based on mutual trust.

In fact, in terms of management philosophy, my work has really been about managing and optimizing the fine balance between multiple parties involved in the Project.

What was needed was an agile and united structure that would produce optimal results while paying strict attention to time constraints and minimizing differences.

One of the most important challenges in terms of management has been to fuse the corporate cultures of four different companies in a very short time and I do consider our performance on this matter quite extraordinary.

As you know we did not only wrestle with technical and administrative difficulties, but we were also in a race against time, which meant that communication, sharing of information and empathy were of the utmost importance in this Project.

It was by no means easy but thanks to the broad vision and accurate projections of our experienced management team and Administration, as well as the selfless efforts of all our employees, the Project was successfully completed on time.

**Overall, how many people and companies have contributed to the planning, design and construction of the bridge to date?**

Considering ÇOK A.Ş., DLSY JV and all subcontractors of these companies, more than 30 thousand people have contributed to the Project during the past four years.

Nearly 400 main subcontractors from 15 different countries have been working with motorway and bridge construction teams.

We have been fortunate to be able to work with some of the world’s leading companies - all global experts in their fields: To name just a few, COWI from Denmark has been our design consultant. Mott MacDonald from the UK acted as a technical advisor. The Men from Marr’s from Australia undertook the world’s heaviest (155 tons) craneage lift at this Project. KISWIRE from South Korea produced our special wires and so on.

Most importantly, however, hundreds of Turkish public officials and servants from various ministries have put their heart and soul in this Project.

We are more than grateful for their undiminished efforts.

I would especially like to extend our thanks to the Ministry of Transport and Infrastructure and The General Directorate of Highways for their continuous support.
How has the experience been like leading and working with multi-cultural and multi-national teams? What did each partner bring to the team?

Naturally, achieving cohesion and harmony between collaborating partners is extremely important.

With regard to your second question, I am very happy to inform you that all partners have brought their best teams to this Project.

Obviously, each partner has provided added value in a different area, depending on their expertise and experience.

Yet we managed to mix all these added values in a blending pot and use it for the success of our partnership.

Beginning with the tender process, we have put great emphasis on establishing a harmonious relationship.

The four partners have spent a lot of time together, physically putting in the working hours, and we still continue to do so. This process has enabled us to get well acquainted with each other. Knowing one another facilitates harmony which in turn creates a great team spirit.

I think concentrating on what unites us instead of what separates us has been the key to our success.

As a final note, I have to underline the fact that both Türkiye and Korea share many similar values like respect for the elderly or family ties.

This cultural similarity also contributed to our establishing a unified organization.

How has the construction been affected by the pandemic?

As of the occurrence of the risk of COVID-19, a committee consisting of experts from different fields (Doctor, Occupational Safety Specialist, Human Resources Specialist, etc.) has been established at our construction sites.

This committee has taken all the measures deemed necessary at our sites by closely following the developments in Türkiye and in the world.

Emergency action plans have been prepared on this issue and necessary coordination has been established with the relevant institutions.

From the beginning, the health of our employees has been our top priority. In order to prevent the spread of Covid-19 in our Project, the number of people was reduced both at the camp sites and the construction sites.

As a result, we were faced with a loss of time and productivity, however managed to avoid any severe effects of the pandemic.

I am also very proud of the fact that we did not face serious obstacles in terms of material supply and transportation since the project management and planning teams have made the relevant purchases in advance at earlier stages.

As a result, the operations on-site have continued uninterrupted, in accordance with the originally anticipated work schedule.

That is to say, through agile and effective management of the potential negative effects, we have succeeded to minimize the impact of coronavirus.

Why is the bridge important for the future development of the region? What makes this bridge different from other long-span suspension bridges?

Before everything else, 1915Çanakkale Bridge and Malkara-Çanakkale Motorway Project is a mega-scale investment in transportation and infrastructure.

Reducing the crossing time over the Çanakkale Strait to six minutes is just one aspect of it. The Project, connecting Istanbul to Çanakkale, and then to the North Aegean, will directly and indirectly make enormous positive contributions to people’s lives within expansive geography.
As Türkiye’s largest city in terms of its population and economy, Istanbul’s connection to our country’s agricultural and industrial areas will accelerate the socioeconomic development of many adjacent regions.

In particular, the industry and agriculture sectors will benefit from the integration of the seaports, railways and airways in the Marmara and Aegean regions with highway transportation systems.

The distance between tourism centres like İzmir, Aydın, Antalya and Europe will be shortened which will contribute to the development of the tourism sector as well.

In other words, all sectors in the Thrace and Western Anatolia regions will gain momentum, with faster and more cost-effective freight operations strengthening the economic activities and social connections of these regions that hold a highly productive population.

We also expect important changes on the international level: Located at the junction point of the Modern Silk Road which stretches from China to England and is currently being reinvigorated between Asia and Europe, Türkiye is going to serve as a base for a significant amount of merchandise trade flow, via logistic centres that are still in the making.

So, besides all the other benefits which I mentioned earlier, the 1915Çanakkale Bridge and Malkara-Çanakkale Motorway Project is also going to be an important point of passage for this merchandise flow which will be conducted via these logistic centres, ultimately serving to boost the commercial mobility between Europe and Asia.

Last but not least, we feel very proud of the 1915Çanakkale Project which has enormous positive impact on Çanakkale itself since Çanakkale is a land that comes to the fore with its cultural heritage as well its unmatched natural beauty and abundant resources.

Can you summarise the critical stages of the construction process?

The length of the bridge, certain geological qualities of the Çanakkale region, and the continual maritime traffic in the Strait have been the main factors that created a unique process for everyone involved.

However, it has to be said that this unique process has also brought along some unique solutions.

To begin with, we employed the most advanced technologies that are currently available in the construction sector.

We also devised and implemented brand new solutions when necessary and we even designed tools from scratch to meet project-specific needs.

For example, since the concrete structures used in the 1915Çanakkale Project are exposed to harsh environmental impacts, not only the durability but also the strength of the concrete needed to be quite high.

For that reason, we used special concrete produced specifically for this Project by our solution partners. It has a processability period of over 3 hours and high-performance capability in terms of fresh and hardened properties.

By reducing the heat of hydration, we prevent microcracks that may form due to thermally induced internal stress.

Thanks to a high dose of binding agent and cinders, chlorine permeability is reduced remarkably, and durability is extended to exceed hundreds of years.

The tower foundations of the 1915Çanakkale Bridge are seated on the seabed. As is well known, the region has the potential to produce great earthquakes.

To minimize the impacts of possible earthquakes on the bridge, we utilized direct displacement-based design for our tower foundations, which may be defined as a system of seismic isolation below the foundations.

Seismic isolation of this scale is unprecedented in the world.

Our bridge’s towers bear the title of “the world’s tallest suspension bridge towers”. However, this title comes accompanied with the reality of massive wind loads.

So, we have in place four active mass dampers, each weighing 30 tonnes, to observe the behavior of the towers and absorb the vibrations. These dampers were also used during the construction phase, allowing an uninterrupted production process.
For the construction of the bridge towers, we used the world’s largest capacity tower crane.

Here, instead of transporting individual smaller components to be assembled later on site, we developed a methodology which involved the transportation of heavier modular components in one trip with assemblage thereafter.

Allow me to say that we have actually broken a world record in collaboration with Marr Contracting during tower erection. In the recent past, we managed to lift 155 tonnes to a height of 318 m using a tower crane with a lifting capacity of 330 tonnes.

The bridge deck is composed of 87 segments, with 21 single and 66 double-decks that are installed either with one of the world’s largest floating cranes or with lifting gantries specifically produced for the Project.

The deck erection process required consecutively successful operations which means that if anything goes wrong in one operation, it jeopardizes the entire progress.

Our teams worked seven-day weeks and 24-hour-days to complete all these operations within as short a period as two months.

Not only maritime conditions (wave height, currents, etc.) but also wind speed could have serious impacts on all the operations.

Since deck installation relies completely on lifting equipment, close monitoring of wind and maritime conditions and taking advantage of all opportunities was paramount.

Sensors and anemometers were set up to measure wind speeds, and the data was gathered and analyzed on a moment-to-moment basis so that the operations could run smoothly.

The wind impact was considered not just in terms of how it affected the lifting equipment and lifting operations but also with regard to its resonance effect on the bridge.

How did you manage to finance the Bridge and Motorway Project? What is the reason that the Project received many finance awards?

For the 1915Çanakkale Bridge and Motorway Project, finance agreements were signed with 25 financial institutions from 10 countries on 16 March 2018, securing a 15-year term loan with a grace period of 5 years, for a total sum of 2.265 billion EUR. 70% of the loan was provided by 19 foreign banks and financial institutions, and 30% by Turkish banks.

The credit package, which is structured in accordance with the international project financing standards, is composed of eight different tranches including Export Credit Agencies (ECA’s) and Islamic financing methods. The Korean export credit agency Korea Eximbank (KEXIM) and Korea Trade Insurance Corporation (K-SURE) participated in the financing with a loan of 1 billion EUR in cash and guarantees which is the largest credit package ever received by a project in Türkiye.

Among other organizations that have provided cover are the Danish export credit agency EKF and The Islamic Corporation for the Insurance of Investment and Export Credit (ICIEC) which is affiliated to the Islamic Development Bank (IDB).

The government institutions and 25 banks and financial institutions taking part in the financing of the Project are as follows:

**Government Institutions:** Republic of Türkiye Ministry of Treasury and Finance, Republic of Türkiye Ministry of Transport and Infrastructure, General Directorate of Highways

**Cover Providers:** EKF, ICIEC, Korea Eximbank, K-Sure

**Mandated Lead Arrangers:** Akbank, Bank of China, Deutsche Bank, DZ Bank, QNB Finansbank, Garanti BBVA, ICBC, ING, Intesa San Paolo, Türkiye Is Bankasi, KEB Hana Bank, KDB Bank, Kuwait Finance House, Kuveyt Türk, Natixis, Samsung Life Insurance, Shinhan Bank, Siemens, Standard Chartered, Vakıfbank, Yapı Kredi

In short, we were able to bring together a wide variety of international resources for this important Project. We have accomplished and undersigned an exemplary job in terms of both resource diversity, optimization of funding structure and lender profile.

That is one of the main reasons why we have received 12 international finance awards.

I am glad to state that being in this Project has brought prestige to any financial institution, investor, professional, and to any consultant or any subcontractor doing business for the Project.
Which innovations provided the greatest benefit to the engineering scheme - design or construction?

During the design and construction of the Bridge, we have faced many challenges and overcame them thanks to the expertise and capabilities of our colleagues.

Let me give you some examples, starting with the installation of the plinth and tie-beam structures in one piece.

The plinth is the link between the steel tower and the foundation to transfer the load from the superstructure. And tie-beam connects the north and south plinths to provide the lateral rigidity against lateral forces.

In the beginning, plinth and tie-beam structures’ installation was planned to be in-situ. However, considering the adverse weather conditions and accessibility of the working area (which is on the sea), our teams came up with an innovative solution for the operation.

To minimize the risks posed by the marine conditions and to optimize the schedule against the original construction method, we decided to pre-fabricate the plinth rebar cage and tie-beam concrete structures on the ground and subsequently utilise a floating crane and a submerged barge for the heavy-lifting operation.

By changing the construction method of plinth and tie-beam structures, we managed to accelerate the construction period dramatically, and to improve the quality of the structures regardless of the marine conditions.

Another example can be the catwalk installation methodology which was developed in such a way that the operation did not interrupt marine traffic despite heavy weather conditions.

Temporary suspender systems were used to erect heavy catwalk ropes which indeed have world-record dimensions.

With the help of this innovation, marine traffic remained unaffected by the construction work on the Çanakkale Strait thanks to the suspender system.

It is common practice in the suspension bridge industry that the steel decks – particularly box girders – are fabricated with lengths equal to hanger spacing. In our case, it is 24 m. However, considering the total number of steel deck segments which is 153 No., the erection operation would require significant time.

And also, as the number of decks to be erected is increased, it also increases the vulnerability against an aggressive wind environment.

In order to minimize not only the risk but also construction time, it has been studied and applied to fabricate double steel segments 48 m long which we call mega blocks.

Therefore, the number of steel deck operations has been reduced significantly.

What measures did you take to protect the environment?

Environmental and social awareness is one of our core values in the 1915Çanakkale Bridge and Motorway Project.

As a result of our sensitive approach towards environmental and social risks and impacts, the 1915Çanakkale Bridge and Motorway Project was further evaluated following the approval of the local EIA Report and an Environmental and Social Impact Assessment (ESIA) study was conducted in compliance with IFC Performance Standards, IFC General Environmental, Health and Safety Guidelines, OECD Revised Council Recommendation on Common Approaches on Environment and Officially Supported Credits, and Equator Principles III in order to identify environmental and social impacts of our Project in more detail and determine associated mitigation practices.

After the finalization of the ESIA Reports, they were shared with the public through online publication and distribution of printed copies in residential areas along the route.
All environmental and social activities are conducted in line with the Environmental and Social Action Plan prepared by the Lenders’ Environmental and Social Consultant ARUP, based on final ESIA reports. Our team of capable professionals are continually diligent in their efforts to implement all the activities indicated in this plan in a timely and efficient manner and improve the Project’s environmental and social awareness.

Communicating with our stakeholders in a healthy and efficient manner is of utmost importance to the 1915 Çanakkale and Motorway Project. We run our communication activities with the stakeholders within the framework of our Stakeholder Engagement Plan (SEP) published on our website. All our stakeholders with an interest in our environmental and social performance are regularly informed - through various communication channels such as the website, project hotline, visits from community liaison officers – in an accurate, extensive, comprehensible and transparent manner.

Was sustainability a consideration for the bridge?

Both environmental and social sustainability efforts are high on our agenda. We ran comprehensive biodiversity conservation activities in the areas that were affected by construction activities.

To illustrate; Pinna nobilis (fan mussel) is a marine species under strict protection according to the European Council Directive 92/43/EEC due to its significant decline in population.

In order to mitigate our impact on this species, a transplantation study was carried out together with Çanakkale Onsekiz Mart University Underwater Research and Application Centre between July and August 2018.

1,015 Pinna nobilis individuals were collected, transferred to safe areas and planted alive to their new habitats.

Between March and November 2018, in order to mitigate the negative impact of the pile driving operations taking place in the Çanakkale Strait on marine mammals, Passive Acoustic Monitoring and Marine Mammal Observation works were conducted with the Marine Mammal Observers.

An Exclusion Zone of 500 m horizontal radius from the centre of the acoustic source was established. In cases in which mammals were seen within the 500 m Exclusion Zone, operations were halted until the mammal left the Exclusion Zone.

During the pile driving operations, there were seven sightings of mammals inside the Exclusion Zone and work was halted for a total of 2 hours and 11 minutes.

In line with the international requirements of our Project, we have committed to planting five trees per each tree affected by our construction activity. The calculation method to arrive at the number of affected trees was approved by the Lenders’ Environmental and Social Consultant ARUP and a protocol was signed with the General Directorate of Forestry regarding the afforestation activities.

To minimise the environmental impact of the motorway in the Project’s operation period, the motorway project also includes an ecological bridge, which is 40 m wide and 50 m long, to facilitate the safe passage of wild animals in areas intercepted by the motorway, ensuring that they meet with no obstacles while trying to get access to food and water.

On the social side, we provided a Community Level Assistance Program with a primary focus to complement the compensation that has been or will be paid by the General Directorate of Highways in accordance with Turkish legislation and to enable households to continue their livelihoods without being negatively impacted by the Project or develop new ways of gaining a livelihood.

Together with our Lead Implementation Partner SÜRKAL (Sustainable Rural and Urban Development Association), we began to implement this program in 32 settlements along the Project’s route in May 2019.

Four main programs designed for CLAP are as follows:

- 1st program: Skills Development and Access to Markets
- 2nd program: Institutional Capacity Building
- 3rd program: Natural Resources and Sustainable Energy Sources
- 4th program: Community Health, Safety and Well-being
Below are some of the activities performed within this framework:

- Training Sessions on Combating Infestations of Tuta Absoluta and Distribution of Input;
- Training Sessions on Combating Infestations of Mediterranean Fruit Fly and Vinegar Fly;
- Apiculture (Beekeeping) Training and Input Support;
- Machinery and Equipment Support;
- Forage Plant Breeding Training and Reygrass Planting;
- Pomiculture (Fruit Growing) Training and Input Support;
- Lavender Farming Training and Input Support;
- Drilling for Irrigation Water;
- Pasture Improvement;
- Support for Building a Reservoir;
- Support for Supplying the Village With Domestic Water;
- Restoration of Crop Drying Zone;
- Building a Bus Stop for Students;
- Setting Up a Workshop for Skills Development.

Can you tell us about the maintenance plan? What special skills and technologies are required to maintain the bridge?

Our aim is to provide the basis for effective and safe inspection and maintenance in order to obtain and maintain a safe and fully operational bridge so that its elements achieve design service life.

Inspection and Maintenance comprise the following types of expected activities on the Bridge:

- Routine I&M (weekly, monthly, quarterly, yearly)
- Principal Inspection (every five years)
- Special Inspection (if needed)

The bridge is being monitored via over 300 cameras in the 24/7 regime.

Moreover, there are a lot of traffic sensors and over 1,000 sensors that are part of the Structural Health Monitoring System (SHMS).

All those cameras and sensors are connected to SCADA system in the control room.

The utilization of all these systems provides the basis for decision-making for the safety, operation and maintenance of the Bridge.

There is some crucial equipment that ensures to maintain the structural behaviour of the Bridge within the allowable limits defined by the designer.

For instance; AMD (active mass damper) ensures that the longitudinal and torsional vibration of towers is reduced by controlling the Vortex-Induced Vibrations (VIV) in such a way that not having any fatigue damage on towers during strong wind.

Such vital importance equipment is monitored from the control room by the Operator in 24/7. In case any unexpected condition occurs, the maintenance team directly handles the problem.

Another crucial piece of equipment in the Bridge is Hydraulic Buffers that are located at all four tower legs towards the midspan at the side of the bridge decks.

These ensure reducing the longitudinal movements of the deck at the tower during a seismic event. The oil pressure and displacement of the buffers are monitored via the deployed sensors.

COWI, the company responsible for Bridge design, gave comprehensive training to the technical staff about Bridge Management, Inspection and Maintenance.

The training consisted of both face-to-face theoretical sessions, including experiences from Operation and Maintenance of Great Belt Bridge, and site visits together with COWI specialists.

All the SPV technical staff completed the training successfully and received certificates for Bridge Management, Inspection and Maintenance.
What are the international and regional awards, technical or financial, that the bridge has won to date?

The list of the awards our Project has won until June 2022 is as follows:

1. Project Finance International (PFI) Awards – Turkish Deal of the Year
2. Islamic Finance News (IFN) Awards – Project and Infrastructure Finance of the Year
3. Infrastructure Journal (IJ) Global – Europe Road Deal of the Year
4. Bonds & Loans Awards – Project Finance Deal of the Year
5. Bonds & Loans Awards – Infrastructure Finance Deal of the Year
6. Proximo Finance Awards – Best EMEA ECA Backed Deal of the Year
7. EMEA Finance Awards – Best Project Finance Deal in Europe
8. EMEA Finance Awards – Best PPP Deal in Europe
9. EMEA Finance Awards – Best Project Finance Deal in EMEA-wide
10. EMEA Finance Awards – Best Road Deal in EMEA-wide
11. EMEA Achievement Awards – Best Syndicated Loan in EMEA
12. International Road Federation (IRF) Global Awards – Best Project Finance and Economics
13. Green World Awards – Gold Level in Environmental Best Practice
14. Korean Society of Civil Engineers – International Civil Structural Awards / Civil Structure of the Year

Most recently we have received some regional awards from the Turkish Social Security Institution which prove the effectiveness of our social sustainability efforts, namely Employment Awards for Providing Most People with Insured Employment in Çanakkale, Providing Employment to Disabled, Providing Women’s Employment.

Thank you again for your time and cooperation. We wish you, your teams and the bridge the best in the future.

Reference:

Mr. Mustafa Tanrıverdi

Mustafa Tanrıverdi completed his secondary education at Kuleli Military Highschool and graduated with a degree in civil engineering from Istanbul Technical University.

He received his postgraduate diploma (MSc) in engineering from The University of Texas at Austin and also completed an MBA at METU (Middle East Technical University).

Upon returning Türkiye, Tanrıverdi worked for a while at the General Directorate of State Hydraulic Works, focusing on water structures, dams and hydroelectric power plants.

Following a short-term appointment at an international consultancy firm, he joined Yapı Merkezi.

Within Yapı Merkezi, he has worked on various projects, at various positions and capacities mainly to Project and Business Development.

In 2011, Tanrıverdi was assigned to the Eurasia Tunnel Project as Technical Coordinator. In 2013, he became the Deputy General Manager of Eurasia Tunnel Operation Construction and Investment Co. (ATAŞ).

He was appointed as ÇOK A.Ş. CEO in 2017 for 1915Çanakkale Bridge and Motorway Project.
PHOTO GALLERY
1915 Çanakkale Bridge, Türkiye
1. INTRODUCTION

Türkiye serves as an important crossing between Asia and Europe. Its rapid economic growth together with an increased number of tourists, agriculture and transit transport has led to chronic traffic congestion. The existing transportation network is unable to accommodate all demands arising from the traffic growth.

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

Part of the programme was building a suspension bridge being the first bridge crossing the Dardanelles Strait, in Türkiye known as the Çanakkale Strait, which will improve the transportation network on the west side of the country, promote socio-economic growth and tourism. In particular, the bridge crossing provides an alternative route for European traffic to and from Izmir, Türkiye’s 3rd largest city, avoiding Istanbul.

The bridge with its main span of 2,023m is the suspension bridge with the longest main span in the world.

2. LOCATION OF THE BRIDGE

The 1915Çanakkale Bridge (in Turkish 1915Çanakkale Köprüsü) is located 200km southwest of Istanbul, spanning the Çanakkale 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, see Figures 1 and 2.
The bridge is located in the 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 1915Çanakkale 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.

COWI has been involved with other major bridge projects in the area, as can be seen in Figure 2, namely the Osmangazi Bridge over İzmit Bay which opened in 2016, and the 3rd Bosphorus Bridge named Yavuz Sultan Selim Bridge, which also opened in 2016.

COWI was responsible for the detailed design of the Osmangazi Bridge which has many similarities to the 1915Çanakkale Bridge.

3. BRIDGE PROJECT DESCRIPTION

A joint venture made up of South Korea’s DL E&C and SK ecoplant and Türkiye’s Limak and Yapı Merkezi, named DLSY, won the tender for the construction of the bridge on 26th January 2017 by offering the shortest concession period of slightly more than 16 years, which includes a minimum revenue guarantee once the bridge is opened to traffic.

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

The General Directorate of Highways (KGM) awarded the 1915Çanakkale 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 ve Köprüsü İnşaat Yatırım ve İşletme A.Ş. (Çanakkale Motorway and Bridge Construction, Investment and Operation Inc.).

The EPC contract for the bridge was signed in an official ceremony on 21st March 2017.

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

The bridge will be handed over to the Turkish Government after the completion of the operation period.
The ground-breaking ceremony took place on 18th March 2017. The opening of the bridge took place exactly 5 years later on 18th March 2022, one year in advance of the centenary anniversary of the declaration of the Republic of Türkiye in 1923.

The Danish engineering consultant COWI was in 2017 awarded the design contract and COWI has been responsible for the detailed design of the bridge and has further provided the design for deck erection.

4. GENERAL DESIGN

The main structure has become the world's longest suspension bridge with a main span of 2,023m and two side spans of 770m each giving a total bridge length of 3,563m.

Together with two approach viaducts, the total bridge length is 4,608m.

The European Gallipoli approach viaduct is 365m long and the Asian Lapseki approach viaduct is 680m long.

An elevation of the bridge can be seen in Figure 3, and a rendering of the suspension bridge can be seen in Figure 4. The towers themselves have a height of 318m and 334m inclusive of the special tower top.

4.1 Design features and challenges

Design of the suspension bridge system relies on accurate FE modelling.

The global analysis model (GAM) is created in the structural design and analysis system IBDAS (integrated bridge design and analysis system) developed by COWI.

IBDAS has been used to design several bridges and is a state-of-the-art FE-program for design of suspension bridges. The GAM is created as a parametric IBDAS FE-model using a combination of beam, shell and solid elements.

Local models have a direct interface to the global model and are activated inside the global model obtaining easy loading and correct boundary conditions.
A rendering of the different geometrical elements within the IBDAS FE-model and element meshes can be seen in Figure 5.

In excess of the general challenge related to design of a world record suspension bridge, a number of specific challenges were being dealt with.

First of all, the timeframe for design and construction was extremely tight.

With a scheduled 5 years for design, procurement and construction, the design process had to be efficient and include optimised solutions to allow for fast construction.

Furthermore, there have also been a number of technical challenges specific to the 1915Çanakkale Bridge which needed to be solved – among others related to the ground conditions, the seismic activity in the area, the intense ship traffic in the Çanakkale Strait, the wind climate and the expected live load on the bridge.

These have called for a special focus on the seismic/earthquake design, aerodynamic design, ship collision risk analysis, live load modelling with a focus on the special traffic on the bridge, etc.

### 4.2 Caisson foundations

The steel towers are 334m high, making the bridge the tallest bridge in Türkiye. Each tower is founded on a cellular concrete caisson measuring approx. 83m by 74m in plan.

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

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

In the wet dock, the concrete construction continued while the two caisson structures immersed deeper under the increased weight. When the concrete works were finished, two double-walled 18m diameter steel cylinders were installed on top of each caisson for later support of the tower legs. The 23 - 26m high steel cylinders were moreover to ensure a controlled immersion of the caissons at the final position.

Simultaneous to the construction of the caissons, the seabed at the tower locations was being prepared for the placement of the caissons. At the seabed, the ground consists of Holocene clay deposits at the European tower and Pleistocene clay and sand deposits at the Asian tower, followed by a Miocene mudstone formation below at both locations. The seabed was initially prepared by dredging to get a levelled plateau. Then 2.5m diameter open-ended steel inclusion piles were driven into the mudstone.
203 piles were installed at the European tower location with lengths up to 46m and 165 piles at the Asian tower location with lengths of 21m.

The inclusion piles reduce tower settlements (for the European tower 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 as can be seen in Figure 8.

For ensuring the load transfer from caisson to steel piles a 3m thick gravel bed is placed around the head of the piles on which the caisson is placed after the controlled immersion.

This arrangement allows the tower/caisson to slide during a major seismic event.

After placement of the gravel bed on the seabed and finalisation of the works in the wet docks, the caissons were towed to their final positions and sunk to the seabed which was at 37m and 45m below the water level at the European and Asian sides respectively.

After immersion of the caissons, the steel shafts were filled with concrete between the double steel walls and solid 10m high plinths were cast on top of each steel shaft.

These plinths are interconnected with a tie-beam making the two tower legs act as one unit particularly for ship impact- and seismic load situations.

### 4.2 Towers

The 318m high towers are being constructed out of steel, primarily to allow for fast erection. They comprise tapered box sections with a chamfered corner for better dynamic performance in the wind.

A plan of one tower leg can be seen in Figure 9 with longitudinal flat stiffeners and a cross frame.
The towers are divided into prefabricated block elements; 32 blocks in total for each tower leg and 3 blocks for each of the three cross beams. The size and weight of the blocks are primarily driven by the erection method.

The first five very heavy blocks of each tower leg have a height of up to 11.0m and a weight of up to 800 tons. They were designed to efficiently utilise the capacity of the floating crane that will erect these blocks one by one on top of each other.

The blocks are interconnected by horizontal block joints with welded skin plates and bolted splice connections of the internal longitudinal flat stiffeners.

For placement of the blocks above block 5 at level +60m, a heavy lifting tower crane was utilised with a lifting capacity of 160 tons. This required the normal block elements to be subdivided into 2 panels, while 4 panels are necessary for the special blocks at the cross beams and deck level. The panels are interconnected by bolts at the corners of the block.

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

To accurately capture the structural behaviour in the complex parts of the towers several local FE-models are used.

Models are created for the tower bottom and at the cross beams as seen in the Figure 11.

Figure 10: Installed tower. Welding platforms indicate block heights

Figure 11: Local FE-models used for verification of towers
It was therefore beneficial to move the anchor blocks away from the shoreline to where the Miocene formation emerges at ground level.

In order to get the anchor blocks placed on the Miocene formation, the ratio of side span to the main span was increased compared to usual and the cables were furthermore tied down at the side span piers.

Increasing the ratio of side span to the main span furthermore made it possible to place the side span piers at more favourable positions where the risk of ship impact is lower and the geotechnical conditions are more favourable, i.e. on the shore on the European side and away from the underwater slope and into shallower water depth on the Asian side.

The anchor blocks are designed to minimise their height so the tension forces are transmitted as directly as possible into the foundation, reducing the over-turning moment.

The anchor blocks are positioned below the decks of the approach viaducts at each end meaning they have a setback of 250m and 350m respectively from the end of the side spans of the suspension bridge.

At the anchorages, the splay saddles will support and splay the main cable. The very high concentrated force in the main cable (approx. 500MN ULS) must be reduced due to the much lower strength concrete anchorage in which it is anchored.

Sectional forces obtained from the global IBDAS model are applied and the local effects are investigated.

On top of the towers, the tower saddles were installed. The tower saddle supports the main cable strands over the tower tops.

4.3 Anchor blocks, side span piers and main cable

The ground conditions for the anchor blocks are critical in order to resist the massive design force of approx. 500MN (50,000 tonnes) from each main cable of the suspension bridge.

The upper soil is, however, weak on both the European and Asian shorelines and the more competent Miocene formation is present at relatively large depths.

**Figure 12: Tower saddle**

**Figure 13: Ground conditions and anchor blocks, European (left), Asian (right)**
Both tower saddles and splay saddles are of paramount importance for the safety of the entire structure.

A failure of one of these saddles will result in a total failure of the bridge. Therefore, these structures are meticulously designed using advanced FE-modelling.

The main cables are formed of prefabricated parallel wire strands (PPWS).

A PPWS is built up of 127 numbers of 5.75mm diameter wires with a breaking load of 1,960MPa.

The main cable consists of 144 strands that are continuous between the anchor blocks and 4 extra strands in each side span.

Elastomeric wrapping and dehumidification of the main cable were done to protect it.

The hangers are PPWS type and consist of 139/151 numbers of 7mm diameter wire.

The first two hangers on each side of the towers are double hangers to account for the increased loading in this area.

The setbacks of the anchor blocks from the side span piers imply that tie-down cables are introduced controlling the vertical position of the main cables at the bridge ends.

Each tie-down comprises four tensioned cables clamped to the main cable transferring loads directly to the piled foundation of the respective side span piers.
4.4 Bridge deck structure

The bridge deck comprises two stiffened closed steel box girders spaced 9m apart, connected by 3m wide cross-girders every 24m.

The 9m airgap between the two box girders ensures the aerodynamic stability of the bridge deck in strong wind.

The overall width of the twin box girder becomes 45m in total inclusive of one maintenance walkway on each outer side.

The bridge will carry six traffic lanes, three in each direction. The depth of the twin box girder is 3.5m.

The twin box girder reflects the advances in technology recently developed and also used on other very long-span bridges.

The underside of the twin box girder is located at level +82.5m at the centre main span ensuring a navigation clearance for the ships of 70m x 1600m (height x width).

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

The bridge deck was verified for fatigue stresses in the top plate region. For this analysis, the semi-local IBDAS model was used.

Part of the deck was modelled using shell elements and stresses were obtained directly from the global model as seen in Figure 21.

Figure 18: Installed hangers ready for deck segment lifting

Figure 19: Erection of deck segments using lifting gantries

Figure 20: Deck section – twin box girder with 9.0m airgap
4.5 Special analyses and tests

4.5.1 Aerodynamic testing

Aerodynamic modelling and testing of long-span bridges are essential in understanding the dynamic response of the bridge structure due to wind loading and to optimise the design to ensure stability against the wind.

Analysing of local wind data gave a basic 10 minutes mean wind speed of \( v_{10} = 29 \text{m/s} \) at level +10m, giving \( v_{10} = 46 \text{m/s} \) at maximum deck level of +86m.

The wind tunnel testing was carried out in three locations around the world, each investigating different specific elements and characteristics:

- Deck section model at 1:60, followed later by 1:30 scale in Canada (BLWTL)
- Tower section model (1:80 scale), full tower model (1:225) and tower erection stages (1:225) in Denmark (Force)
- Hanger vibration (1:1) and wake galloping (1:1 and 1:31.8) in Denmark (Force)
- Full bridge model (1:190) and deck erection stages (1:190) in China (RCWE)
The aerodynamic stability of the bridge structure was verified through wind tunnel tests of the full aeroelastic model of the bridge.

The twin box girder was verified for the selected airgap of 9m and for the towers additional damping was introduced by an active mass damper (AMD) positioned 2/3 of the height in the upper part of each tower leg. Each box girder is shaped to minimise the effects of wind forces and to maintain aerodynamic stability.

A number of different box profiles were tested to optimise the behaviour with variations to the geometry of the inner web, gap width and use of different heights of outer wind screens.

The flutter stability is dependent on mean twist angle of the bridge girder with its nose up due to wind loading and to ensure stability, the models must prove that the deck remains stable for a wind speed up to 69m/s for 0°.

### 4.5.2 Ship impact

The Çanakkale Strait connects the Mediterranean and the Black sea through the Sea of Marmara and constitutes an important link for freight transport with approximately 44,000 registered vessels passing the strait in 2016.

The traffic today includes 260,000 DWT bulk carriers, 167,000 DWT oil tankers and 16,000 TEU container ships.

Even though these are not the largest ships in the world fleet they are of very significant size and it is considered that there may be even larger ships in the Çanakkale Strait in the future.

The navigation clearance envelope for the bridge is 1,600m wide by 70m high, centred at the main span.

This will allow for safe passage of the approximately 44,000 ships annually as of today and as well account for a potentially large future increase in ship traffic.

However, even with this large navigation span and appropriate traffic control, the caissons foundations for the tower structures need to consider the potential impact from ships. Also, the lower sections of the towers, up to 29.5m above sea level, are exposed to ship impact.

The ship impact design requirement is based on ship collision risk analysis leading to required resistance for a ship, impacting at an angle of up to 30 degrees with a global impact force of 370 MN (37,000 tonnes).

A potential design vessel is shown in Figure 24 to indicate the size of the vessel compared to the dimensions of the composite caisson shafts.
These loads are then transmitted primarily down through the composite shafts and caissons to the soil-improved seabed.

Semi-local and local impacts govern 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 the local bending resistance of the skin plates.

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

This has resulted in specific design challenges and detailing of reinforcement, e.g. diagonal bars in some walls and slabs.
4.5.3 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) – 145-year return period
- Safety evaluation earthquake (SEE) – 975-year return period
- No collapse earthquake (NCE) – 2,475-year return period

To analyse the non-linear element behaviour of the bridge during a seismic event, dynamic analyses were performed using the global finite element model and applying earthquake displacements in three directions at the six main supports, being two anchor blocks, two end supports and two towers.

In total seven sets of time-displacement actions, which are to model seven different earthquakes, are applied for each of the three design earthquakes magnitudes/return periods.

The analyses investigated the influence of using hydraulic buffers at the towers, wind bearings and soil-structure interaction.

4.5.4 Traffic load on the bridge

The traffic load on a bridge with a main span length of more than 2,000m becomes very important as the Eurocode system only considers bridges with traffic up to 200m in length.

For bridges above this length, the load models are therefore conservative and can instead be defined for the individual project.

For the 1915Çanakkale Bridge, the Swedish national annex was utilised for loaded lengths above 200m.

The design, therefore, considers traffic loading as follows:

- Loaded lengths ≤ 200m, the uniform distributed load (UDL) becomes 81.8kN/m (2x3 lanes) based on Eurocode 1991-2 load model 1, 2, 3
- Loaded lengths > 200m, UDL = 58.8kN/m (2x3 lanes) EN 1991-2 SE-NA taking effect of long loaded length into account

CONCLUSION

This article takes the basis in the detailed design undertaken by the COWI project team. We are thankful to our colleagues who provided the expertise to the detailed design of the 1915Çanakkale Bridge.

Further, we have to express our appreciation to the contractor DLSY for fruitful collaboration throughout the detailed design allowing for a to-the-point design of this world record span suspension bridge.
INTRODUCTION

Any complex bridge deserves independent design verification or check to provide another tier of reliability in the structure and in construction.

This applies even more so in a bridge such as the 1915Çanakkale Bridge where the boundaries of what has previously been achieved are being stretched.

The check is entirely independent with the guiding principle to verify construction documents not calculations.

Contractors build based on drawings and specifications - not based on calculations. When things go wrong it is because the concrete and steel which have been built fail.

So, one needs to be checking the design deliverables which form the basis of construction.

Checking calculations has too many pitfalls - it can lead to a simple numerical check where flawed methodologies are adopted without question.

It can also lead to a failure to check that the design intent has been accurately translated onto drawings.

By doing an independent check, before any component is constructed, both the designer and the independent verifier are satisfied that the design is correct.

In theory, with totally independent calculations being carried out, the probability of error in design is reduced by the square of the probability of error in design produced by a single party only, an order of magnitude improvement in the safety and reliability of the design.

On the downside, a further step is introduced into the release of information for construction. In the design and build environment, this release is almost certainly on the critical path for project completion, particularly for the first components to be built.

The check process cannot therefore be a serial one. There must be overlap between design and check activities, with the lag between them being minimised.

Collaboration and comparison of primary analyses are key to this.

The role of the independent checker is not one that naturally leads to popularity as at best one is agreeing with the current plan and at worst being the bringer of bad news requiring change and adding to cost.

However, the value is in the assurance and safety that is given, and this is appreciated by clients and contractors alike.

The result is a safer structure for the travelling public and those building the bridge.

For the 1915Çanakkale Bridge, the client, KGM specified that the contractor, DLSY should provide independent design verification for all the permanent works.
This is relatively typical of large design and build bridge projects, although sometimes the client elects to employ the checker directly.

Less common is that DLSY chose to add to this scope the verification of nearly all the temporary works.

Arup and Aas-Jakobsen were appointed by DLSY as Independent Design Verifiers (IDV) in July 2017.

The IDV received further specialist support for elements of temporary work from DLT Engineering (catwalk and cable construction) and Tony Gee (deck lifting gantries).

This article will describe the verification process adopted and measures that contributed to its success and some description of independent analyses and checks undertaken in the verification.

THE VERIFICATION PROCESS

The verification process is illustrated in Figure 1 below. The lag between formal issue to IDV of design documents to return of comment or certification was only 14 days.

For this to be feasible, there were critical actions taken by all to allow the 14 day period to be the final stages of the check rather than the whole of the check.

A collaborative and proactive approach was developed to ensure swift resolution of comments.

The process included:
1. Design basis
2. Preliminary design information
3. Global analysis model comparison
4. Informal issue of documents
5. Comment Resolution

1. Design Basis

The cornerstone to all bridge designs is the Design Basis that draws together all the requirements that will need to be satisfied within design.

It needs to be project specific to cover the functional requirements of the bridge and to define the site specific design conditions (geotechnical, seismic, wind, accidental impact etc.).

The Eurocodes, the suite of codes used for the project, are comprehensive, but a structure with a main span of 2,023m is beyond their application limits in some respects and so adaption and extension is needed as a result.

As the Design Basis along with the KGM technical requirements are the primary documents referenced in the Design Verification Certificate.
(DVC), it was the first item to be verified based upon the requirements of the contract and independent interpretation of the factual data.

It should be noted though that the requirements for design need to be updated as a result of further data gathering exercises (wind tunnel test for example) or as construction methods and sequencing is further defined.

The document is therefore a live one for the duration of the design.

2. Preliminary Design Information

Preliminary design must be defined very early in a fast-track delivery process as the demand in each element of construction is intrinsically linked to the behaviour of the whole structure.

Adequate definition of the preliminary design of the whole structure must exist before individual elements can be verified.

A staged process was adopted for Çanakkale. Firstly, overall geometry and primary elements were defined to allow initial analysis to be done. Thereafter for the primary structural items a 40% complete design package was submitted for verification.

This allowed the early development of analysis models and the communication of the majority of design intent.

These packages were certified by IDV, not as ‘For Construction’ but as ‘capable of development into compliant final design’.

In addition to allowing an early start on the check, the verification of the 40% submission brought early attention to any significant differences between Designer and IDV.

3. Global Analysis Model Comparison

The backbone to the design and the check is the Global Analysis Model.

Independent models were created by both Designer and IDV but divergence in results from these models needs to be removed as a source of difference in design demand or structural behaviour.

Throughout the project, a comparison of results from the Global Analysis Model was made and the source of any differences understood. A unified approach was agreed, or the difference accepted.

This could be seen as a loss of independence between the designer and IDV approach, but the comparison and reconciliation of results in reality formed as verification of the analysis models of both the Designer and IDV.

The process was helped greatly by open channels of communication between the analysts responsible for each analysis model and corrected diverging understanding of the structure at an early stage.

4. Informal Issue of Documents

A small measure that limited the lag between design and verification was the informal issue of each package to IDV.

Each design package was reviewed by DLSY prior to submission to IDV for certification.

To start the verification process early it was agreed to forward the package as an advanced informal copy to IDV prior to DLSY review.

5. Comment Resolution

There is a risk that the feedback loop of comments and responses between IDV and the Designer can absorb critical time for the completion of the project.

Positions can become entrenched unless the IDV explains in detail how they have come to the conclusion that comment is necessary and in turn the Designer explains how they have justified the information they have produced.

To do this both parties have to open their books to the other. This is not a detailed check of each other’s work which would dilute the independence of approach but allowed each to challenge each other and be persuaded whether or not the comment was valid.

Where significant comment was returned, DLSY initiated face-to-face comment resolution meetings.

These allowed cycling of the feedback loops to be avoided and the source of difference rapidly eliminated. Open dialogue and preparedness to accept scrutiny by both parties made these meetings particularly effective.
EXAMPLE VERIFICATION TASKS

Wind Engineering

Due to its record span of 2,023m and 318m high towers, wind is one of the dominating loads. It drives both structural capacity through the ultimate load level but also contributes to fatigue accumulation, comfort assessments and stability at extreme wind speeds.

To control comfort for the user, acceptance limits on acceleration were set for deck movement in both vertical and horizontal directions.

These were based on ISO standards for motion sickness and set to $0.196\text{m/}{s^2}$ (RMS-value) in both directions for gust wind speeds below 15m/s at deck level.

In order to do an independent check of the proposed wind climate at the site we conducted an independent analysis of it.

This was done by combining two dataset (WRF and Merra) and interpolating the results to the bridge location.

This approach created a 38 year long time series which formed the basis for a statistical estimate of the design wind speed.

In addition to the design wind speed, long term distribution was obtained, which is relevant for calculation of wind driven fatigue and assessing how often certain wind speed thresholds are exceeded.

This approach indicated that the chosen wind climate for the bridge was slightly conservative.

One of the requirements for assuring sufficient safety of long-span bridges is to document that it fulfils the stability requirements for high wind speeds.

When developing cross sections for long-span bridges one aims to:

- minimize aerodynamic loads which leads to an economic structure,
- minimize vortex shedding normally occurring at frequently occurring wind speeds. This assures that the bridge can be used comfortable and with confidence, and
- maximize wind speeds at which instability occurs to fulfil basic safety requirements from the client.

Section model tests are efficient ways to develop and document that the cross-section has the desired properties.

However, for a long span bridge with multiple simultaneously active modes, aerodynamics of the cross-section influences its damping and stiffness properties which can promote mode coupling.

This could be source for modes coupling more easily and thus, changing onset flutter speed to a different value than recorded in the wind tunnel.

To clarify if this was a possibility we did an independent check of the expected stability limit for the bridge.

We extracted the dynamic properties from our independent global analysis model and combined this with aerodynamic derivatives from wind tunnel tests of the proposed cross-section and calculated the onset flutter speed by use of a multimodal flutter analysis.

This showed that the cross-section had sufficient safety to be taken forward and reassured us at an early stage that we would not get any surprises with respect to aerodynamic stability, which was later confirmed by the full-bridge model test.

GLOBAL ANALYSIS MODEL

In the core of our independent checking stands our independent global analysis model (GAM).

This model provided all results needed to do our independent check.

Our model was developed based on input provided by our client and consisted of drawings and the design basis.

Due to the non-linear behaviour of the structures, we chose RM bridge as our GAM tool.

Due to the fast-track nature of the project, where there is little slack to accommodate delays, we found it important to create a common global analysis baseline with the designer early in the project.

The key with developing this baseline at an early stage was to avoid rewinding the project if major discrepancies were discovered at a later stage.
However, this baseline must be performed in a way that maintains independence between the two teams.

This was done by a meeting series which covered key static loads, dynamic properties, and reference wind loading, without calculating the actual loads defined in the design basis.

In general, good agreement was found during the process and for the most important forces checked differences between our models were less than 1%.

One important and challenging issue in these checks is a comparison of modes and vibration frequencies, as this forms the basis for dynamic response and mode selection for flutter wind tunnel tests.

Since vibration frequencies are proportional to the square root of the modal stiffness divided by the modal mass, small numerical differences in frequency can hide large differences in stiffness and mass, thus, it is recommended to scrutinize these results in detail to identify major differences not immediately obvious.

After a few meeting sessions, all parties were satisfied with the results, and we continued with implementing design loads and combinations.

Figure 2: European tower in global analysis model (GAM v3.5). Asian tower is the same from tie beams to top, but uses element series 7000/57000 instead of 6000/56000. Cross sections and volumes shown for all elements. The caisson is simplified in the model, but has correct weight and mass. It appears to be hollow, but it is massive.
In general, we believe this process was a key to keep the challenging schedule for the project.

One of the special properties of this bridge is the twin deck configuration with cross beams every 24m.

This design was necessary to fulfil the stability requirements at extreme winds and control vortex shedding at low wind speed.

When modelling aerodynamic properties in the analysis this design poses a challenge. In contradiction to single deck bridges, where aerodynamic coefficients derived in the wind tunnel can be used more or less directly, aerodynamic coefficients of twin deck need to be split between the two decks in order to model wind load and aerodynamic damping properly.

E.g. torsional aerodynamic damping of twin deck bridges will have contribution from both lift and moment terms of each deck.

This was solved by applying wind load to massless, non-structural, wind load elements tuned to get the properties defined by the wind tunnel tests.

Several complex properties were built into our model.

One of these were buffers. The buffers are connected between the deck and the towers, and are designed to allow slow movements like temperature changes and traffic UDL displacements, but resist rapid movements due to e.g. seismic events, severe wind or a passing truck.

![European Approach Bridge](image1)

**Figure 3:** European Approach Bridge in global analysis model (GAM v3.5). Piers in axis PE1 are rigidly connected to the rigid anchor block.

![Asian Approach Bridge](image2)

**Figure 4:** Asian Approach Bridge in global analysis model (GAM v3.5). Piers in axis PA6 are rigidly connected to the rigid anchor block.

Yellow lines represent rigid connections. Green elements at bottom are system of springs to represent Soil-Structure Interaction (SSI).
Each tower has two buffers connected to each leg, both with a maximum resisting force of 5 MN.

These are simplified in the GAM to one series of elements per leg with a maximum resisting force of 10 MN. Modelling of these buffers was done by connecting a series of dashpot elements, each with properties such that they in total give the desired behaviour.

Example modelling methods include soil-structure interaction springs and seismic isolation bearing (SIB) performance.

Tower Foundation

The tower foundations are a critical element in construction and required sophisticated analyses to verify their performance under permanent, wind, seismic and ship impact forces and given their location in deep water and founded on 10 to 20m thick loose sands and soft clays over stiff clays and very weak to weak mudstones.

The tower foundations consist of concrete caissons on gravel bed supported by steel inclusion piles. This concept was inspired by the Rio-Antirion foundation and was used for the Izmit Bridge (Osmangazi Bridge).

This ingenious concept allows the gravel mat to act as a “fuse” and permits the caisson to move independently from the ground, critical for dynamic loading such as ship impact and seismic shaking.

The inclusion piles stiffen the ground to reduce in-service settlements and provide enhanced bearing capacity during extreme loading.

Constructing the concrete caissons were substantial works in their own rights.

A 300m x 300m dry dock and a large wet dock and jetty structure were constructed both of which formed part of IDV scope for verification.

The concrete caissons were constructed on the dry dock. Once the caissons were ready, the dry dock was flooded, see Figure 7.
After that, the caissons were floated to the wet dock, see Figure 8, whilst awaiting transport to the tower sites.

At the tower locations, the superficial loose sands were dredged and 200+ 2.5m diameter steel inclusion piles were driven to the mudstone.

Gravel was then dumped to form the gravel bed prior to sinking of the caissons.

Whilst the foundation concept was deemed appropriate for the site, it posed a challenge in accurately assessing the performance of the individual components, especially during seismic loading.

In addition to assessing how the soft soils affect the response of the towers, it was also necessary to assess the effect of the rigid pile inclusions and the gravel mat on the tower response as well.

The presence of the inclusion piles will cause the ground movements to deviate from the surrounding “free-field” motions whilst the gravel mat will cause additional compliance in the tower-soil interface in the lateral direction.

To assess the complex tower foundations, it was decided to implement the direct method to explicitly model the complex dynamic soil-structure interaction (DSSI) occurring at the tower foundations.

The direct method entails detailed modelling of the tower superstructure or loads, the gravel bed, inclusion piles and the soil, Figure 9.
The towers and caissons were modelled using beams, shell elements, and concentrated masses to capture inertial response.

The rigid pile inclusions were modelled as beam elements with equivalent section properties and were connected to the soil elements using nonlinear springs.

The soil is modelled using a nonlinear model that captures the degradation of soil stiffness with increasing strain and hysteretic damping.

The shear stress time histories are then applied at the base of the model to propagate shear waves to the surface and the tower.

The DSSI analyses were performed using the explicit three-dimensional finite element code LS-DYNA. LS-DYNA enables the solution of three-dimensional problems involving a high degree of geometric and material non-linearity.

Arup are pioneers in implementing and developing LS-DYNA for use in civil engineering problems.

The direct method allows accurate nonlinear representation of soil and structural responses and avoids the pitfalls of the conventional substructure approach that assumes linearity during superposition.

The conventional substructure approach uses separate models to model certain aspects of the foundation and the towers and is generally cheaper and faster to perform.

However, this approach severely limits the interaction between the soil, inclusion piles, caisson, and tower and entails conservative assumptions at every stage or interface of the analysis.

Moreover, the benefits of nonlinear response and damping of the soil, inclusion of piles, gravel mat, and towers will not be accurately captured in the substructure approach.

The challenges with performing the direct method are twofold:

- It is computationally expensive; and
- It requires expertise in setting up and making sense of the results. Hence, Arup leveraged its pool of numerical modelling specialists, automation scripts, and high-performance computing (HPC) clusters to efficiently build the models, run the analyses and post-process the results.

As an added benefit, the existing model can then be used for other assessments such as ship impact and settlement analysis with minor adjustments.

The use of the post processors and automation scripts allows convenient and efficient visualisation and extraction of results, see Figure 10.

![Figure 10: Lateral displacements of the rigid inclusion piles](image-url)
For example, for the 200+ inclusion piles, it is easy to envelop the bending moments at each pile segment and at each time step to check if the piles have reached their structural capacity, see Figure 11.

The same method can also be used to locate the critical piles (e.g. maximum and minimum bending moments and shear forces) and plot the results in a typical axial force vs bending moment (N-M) diagram to assess structural capacity, see Figure 12.

→ Figure 11: Visualisation of pile bending moments at different levels of bending moments

↓ Figure 12: N-M plot of critical piles

![N-M comparison for all critical piles](image)
CONSTRUCTION ENGINEERING

In addition to design verification of the completed bridge, the IDV performed detailed global analyses of all construction stages, including tower erection, catwalk, cable installation and deck erection – all following a construction sequence provided by the designer.

The sequence was a live entity during the entire construction engineering phase.

To effectively handle changes, not to mention the large number of stages by itself, the analysis setup and post-processing were automated by extensive use of TCL and python programming.

TCL is a language understood by RM Bridge, and python is a general-purpose programming language.

At the end, a total of 185 construction stages were defined, which were analysed in two batches.

The first 31 stages were simulating the tower erection, while the following 154 stages started by pullback cable installation and ended by applying long-term settlements.

To ensure that the structure state – both forces/moments and displacements – was correct at each stage, the entire construction sequence was run stage-by-stage on the same model.

This was then used as a reference state for wind, temperature and construction load analyses of each stage.

Temporary structures, cables and joints required the completed bridge model to be heavily extended.

The completed bridge GAM had 2612 elements, and the towers erection required 739 additional elements.

Cable and deck erection, including pull-back and catwalk, required 5807 additional elements – more than twice of what was required for the completed bridge – most belonging to a detailed catwalk model.

Temporary structures, scaffolding and welding platforms increase the wind impact on the structure, and this is represented in relevant stages.

A particularly interesting challenge that arose was to implement correct aerodynamic damping of torsional vibration.

When applying quasi-static expressions in the buffeting calculations, which is the normal procedure in most analysis software, this damping becomes zero.

Wind tunnel tests show that this is not the case. The practical impact is negligible for completed bridges, which normally have torsional restraining of the deck at both ends.

For construction stages like the one shown in Figure 13, where the side spans only are torsionally restrained at one end, this does however have a significant impact on the restraining forces.

Figure 13: Global analysis model of a given deck erection stage. Approach bridges are not considered in the construction analyses
In addition to providing a comprehensive verification of the construction engineering and identifying possible issues at an early stage, the IDV was also able to provide DLSY enhanced understanding of the bridge behaviour during construction.

We have also provided other details, like more detailed weather restrictions at individual stages.

← Figure 14: Left to right: Tower erection model with full model of tower crane, equivalent model of tower crane, cross sections and elements.

↓ Figure 15: Catwalk modelling details
Figure 16: Temporary deck release joint modelling details, with geometry visualisation (top), without geometry visualisation (bottom)
CONCLUSION

Independent design verification was applied to all permanent works and major part of the temporary works engineering for the 1915Çanakkale Bridge. Arup and Aas-Jakobsen (AAJ) carried out this verification through completely independent analysis, calculations and drawing/specification review.

Highly complex and expert techniques supported this work as illustrated in the examples above.

This independent process was significantly smoothed due to the collaboration and dialogue held between AAJ, DLSY and COWI.

The end result is increased safety and assurance in the permanent structure and the construction stages and contribution to the success of the project as a whole.
CAISSONS FOR THE 1915ÇANAKKALE BRIDGE: EXACTLY IN THE RIGHT PLACE

Peter van Westendorp, Director
Maurice Reijm, Project Manager
Strukton Immersion Projects

INTRODUCTION
The new suspension bridge over the Çanakkale Strait (Dardanelles), a strait in north-western Türkiye, is an important part of the highway that will connect the cities of Çanakkale and Malkara (near the Greek border).

The Turkish companies Limak and Yapi Merkezi, with DL E&C and SK ecoplant from South Korea, are the Joint Venture responsible for it.

The DSLY JV in turn commissioned specialists Strukton Immersion Projects to float out, transport and install the foundation structure: two gigantic caissons measuring 74m by 83m and 45m high.

The installation of the caissons was successfully completed in May 2019.
METICULOUS RISK MANAGEMENT

More than a year before the immersion, Strukton Immersion Projects started designing the necessary temporary works and preparing for the operation.

A small project team flew regularly to Türkiye to coordinate the various tasks.

At first, it was once every four weeks and then more frequently, ending up in a full-time stay at the project location.

The first task was to review the submitted design.

Based on years of our knowledge and experience, we realized that the originally planned 17 compartments in the caisson, intended for ballast water, were not sufficient to guarantee a stable and safe immersion process.

We proposed 29 compartments and an adjustment to the dimension (thickness) of the base slab and the design was adapted accordingly.

100% CERTAINTY

To comply with the strict placement tolerance (+/-20cm), an L-shaped guiding structure consisting of hydraulic jacks and four steel frames installed on tubular piles just above the seabed was designed.

Additionally, other temporary facilities, including the seabed anchors to which two tugs were attached, had to be designed.

These 15-tonne anchors had a holding capacity of up to 150 tonne and were needed because of the enormous forces, primarily caused by water currents, exerted on the tugs and the caisson.

To be 100% certain, we submitted our designs for the requisite temporary works to external agencies for third-party checks.

CONSTRUCTION OF THE CAISSONS

The caissons were built in the temporary dry dock at Gallipoli (Gelibolu), around 4km from the immersion site. However, the dry dock would not be deep enough to handle the water displacement needed to float these massive structures.

For that reason, the (partly built) caissons were floated out earlier to complete them at the temporary mooring jetty a few hundred metres away.
INSTALLATION OF THE BALLAST SYSTEM

The concrete construction work was completed with floating and fixed cranes, after which the steel shafts with a diameter of 18m were positioned (two per caisson).

After the installation of the first shaft, we started with the installation of our ballast system; approximately 30 trucks of imported materials, such as pumps, pipework, valves, jacks, floating hoses, etc, arrived on site and allowed us to install the system using the shafts in the caissons, in parallel to the construction of the structures themselves.

This required significant coordination because our client had more than 1,000 people working on the concrete construction!

For safety reasons we took turns to avoid having any construction work going on above us while we were working in the caissons.

SMOOTH-RUNNING ORGANIZATION

After all the installations had been tested, the checklists had been checked and the crew had been instructed at a toolbox meeting, we got green-light approval for the immersion.

The immersion was supervised by the immersion commander. For every shift, there was one immersion commander with his own team – because the immersion of each caisson could take up to 72 hours.

We alternated with each other: 12 hours on and 12 hours off with an overlapping hour for the handover.

The immersion commander was supported by an immersion engineer and a ballast engineer. The immersion commander determined the course of the immersion operation.
Based on data analyses and the predefined conditions, he decided through twelve ‘Go/No Go’ decision moments whether the next phase could start.

We needed to be alert at all times. Both teams were based on the ballast vessel on which the command unit was located.

72 HOURS OF PRECISION

Four sea-going tugboats towed the floating caisson to the immersion site and positioned the caisson to the desired location.

The two upstream boats attached themselves to the pre-positioned 15-tonne anchors on the seabed.

Because of a large array of seabed cables on the downstream (western) side, the ships used dynamic positioning to stay in the right place and keep the caisson in place.

After another confirmation of the procedure through the checklists, the operation could start.
We tested the ballast and survey systems and the cameras and hydraulics again, and then the intake of the ballast water started.

We monitored the system data and weather and water conditions non-stop and sent the client regular progress updates.

The 29 compartments were filled with water in exactly the right sequence and proportion – an interaction between the water level in the compartments, the pressure on the concrete structure and the operation of the ballast pumps.

This ballasting could take up to 48 hours. After that, it took another 12 to 24 hours before the caisson was finally placed on the 45-metre-deep seabed.

Monitored at all times by the team using the sensors and cameras, the caisson descended slowly but surely to 1m above the gravel bed.

Then the winches of the tugs pulled the caisson against the guide structure.

By pushing the jacks on the caisson against the frames, the caisson was moved into the exact horizontal position.

In the final ballast step, the caisson slid down the guide structure until it rested on the gravel bed.

After acceptance by the client, we filled the compartments completely with water, around 60,000m³ in total.

We then removed the ballast system from the shafts and filled it with water too. The immersion was complete.

**TEAMWORK**

The operation involved 72 hours of working under high pressure and with enormous concentration to handle that. We had spent months working closely together so that everything was ready and everyone was prepared.

This enabled us to place two enormous caissons on the bottom of the Çanakkale Strait with extreme precision: just ten millimetres off the target, well within the maximum tolerance of twenty centimetres.

We were completely focused and we trusted each other. That sense of solidarity felt fantastic.

This is real work for team players.
AN INNOVATIVE HEAVY LIFTING SOLUTION FOR THE CONSTRUCTION OF THE 1915ÇANAKKALE BRIDGE TOWERS

Simon Marr, Managing Director
Marr Contracting

Figure 1: Marr’s M2480D heavy lift luffing cranes working on construction of the 1915Çanakkale Bridge from both sides of the Çanakkale Strait
Photo: FilmGenetik

PROJECT OVERVIEW

Taking its place as the world’s longest mid-span and highest tower suspension bridge, the 1915Çanakkale Bridge was completed 18-months ahead of schedule.

For Marr’s team, it was the project of a lifetime and one that could change the future of how bridges and other large-scale construction projects of this nature can be delivered.

Soon after the Turkish Ministry of Infrastructure and Transport General Directorate of Motorways appointed the Turkish-Korean joint venture partners – DL E&C – Limak – SK ecoplant –Yapi Merkezi (DLSY) – as the construction partners on the project in 2017, DLSY contacted us for a craneage solution to match how they wanted to construct the project.
PROJECT CHALLENGES

On a project of this scale, the engineering feats were staggering – and so were the heavy lifting requirements which included:

- 8 x 160-tonne lifts;
- 36 x 150-tonne+ lifts; and
- 208 x 100-tonne+ lifts.

The DLSY JV had a clear idea about how they wanted to build the project, but they needed a craneage partner who could think outside the box to bring that vision to life.

Impressed by our track record in designing and delivering large-scale lifting solutions on similarly challenging projects in Australia and around the world, DLSY JV challenged us to develop a craneage solution that would:

- decrease the construction time and associated risk;
- reduce project costs; and
- improve safety on the project.

The project also came with the additional technical challenges of working in a high wind area, over water and in an earthquake zone.

And of course, the COVID-19 pandemic created a new set of challenges that none of us could have predicted.

MARR’S SOLUTION

Through working directly and collaboratively with DLSY JV’s project team on the front-end engineering design, we were able to develop a craneage methodology using two of our 330-tonne capacity M2480D Heavy Lift Luffing (HLL) cranes that met all the requirements of the project.

M2480D Heavy Lift Luffing is the largest capacity tower crane in the world.

With a standard lift capacity of 330 tonnes at a 15-metre radius, the M2480D lifts 100 tonnes to a 45-metre radius with around 130 metres of hook height and no support ties.

Unlike conventional crawler cranes or truck cranes, the M2480D is fully rated to operate in wind speeds up to 20 m/s which is more than double that of crawler cranes – which along with its superior operating speed, allows far higher levels of productivity.

Early engagement was key

We know from experience that the key to achieving maximum efficiency for any large-scale construction project is early engagement with the client – and the earlier the better.

The initial contact we had from the DLSY JV was an email from one of the project engineers searching for a craneage solution to match how they wanted to construct the project.

DLSY knew what they wanted, and they were also open to a non-traditional heavy lifting solution.

As experts in construction, they respected our expertise in heavy lifting and together we have been able to construction the tower stage of the project in record time.

I think for us to get involved so early in the design of a solution to suit what DLSY was trying to achieve was really the key to the success of this project.

Reaping the benefits of modularisation

One of the other main benefits of early engagement, and strategically deploying heavy lift tower cranes, is that it opened the door for DLSY to “think big” with their construction methodology.

The M2480D HLL’s capacity allowed heavier modularised sections of the bridge towers to be fabricated in a controlled environment offsite before being delivered to the worksite by barge for installation instead of the more traditional approach of lifting smaller components one-by-one and then welding onsite.

Because there is far more control (and safety) in welding or building sections on the ground and installing in one lift, rather than welding multiple sections at height; this kind of approach can de-risk a project and protect the construction schedule because off-site assembly is faster and more accurate, and therefore there is greater certainty of holding to deadlines.

THE RESULT

The M2480D HLL’s capacity allowed for one lift to replace the eight lifts that had earlier been thought necessary subsequently reducing the number of lifts and the overall construction schedule – with less site-based activities and a higher level of on-site safety, Figures 2 and 3.
The unparalleled lifting capacity of our M2480D HLL cranes also delivered two ‘world firsts’ during the construction of the bridge towers including:

- a 2000-tonne capacity Taklift 4 floating heavy barge crane lifting the 600-tonne assembled M2480D from the dry dock to the worksite 1km in the middle of the Çanakkale Strait; and
- the heaviest (155 tonnes) at height (318 metres) craneage lift during the installation of the upper cross beam (UCB).

Working at 24/7 availability, both M2480Ds worked at an average utilisation rate of 20 hours per day. Even during the COVID-19 pandemic we achieved all our milestones – through the right combination of an open-minded client, an innovative craneage solution and teamwork.

**PROJECT TIMELINE**

**APRIL – JUNE 2019:** After two of our M2480D Heavy Lift Luffing cranes were shipped from Australia to Türkiye via Singapore, our engineers from Australia, the UK and Middle East worked together to fabricate specialised equipment for the project in our Middle Eastern fabrication facility, Figure 4.

Our first milestone on the project was to assemble both cranes on purpose-built quayside foundations, see Figure 5.

This included building the 300-tonne grillages in preparation for lifting the M2480Ds from the quayside and installing them at the bridge work front.
NOVEMBER 2019: Using a 2,200-tonne capacity Taklift 4 floating heavy barge crane, the cranes – each weighing 600 tonnes – were lifted from the quayside and transported to the worksites a kilometre off-shore on the Çanakkale Strait, see Figure 6.

It was the first of two world-first engineering feats on the project.

JUNE 2020: After climbing the cranes to their final height of 328 metres, the next major milestone was the installation of the upper cross beam (UCB), Figures 7 and 8.

With the M2480D positioned 328 metres above the water, it took approximately 30 minutes (and a lot of planning) to lift the 155-tonne section into position – creating a new world record for the heaviest lift (155 tonnes) at height (318 metres).
JULY – NOVEMBER 2020: After successfully completing the construction of the bridge towers, the M2480D HLLs were climbed down the completed bridge towers and safely recovered.

18 MARCH 2022: The 1915Çanakkale Bridge was officially opened 18 months ahead of schedule in a ceremony attended by Turkish President Recep Tayyip Erdoğan.

PAVING THE WAY FOR THE FUTURE OF BRIDGE CONSTRUCTION

We are incredibly proud to have been part of this amazing project, and the successes achieved for Marr and our client are a case study in how early engagement and true collaboration can drive a successful outcome on any large-scale construction project.

The way DLSY and Marr’s team approached this project will also potentially change the way our industry looks at how bridges and other large-scale projects can be built.

Marr’s team is using the same way of thinking to challenge methodology on the construction of other projects including metro train stations and other major public infrastructure projects, data centres, large commercial construction, energy construction and working refineries both at home in Australia and around the world.

CONCLUSION

Marr Contracting are world leaders in the design and delivery of heavy lift luffing tower cranes and heavy lifting services.

With almost 100 years’ experience working on large-scale construction projects in Australia and around the world, our expertise spans the large-scale construction, mining, oil and gas, power, nuclear, major transport infrastructure, technology and marine sectors.

We were one of the multiple subcontractors from a global team of companies engaged to work on the project: our scope of work on the construction of the 318-metre high bridge towers included engineering the heavy lift crane solution involving its integration into the temporary and permanent works, the supply of two of our M2480D cranes (including installation, climbing, dismantle and maintenance), and crane operation.

Video.1: Credit FilmGenetik

Click on the image to play the video

Figure 11: Marr Contracting crew at the 1915Çanakkale Bridge worksite

Figure 12: The completed 1915Çanakkale Bridge was opened on 18 March 2022, 18 months ahead of schedule
INTRODUCTION

DLT Engineering Ltd supplied specialist equipment for the installation of the main cables on the 1915Çanakkale Bridge Project.

This included the equipment used to install the preformed parallel wire strand (PPWS). As well as the main winch system, DLT supplied various ancillary winches, rope unreelers, winch rope guide rollers, horizontal and vertical turn sheaves, and Nylon PPWS rollers.

DLT also supplied innovative machines for compacting the main cables after installation of the PPWS and machines to install the wrapping wire on the completed main cables.

DLT provided site support services to assist in the operation of the PPWS installation equipment, the compaction machines, and the wrapping machines. All the equipment supplied was bespoke designed for this project.

PPWS INSTALLATION HAULING SYSTEM

The construction requirements of a large suspension bridge in such a short time scale meant that a sophisticated computer-controlled winch system was needed.

To ensure the safe, fast, and reliable operation was achieved at low cost, a combination of hauling winch and rope storage winch system was provided, see Figures 1 and 2 below.

This reduced the overall size of the equipment and consequently, shipping and installation were cheaper and easier.

The 4no. hauling winches provided up to 300kN pull force each and worked in pairs.

One pair on the north side and one pair on the south side of the bridge, working as reciprocating systems. The total rope length for each system was over 14 km.

Figure 1: Rope Storage Winch

Figure 2: Main Driving Winch
The maximum capacity of the rope storage winch drums was 4,700 m or 27 tons of 37.5mm diameter wire rope.

The control system offered fully programmable tension and speed control. The normal operating speed was 30 m/min with up to 50 m/min available.

The following was carried out by project site as per our client DLSY JV’s specifications.

Initially, the winches were positioned at either side of the bridge only allowing a single pull from the Asia anchorage once a day due to the time spent resetting the position of the hauling carrier.

After the catwalk installation was completed, the winches on the European side were relocated to the Asia anchorage and configured to a more permanent arrangement, Figures 3 and 4.

This allowed for 2 hauling carriers to be installed. This meant that, as soon as one PPWS bundle is hauled across the bridge, the next one could be connected and underway with no downtime.

The entire system was controlled from a control room positioned at the Asia anchorage allowing a full view of the winch equipment by the operators. In addition, a CCTV system was provided by DLT with cameras positioned along the full length of the PPWS installation route seen in Figure 5.

DLT provided equipment-related customer training and site support services throughout the project. It was an international effort with supervisors, operators and site workers from the UK, Türkiye, India, Brazil, Malaysia, China and Korea.

4no. 100kN winches were positioned at the anchorages for general use.

One task for these winches was to lift the hauled PPWS bundles out of the nylon rollers and into the correct position in the main cable.

Significant force was required so sheave blocks were used to multiply the pull force.
Used in conjunction with the 150kN winches performing a similar procedure at the tower tops, the PPWS bundles were positioned and tensioned with millimetre accuracy. The PPWS bundle clamp is shown above in Figure 7.

**TOWER TOP WINCHES**

8no. 150kN winches were provided for installation at the top of the 318m main towers. These winches were used for all stages of main cable construction including catwalk erection, main cable tension adjustment and for pulling the compaction machines along the main cable.

**CABLE UNREELERS**

DLT supplied 2 powered unreelers and 2 unpowered unreelers for use on site. These unreelers were designed to accommodate the different wire ropes used during the bridge construction process.
These include the catwalk floor ropes, tramway support ropes and pullback ropes. The maximum drum capacity was 4 m in length, 3.3 m in diameter and 55 tons in weight.

As the drums were swapped out, the control system needed to be able to adjust the outlet guider seen below, to the corresponding speed and position, so a servo motor was used in conjunction with software to provide repeatable accuracy and ease of use for the operators.

**COMPACTION MACHINES**

Compaction of the main suspension cable needed to be completed to allow the installation of the deck lifting gantries.

To achieve the incredible construction targets, DLSY (main contractor) purchased 8no. compaction machines from DLT.

With this approach, main cable compaction could be conducted simultaneously at various locations along the cables.

This was essential to achieve the programme since cable compaction was on the critical path.

Figure 13 shows a compaction machine during factory tests. All of our equipment goes through an extensive factory acceptance test procedure.

Each compaction machine consisted of 6no. 250t capacity compression jacks in a ring formation.
Once again, DLT used an array of sensors and controls to ensure the main cable final dimensions and PPWS compaction ratio was within the tight bridge design tolerances.

**WRAPPING MACHINES**

Again, in order to achieve the very short construction programme, it was necessary to begin the main cable wire wrapping before the deck erection had finished.
This was made possible due to DLT’s innovative gantry self-dismantling system which meant that as soon as the gantries had moved from the centre of the main span towards the towers, the wrapping machines could be installed and began wire wrapping.

As with the compaction machines, 8no. wrapping machines were supplied to ensure that the wire wrapping could be completed in as short a time as possible.

A custom test rig was fabricated to test all compaction and wrapping machines at a 30-degree angle, see Figure 16.

Each wrapping machine used 2no. 400kg bobbins of 3.5mm round wire to wrap the PPWS cables. The wrapping wire tension was adjustable up to 3kN and a maximum wrapping speed was 210 mm/min.

The wrapping tension control device is shown in Figure 17.

The wrapping machines were self-propelled and designed to pass over deck hanger clamps up to 5.1 m in length.

**CONCLUSION**

DLT undertook the challenge of designing and supplying innovative cable erection equipment for a bridge which on completion has set a world record of having the main span of more than 2 km.

To achieve record construction time, DLT was given very stringent deadlines for equipment design and delivery.

Despite the pandemic affecting all stages of the project, DLT Engineers came up with creative ideas to develop state of the art equipment which were manufactured, tested, and used on site for the successful completion of the bridge.

Providing site support with several pandemic restrictions was more challenging, but the continuous presence of DLT Engineers ensured the safe completion of cable erection.
INTRODUCTION

The 1915Çanakkale Bridge across the Çanakkale Strait (Dardanelles) in Türkiye is the longest suspension bridge in the world with a main span of 2,023 m.

The development of construction methods for the bridge was determined by the site constraints, in particular the environmental conditions and shipping traffic in the strait.

Eight 450t capacity lifting gantries were required for deck erection to deliver a tight construction schedule.

Almost 3.3 km of the deck was erected in two months.

The innovative lifting gantries were self-erected onto the main cables and developed to minimise disruption to the navigation channel, maximise pre-assembly off the critical path and avoid the use of floating cranes.

DECK ERECTION CHALLENGES

The overall length of the suspended deck is 3,563 m, see Figure 1. There was a total of 153 deck segments, most of them 24 m long to suit the hanger spacing. Their weight varied between 300 t and 420 t.

DLSY, the main contractor, awarded DLT Engineering contracts for the design, supply and supervision of the deck lifting gantries, including self-erect and self-dismantling systems, to erect 143 deck segments, most of the suspended deck.

There were several challenges to overcome for the successful completion of the lifting operations:

- The Çanakkale Strait (Dardanelles) is a busy international shipping channel. Therefore, it was important to minimise disruption to the sea traffic.
- In a suspension bridge, most construction operations are sequential and cannot occur in parallel.
Thus, tower construction must finish before cable construction can start and similarly deck erection cannot start until the cable has been erected. Introducing some flexibility was desirable. This could bring cost reduction and potential early completion, which, in a “built-operate-transfer” model, was an incentive for the main contractor.

- The Çanakkale Strait’s orography makes the bridge site very windy. There is a rapid surface current from the Sea of Marmara to the Aegean and a compensatory undercurrent returning more saline water. Minimising the impact of environmental factors on the construction schedule was key.
- Developing an installation method for lifting gantries onto the main cables that avoided the use of floating cranes.
- Erection of the deck segments near the towers without floating cranes.

SOLUTIONS OVERVIEW

Early involvement and collaboration with DLSY and COWI, the bridge designer, allowed DLT to develop specific solutions for this project.

They minimised disruption to the navigation channel and fish-rich waters and offered reduced costs and contribution to the early completion of the overall project.

DLT supplied eight gantries and two self-erect systems to achieve the following:

- Self-erecting eight gantries without the need for floating cranes, Figure 2.
  Self-erection brought flexibility to the programme by allowing the gantries to be pre-assembled in parallel with cable construction.
- Erecting almost 3.3 km of the deck in just two months, Figure 3.
  The deck lifting gantries working in tandem, Figure 4, could erect double deck segments which weighed up to 826 t and were 48 m long with minimal disruption to the navigation channel.
- Erecting the deck segments near the towers by developing special schemes that eliminated the need for a floating crane.
- Self-dismantling the main span gantries, improving the construction schedule.

Figure 2: Self-erect system

Figure 3: Deck erection progress 21 September 2021
(with kind permission of 1915Çanakkale)
DECK LIFTING GANTRIES DESCRIPTION

The gantries are movable devices supported on the main cables, Figure 5. The gantry capacity (450 t) excludes the weight of the strand, anchors, lifting beam and connecting plates, it is therefore a net lifting capacity.

DLT designed them for in service wind speeds of up to 20m/s to minimise the impact of high winds on the construction schedule.

To reduce the duration of the deck erection cycle, DLT equipment was optimised to deliver higher operating speeds, Figure 6.

When operating in tandem, a full deck erection cycle took approximately 11 hours. Up to four tandem lifts could be completed in a day.

Each deck lifting gantry comprises a steelwork main truss spanning between main cables connected to the movement system by pivoting elements such that the truss is self-levelling due to self-weight but rotates to align its vertical axis with the strand inclination during deck erection operations.

The geometry is chosen to ensure that the gantry clears the catwalk and its centre of gravity is below the pivot, Figure 7.

All lifting equipment is located there. The splice positions were chosen not only for transportation limits but also to suit self-erection.
Each gantry has two 294 t capacity strand jacks used for lifting the deck segments from a delivery barge, positioned below the gantry, to their final level, more than 70 m above water level.

The strand jacks have a lift/lower speed of 45 m/h, requiring less than two hours to clear the navigation channel.

The strand bundle is fed out of the top of the strand jack through a strand guide into a recoiler. In order to reduce overall cycle times, the recoiler is powered and can be operated, similarly to a winch, to take the lifting beam down to the delivery barge.

This increases the system lowering speed to 70 m/h when unloaded, saving an hour per operating cycle.

The movement system is streamlined and supported on the main cables. It was developed for a previous project (Ascaso Til and Sancho Santamaria, 2021) and improved for these gantries, which were 30% heavier than the previous ones, incorporating any lessons learnt.

There are two configurations, one for lifting and another one for relocation, Figure 8.

At each main cable, two load transfer rams transfer the gantry weight from the lifting supports onto the wheeled bogies, see Video 1.

Cast nylon wheels shaped to suit the main cable and clamp improve load distribution.

Since there is a single ram per bogie, a torsion box is required for stability.

Aluminium ramps at either side of the permanent cable clamps allow the wheels to roll smoothly onto the cable clamp, see Video 2.

A strand jack connected to an anchor point further upslope the main cable, is the driving force to move upslope at a speed of 35 m/h, see Video 3.
A 15t capacity strand jack is provided to move the gantry down the main cable when its slope is too small for gravity alone to move the gantry over the cable clamp.

Both during lifting and relocation operations, the longitudinal restraint to the gantry is provided by the resistance of the cable clamp against sliding.

In this project, it was a requirement for the lifting beam to connect to the hanger anchorages on the deck, using the pin holes for hanger replacement. This eliminated the need for temporary lugs on the deck and associated reinforcement.

However, it made the lifting beam heavier because it had to span 38 m. In order to clear the hangers during relocation, sliding beams were required at both ends, Figure 9.

All the hydraulic equipment on each gantry is powered by two electrically driven hydraulic power units located adjacent to the lifting strand jacks. Power to the hydraulic power units and the control cabin is provided by an on-board diesel generator.

All main gantry functions are controlled by a central computer system, which incorporates safety interlocks to prevent unsafe operation of the gantry and allows operating up to four gantries from a single computer.

Ladders from the main cable catwalk give access to platforms along the gantry.

Careful consideration was given to providing safe access to all equipment for maintenance and operation.

**DECK ERECTION**

Deck erection started in the main span on the 20th of July 2021 and progressed efficiently so that all deck segments except the tower deck blocks, were erected by the 21st of September 2021.

The main achievements during site operations are listed below:

- Tandem lifting halved the number of lifts and welding over water;
- DLT computer control system, developed in house, was key to perform these lifts safely
avoiding across corner load distribution that could overload either the gantries or the permanent works;

- The central deck segment at mid-span was a single lift. A special lifting beam with a slope adjustment system that could accommodate errors in the centre of gravity was designed and provided for this lift, Figure 10;

- Special schemes using two lifting gantries in tandem and edge protection for the previously erected deck were developed and implemented for the four single deck segments near each tower, Figure 11;

- After completion of all welding, in December 2021, six deck segments were lifted as two blocks of three at each tower, Figure 12, using four lifting gantries simultaneously. It was an alternative to the use of a floating crane and temporary hangers. It brought both programme flexibility and cost savings.

It also improved quality and safety since three deck segments, the tower deck segment and the two adjacent to it were welded on a temporary working platform outside the critical path and lifted as a block weighing over 1200t to their final position;

- Main cable wrapping and deck surfacing operations started at mid-span prior to completion of deck erection thanks to the self-dismantling scheme for the main span gantries.
SELF-ERECTION

Installation of the lifting gantries on the main cables is a complex operation in the critical path that can have a significant impact on the construction programme depending on the method chosen.

For the construction of the 1915 Çanakkale Bridge, the main span gantries were required at mid-span of the main span to start deck erection from there towards the towers, and shortly after the side span gantries were required next to the side span pier to start deck erection from there towards the tower.

Advantages of self-erection with respect to other installation methods

There are various traditional methods to install lifting gantries onto the main cables, such as using a floating crane to install the gantries at the lower points of the cable profile or using the tower cranes to install the gantries near the tower.

Floating cranes are used to install the lifting gantry in a single operation thus, they require to have a large lifting capacity (approximately 200 t for this bridge) and the ability to reach the lowest point of the main cable (e.g. approximately 105 m at midspan and 130 m at the installation position on the side spans for this bridge).

Floating cranes of such characteristics are expensive to hire and need to be booked long in advance.

Erection near the towers is governed by the capacity and range of the tower cranes, and it requires a significant amount of temporary works and construction time in the critical path.

It also requires the gantries to be relocated to the first deck lifting position, the main cable to be compacted in its entire length and all the cable bands to be installed to have anchorage points during relocation. All of the above would have a significant impact on the programme.

The self-erection method developed for the lifting gantries of the 1915 Çanakkale Bridge offered several advantages with respect to the two traditional methods.

The lifting gantries can be:

- Pre-assembled in parallel with cable construction, giving programme flexibility;
- Erected anytime and anywhere along the main cable;
- Lifted off the navigation channel within a few hours, thus minimising the disruption to the navigation channel.

Self-erection concept sequence

Self-erection of a lifting gantry relies on splitting the gantry in three sub-assemblies and providing a way of delivering them to the main cable level using an auxiliary structure for the assembly to be finished and the gantry to be lowered onto the main cable. In essence, the self-erection sequence, Figure 13, can be divided in the following parts:

- Installation of the self-erection system with the gantry sub-assemblies on the barge;
- Delivery of the barge to the self-erection position underneath the main cables;
- Lift-off from the barge and lifting of the self-erection system until main cable level;
- Assembly of the gantry by skidding out the gantry end sections and lifting the gantry central section;
- Load transfer of the gantry self-weight to main cable;
- Lowering of empty self-erection system to the barge;
- Delivery of the barge to the assembly yard to start the cycle with the next gantry.

Figure 13: Self-erection sequence

Click on the image to open it in a higher resolution
Self-erect system and components

The self-erect system is a mechanized system comprised by multiple components: a pair of braced lifting beams, two trestles on top of them, and four jack carriages located at the corners, each with a single 185t capacity self-erect strand jack (Ascaso Til et al., 2022).

There were two configurations of the self-erect system: a lifting configuration, Figure 14, used until the gantry is completely assembled and supported on the main cable; and a lowering configuration, Figure 15, used to lower the empty self-erect system back to the barge.

The self-erect cable anchors, Figure 16, installed on the main cables using the catwalk service winch, provide anchor points on the main cable for the self-erect strand bundles of the lifting configuration to hold the self-weight of the self-erect system with the gantry.

At the start of the self-erect operation, the gantry central section is located between both self-erect trestles, and each gantry end section is supported on skid shoes on top of the runway beams of a trestle.

The gantry end sections are at a different level, above the gantry central section, and closer to the centreline of the bridge to fit between the catwalks during lifting.

Two winch lines are used to skid the gantry end sections outwards for the gantry central section to be lifted between them using four 15t capacity strand jacks.
After the complete gantry is assembled and lowered on the main cable, the lifting strand jacks of the gantry are connected to the empty self-erect system with lowering slings to lower it back to the barge supports, Figure 15.

Given the inability to access the self-erect system by external means due to the location of the self-erect operations, the system required a comprehensive set of platforms to access multiple locations at different stages to safely operate the equipment, supervise and coordinate the skidding and lifting operations, connect or disconnect elements.

**Reuse of steelwork and equipment**

From the concept design stage, the self-erect system was conceived on the principle of reusing other elements of the gantry to reduce the economic cost and the environmental impact of the solution, making it more attractive for the Client.

This applied not only to steelwork components but also to hydraulic and electrical equipment. The self-erect system needs to span the distance between main cables, which is the same distance spanned by the deck lifting beams.

These were assembled in pairs to provide support to the self-erect system, becoming the main primary steelwork element of the system and being subject to significant bending moments.

Since two self-erect systems were required, reusing the side span lifting beams for this arrangement saved approximately 200 t of steelwork.

Each lifting gantry is equipped with a 1t electric service winch to lift diesel and other supplies to the gantry. Two of these winches were used with sheaves and construction blocks to move the gantry end sections outwards.

The winches of the side span gantries were used on both self-erect systems. The 1t service winch is located on the top level close to the centreline of one of the main cables, facilitating its installation using the catwalk service winch after completion of all self-erect operations.

The 15t capacity strand jacks used for downslope movement of the downslope gantries were repurposed in the self-erect system to lift the gantry central section between the two gantry end sections.

**Site feedback**

Two self-erect systems were used to speed up the process of installation of the gantries on top of the main cables, which allowed the construction teams to carry out the critical operations staggered and complete other preparatory work outside the critical path.

The four main span gantries were self-erected on the main cable between 20th June and 13th July 2021, Figure 17, allowing the start of the deck erection operations on the main span.

Deck erection on the main span started immediately after the four main span gantries were installed on the main cables and continued in parallel while separate teams carried out the self-erection of the four side span gantries between 29th July and 11th August 2021, Figure 18.
Excluding the activities off the critical path i.e. preassembly at the assembly yard and commissioning, a gantry could be self-erected within 2 or 3 days.

**DISMANTLING**

The gantries could be dismantled by using traditional erection methods in reverse or by relocating them to the low part of the main cable close to the deck for them to be usually dismantled piece small using cranes on the deck.

The side span gantries of this bridge were dismantled by doing something similar to the latter. The gantries were relocated from the towers to a suitable point of the main cable, Figure 19, close to deck level and the self-weight of the gantry was transferred to a set of supports on the deck.

The gantry was split into several sub-assemblies and each of them was removed from the bridge by a gantry located on the ground surrounding the side span pier.

However, the main span gantries were self-dismantled near the tower using a similar sequence to the self-erect procedure in reverse, Figure 20.

Each gantry was split into three sub-assemblies and brought down to deck level with the self-dismantling system.

Those sub-assemblies were later moved from the deck to a barge next to the tower by cranes.

The key advantages of using this methodology were:

- Programme efficiencies, as each gantry could be brought down to deck level in a few days near the towers, particularly allowing cable wrapping to start even before deck erection had been completed;

- Minimal changes between the self-erect system and the self-dismantling system. The same main components were used with minor additions or changes in configuration, requiring a very small investment from the Client.

The self-dismantling system introduced mainly the following requirements:

- Suitable supports on the deck for the self-dismantling system;

- A system of stabbing guides to align the self-dismantling system and the gantry as the former approached the latter at the main cable level;

- A different winch layout to skid the end truss section inwards and a suitable load path for the loads introduced in the system;

- Strand recoilers with a larger capacity for the 250 m long strands required for self-dismantling as opposed to the 150 m long strands required for self-erect.

- Additional geometrical requirements to avoid clashes between the different items due to the
larger main cable inclination, i.e. the self-dismantling system, the catwalk, the gantry sub-assemblies and the main cable.

Two self-dismantling systems were used, one next to each tower.

Preparatory works for the self-dismantling operations took place in the first half of January 2022, and all four main span gantries were successfully self-dismantled in the second half of January 2022, Figure 21.

CONCLUSION

This paper illustrates the challenges faced to successfully erect the deck of the 1915Çanakkale Bridge.

It emphasizes the development of solutions to solve specific project constraints and meet the main contractor programme requirements.

Existing technology was improved to produce state of the art lifting gantries that erected almost 3.3 km of the deck in two months.

Special schemes were developed to install the deck segments near the towers without the need for floating cranes.

An innovative solution for the installation of the deck lifting gantries on the main cables was developed and implemented successfully.

The self-erect system is a fast, versatile, safe and economical method to install deck lifting gantries on suspension cables.

It could also be used with minor modifications for dismantling of the main span gantries at the towers.

This improved the construction schedule by allowing several activities to occur in parallel.

References


INTRODUCTION
Transportation infrastructure plays a critical role in Istanbul and the Marmara Region of Türkiye. The city of Istanbul, with its population of 18 million, is located in the heart of the Marmara Region; the city links the two continents of Asia and Europe.

As a result of the increasing population and traffic in the Marmara Region (25% of the total population of Türkiye live there), long-span bridges significantly enhance the efficiency of the regional motorway network and offer tangible and real benefits to the economic and cultural growth of this rapidly developing region.

More specifically, Istanbul has a strategic position with three Bosphorus Bridge crossings and being close to the Osmangazi Bridge and the newly opened 1915Çanakkale Bridge.

These long-span cable-supported bridges are the lifeline structures for the transportation network in the region.

All of these bridges feature orthotropic steel deck superstructures and are among the main and the most critical elements in the transportation network.
The 1915 Çanakkale Bridge in Türkiye with its main span of 2,023m is the world's longest suspension bridge - the bridge has superseded the previous world's longest span suspension bridge the Akashi Kaikyo in Japan, which has a 1,992m span.

The 1915 Çanakkale Bridge is located south of the Sea of Marmara and connects Turkey's European and Asian shores. It was named after the year and place of a critical Ottoman naval victory against the British and the French during World War I.

The distinctive 318m-high red towers from which the Bridge's steel deck is suspended are also one of the tallest of any suspension bridge in the world.

The Bridge is expected to carry up to 45,000 vehicles across its six lanes each day and support tourism and commercial activity.

The position of the bridge has posed many design and construction challenges. Moreover, it is located in a region with high winds and high seismic activity.

It achieves its aerodynamic stability partly through a twin-box girder.

The clearance between the water and the deck is engineered to accommodate high-stacked container ships and cruise ships that need to pass under it.

Waterproofing of the steel deck brought many challenges:

- Lightweight construction can lead to greater dynamic movements. Increased weight reduces span and increases cost.
- Thinner surfacing layers give higher stress concentration at substrate and waterproofing/asphalt interfaces.
- Fatigue of stressed components.
- Long steel bridges are landmark structures of strategic importance; therefore, durability and periods between maintenance cycles must be maximised.

Reducing surfacing depth reduces load distribution and leads to more significant stress within the composite materials.

The thinner the surfacing layer, the greater the waterproofing bond requirement between the surfacing and substrate. The stiffness of composite material is limited by the element with the lowest flexural modulus.

A soft membrane between the substrate and surfacing of relatively high modulus will reduce composite action. For steel decks, bituminous systems can prove challenging in this scenario and do not offer weight savings.
The difference in flexural modulus of the individual components of the composite must be addressed within the adhesive bonds of the various layers. If this difference is too significant, the bonds can fatigue, and delamination can occur, proving costly with regular repairs to the asphalt.

The differences in flexural moduli will also vary with temperature, and this must be recognised and considered when relating to the service conditions that the structure will face.

Therefore, Methyl Methacrylate systems are used worldwide on steel structures. Methyl Methacrylate is a reactive resin and its polymerized form has many useful applications.

When used for bridge deck waterproofing, the system is applied wet and cures at a molecular level through an exothermic reaction. As it heats up, it simultaneously bonds to the deck creating a composite effect. USL Speciality Products Britdex is a Methyl Methacrylate system.

The higher flexural modulus of Britdex gives rise to greater stress damping ("tan delta"), with imposed forces being absorbed by, rather than transmitted and reflected through the membrane.

These factors were why Britdex was the waterproofing solution of choice for 1915Çanakkale Bridge’s deck.

The Britdex system consists of:
- Britdex MDP Primer — a two-part, solvent-free, highly-reactive methacrylate resin, comprising Part A and Part B.
- Britdex MDP Waterproofing — a two-part, solvent-free, methacrylate resin, comprising Part A and Part B pigmented yellow or grey.
- Britdex MDP Tack Coat — a single component, solvent-based, acrylic resin solution, orange pigmented tack coat, for use with an additional protective layer (APL) of sand asphalt.
The bridge deck was designed with a 50mm asphalt in two layers; 25mm Mastic asphalt as the base course, and 25mm Stone Mastic Asphalt as a sacrificial layer to be re-laid when required, which in lifelong costing will reduce the expense, allowing replacement of the asphalt, preserving the waterproofing and reducing the life costing of the structure.
USL Servet Group, our partner on this project installed in total:

- 90,000m² of Britdex bridge deck waterproofing
- 35,000m² of Tredseal wearing system on the walkways
- 300m of BEJ type 6 expansion joints

Works were completed in 30 working days, with 4 crews of 90 operatives using 20 vacuum blasters and 5 spray pumps.

CONCLUSION

When selecting a suitable material for the job on the critical path, it is essential to understand its physical properties.

Other mechanical and chemical features should also be considered, e.g. density, solvent-loss, reaction mechanisms, chemical and UV resistance, and toughness.

USL manufactures a whole range of waterproofing systems, bearings, expansion joints and drainage solutions, offering a full water management approach to prolong the life of these structures.

The company’s knowledge, hands-on UK and international contracting experience and proven ability to support and supply projects across all parts of the world in a varying range of climatic conditions have proven invaluable.
THIRD-PARTY INSPECTION OF THE 1915ÇANAKKALE BRIDGE

Görkem Koç, International Projects Coordinator
TÜRK LOYDU

TÜRK LOYDU – SCOPE OF SERVICES

TÜRK LOYDU is a Classification Society and a Conformity Assessment Body performing classification and statutory services, inspection, certification and notified body activities.

It has constituted and has been managing its organization to protect independence and impartiality values and maintain the continuity of improvement.

"A Type" Inspection Body activities are performed in accordance with the "ISO/IEC 17020 General Criteria for the Operation of Various Types of Bodies Performing Inspection" standard and accredited by TÜRKAK.

Notified Body activities which are composed of conformity assessment activities are performed in accordance with the relevant directives of EU legislations and the Guide to the Implementation of Directives Based on New Approach and Global Approach.

INSPECTION OF BRIDGES BY 3rd PARTY

To reduce the risk and ensure that the project progresses at minimum quality requirements in accordance with the standards and technical specifications, it is of high importance that third-party surveillance companies take part in the projects.

Not only for the safety of construction but also in products with the 3rd party inspection, insurance costs are reduced which is the other advantage of the 3rd party inspection.

Because bridges are exposed to a wide variety of loads such as wind load and earthquake load and operate under dynamic loads, they are structures of high importance in terms of safety.

Accordingly, after the construction standard of the bridge is selected, the execution class is determined according to EN 1090-2.

Bridge structures are usually built according to the highest execution classes; EXC3 and EXC4. The choice of select execution classes mostly used to determine the acceptance criteria of weld seams, dimensional tolerances, and extra tests to be applied during the fabrication of the bridge, the documentation requirements, and the traceability requirements.

1915ÇANAKKALE BRIDGE PROJECT

Türk Loydu provided its services in the 1915Çanakkale Bridge Project within the scope of main cable fabrication inspection, hanger cable fabrication inspection, pile pipes fabrication inspection, bridge shaft fabrication inspection, and deck lifting gantry fabrication inspections.

Manufacturing and inspection of main cables, hanger cables, hand ropes, etc. were carried out according to COWI Technical Specification 5.1 "Cable Structures" for the Project. Technical specification refers to Euro Standards, and it is in accordance with the inspection and test plan which was created according to technical specifications and standards of the project.

In the overseas leg of the project, the main cable fabrication inspections were carried out in Zhejiang, China, the hanger cable fabrication inspections were carried out in Changzhou, China, the deck lifting gantry fabrication inspections were carried out in Shanghai, China, and the fabrication controls of the wrapping and compaction machines were carried out by Türk Loydu personnel in Wuxi, China.
The stages of cable manufacturing were inspected by socket manufacturing controls (casting, heat treatment, machining, dimensional checks), wire stranding and socketing inspections, measurement dimension inspections, witnessed mechanical laboratory tests, witnessed chemical analysis tests, witnessed cable wrapping inspections, visual and non-destructive inspections, and the conformity of the fabrication of cables to the standards was checked and reported to the owner.

At the beginning of fabrication Inspection Test Plan (ITP), Method of Statements (MS) was created by the manufacturer, and was submitted and agreed by all parties of the project; manufacturer, owner, 3rd party inspection body.

ITP shows the responsibility of each party, and shows which step will be controlled by which party. At ITP perform point, witness point, review point and hold point responsibilities are determined for each party. MS shows the methods with all details which will be applied to execute fabrication process by manufacturer.

At the 1915 Canakkale Bridge Project, the same process was followed for each fabrication part.

The meanings of responsibilities at ITP are given below:

- **Perform Point**: Shows the activity which will be performed. This point is under the manufacturer’s responsibility.
- **Hold Point**: Parties shall be notified by the manufacturer and the work shall not proceed without the owner and the 3rd party release by letter, e-mail or put on the inspection form.
- **Witness Point**: The parties must be notified to witness the inspection and testing of the manufacturing activities.

If the owner and 3rd Party are not available at the required inspection time, work can proceed. In that case, the preferred practice is owner and 3rd Party to review of inspection & test results for acceptance.

- **Review Point**: Review of quality documents, reports, certificates, inspection & test results for acceptance.

If any non-conformity was detected at inspections, a non-conformance report (NCR) was issued and published by 3rd party to both the owner and the manufacturer.

After issuing an NCR, the manufacturer reported to the NCR for a corrective action which was done to close the related NCR issue and the manufacturer should report on what preventive action was taken to avoid the non-conformance again. After confirmation by all parties, the manufacturer took the action to close the NCR.

**INSPECTION ITEMS**

**Review of documentation and certification**

Fabrication and quality procedures were submitted by the manufacturer’s quality department for review. The 3rd party body and the owner’s QA/QC department reviewed the documents to check procedures were compliant with standards and project technical specifications and gave comments if necessary.

Certificates such as quality system certificates of the factory, raw material certificates, calibration certificates of measurement and testing devices, welder certificates, welding operator certificates, and non-destructive testing operator’s certificates were reviewed by the 3rd party body and the owner’s QA/QC department.

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*Figure 1: Inspection of socketing by Türk Loydu inspector*

*Figure 2: Length and visual appearance inspection of cable by Türk Loydu inspector*
**Welding inspection**

Welding procedure qualification record (WPQR) and welding procedure specifications (WPS) were prepared or performed by the manufacturer before welding processes. The 3rd party body checked whether the weld was made according to the approved WPS, and the qualification of the welder was checked.

Visual inspection and non-destructive inspections after welding were witnessed and monitored. Welding inspection was done with special gauges specially developed for welds.

Before non-destructive tests (NDT) such as Ultrasonic test, Magnetic Particle test, radiographic test and penetrant test, visual inspection was done by a qualified person.

After the visual test, other NDT methods could also be applied by a certified person according to related standards. The 3rd party body witnessed and monitored the tests. All NDT devices should be calibrated according to related international standards.

**Heat treatment inspection**

If heat treatment was applied, the heat treatment process was checked by the 3rd party according to the approved heat treatment procedure. At Canakkale bridge project cable sockets were applied heat treatment process.

The placement of the parts at the furnace and the heat treatment graphics were examined and their compliance with the procedures was checked.

**Dimensional inspection**

After all welding and assembling were completed, the parts were dimensionally inspected by the manufacturer’s QC personnel to approve project shop drawings and witnessed by 3rd party.

Dimensional tolerances were given at drawings, standards and project technical specifications. All dimensional inspection tools should be calibrated according to related international standards.

**Painting inspection**

Painting processes were inspected according to project technical specifications, standards and painting procedures. Environment conditions were checked before and during the painting process; after painting visual and dry film thickness (DFT) inspections were done with DFT ultrasonic test device.

**Bridge cable inspection**

For Cast Socket forks, each fabrication step such as pouring, molding, sampling and mechanical tests, chemical composition tests and dimensional inspection tests, NDT tests, welding repairs (if needed) and heat treatment checks were done by the manufacturer’s QC personnel and the 3rd party inspector.

Polyethylene, heat shrinkage tube and socketing material certificates were checked. After stranding of galvanized wires, dimensional inspections of wires before socketing, socketing processes, sealing and length checks were done.

During the manufacturing of cables, fabrication tests such as a tensile test of cable strands, socketing procedure test, and fatigue test of cables were performed by the manufacturer and checked by the 3rd party according to project technical specifications.
INTRODUCTION

Turkish Straits are unique and important waterways connecting the Mediterranean Sea to the Black Sea.

Any vessel travelling to the Black Sea needs to pass through the Çanakkale Strait (Dardanelles) first and then through the Bosphorus Strait.

There is always a big challenge for the drillships, platforms and Jack-Up rigs travelling to the Black Sea as they need to go through the two Straits to reach their final drilling project location, with the erected derrick.

The height of the erected derrick together with the ship or platform itself can be up to 100 m high which we specify as the “air draft” of floating equipment.

This calculation is based on the measurement from the sea level up to the final touch point of floating equipment.

The very first bridge over the Bosphorus (at Istanbul) has a 56 m accessible air draft which means any floating equipment passing the Strait should have maximum 56m air draft.

The 1915Çanakkale Bridge has a designed air draft of 70 m which will also serve vessels that may be destined to pass under the Osmangazi Bridge in İzmit Bay which has 60 m of air draft.
1. Çanakkale Strait (Dardanelles) with the 1915 Çanakkale Bridge with air draft 70 m
2. Bosphorus Strait with three Bosphorus Bridges (1st Bosphorus Bridge is the most limiting bridge in terms of air draft which is 56 m)
3. Osmangazi Bridge in Izmit Bay. It has 60 m headroom (air draft) over the water to allow for cargo ships

Due to such restrictions, there is a need for important but expensive logistics planning as per below.

- Floating equipment with more than 56 m air draft should be taken to a shipyard or available port for “derrick operation”;
- Derrick operation means to cut the Derrick down to an accessible level for safe passage;
- Derrick parts to be loaded either on a barge or Platform Supply Vessel (PSV) or similar type of vessel;
- After completion of passage, the floating equipment should be taken to another port in the Black Sea for the erection of the derrick

Like the three bridges over the Bosphorus, any newly built bridge brings new rules and regulations for vessel passages through the Straits which requires know-how and experience.

It is one of the said straits that hosts many different sizes and types of vessels every day.

To better explain the traffic in the Çanakkale Strait, we need to look at the number of vessels passing through it.

Between the years 2006 and 2021, the strait hosted about 45,500 vessels on an annual basis which makes almost 3,800 vessels per month and 125 vessels per day.

We, BATI Innovative Logistics, are providing agency services to the vessels for their Strait passages but we are far more involved with the operation of oversized construction vessels and similar types of high-value cargo-carrying vessels which are subject to special requirements for the passage.

We will describe two interesting case studies of vessel passages during and right after the construction of the 1915 Çanakkale Bridge.
CASE STUDY 1: PASSAGE OF MV BIGROLL BEAUFORT WITH STS CRANES ONBOARD

There were no “so-called” air draft restrictions for the passage through the Çanakkale Strait until the moment when the catwalk ropes started to be installed on the 1915 Çanakkale Bridge.

Passage of vessels and other floating equipment through the Çanakkale Strait started being subject to new restrictions after the catwalk linked two sides of the Çanakkale Strait and after the assembly of the Bridge deck.

The restrictions started being applied just before the entrance to the Çanakkale Strait from the Southern end named Kumburnu until the Northern end called Gelibolu (Gallipoli) and are applicable for 61 km (37 nautical miles). The passage also requires tug assistance and pilotage.

In March 2021, we assisted MV BigRoll Beaufort in passing the Çanakkale Strait with an air draft 88 m high.

The vessel is a multipurpose Heavy Lift carrier but this time it had 4 units of STS (Ship to Shore) cranes used for container terminals.

At that time, the Çanakkale Strait passage was restricted to max. 95 m due to the catwalk ropes. Moreover, it was a day with heavy fog and dark weather, Figure 4.

In close coordination with the contractors of the bridge construction and respective authorities, we managed a safe passage with very limited clearance (7 – 10 m) underneath the Bridge catwalks during its construction.

Figures 3 and 4: MV BigRoll Beaufort

Figure 5: MV BigRoll Beaufort passing under the Bridge during catwalk installation
CASE STUDY 2: PASSAGE OF A JACK-UP RIG WITH ERECTED LEGS ON A HLV

Non-self-propelled Jack-Up rigs can be either pulled or carried on a Heavy Lift Vessel (HLV). In this case, we had to manage the safe passage of a Jack-Up rig travelling through Turkish territorial waters with a 130 m air draft onboard a Heavy Lift Vessel.

In our case, we had the following conditions:

- Jack-Up rig to arrive in Turkish territorial waters onboard an HLV with 130 m air draft;
- Jack-Up rig to be offloaded from the HLV somewhere safe and convenient within the Çanakkale Strait entrance or any other safe dock, bay or simply an area where the HLV can perform submerge operation;
- After the unloading operation, the air draft of the Jack-Up rig is to be 123 m high;
- Jack-Up rig to lower the legs down to maintain safe passage clearance in terms of air draft underneath the newly built bridge;
- Once the Jack-Up rig lowers the legs down into the sea, the air draft can be min. 66m high but this time the draft* (*draft = the vertical distance between the waterline and the bottom – touchpoint of the legs down into the sea) of the vessel increased to 57 m.

The above mentioned 66 m is minimum. The rig has three adjustable legs and they can be lowered 120 – 130m into the sea but there is a static/non-adjustable touch point (as we call derrick) on Jack up rig and the height of nonadjustable touch point is 66 m.

That is why we lowered the legs to the same level of the said touch point as there is no merit to lower the legs more if we have the air draft of 66 m anyway.

In normal circumstances, any vessel with more than 70 m air draft cannot enter the Strait but in our specific case, we had to maintain excellent planning and coordination among many different parties.

The planning phase took more than 6 months including bathymetric analyses to create a safe navigational channel for non-self-propelled floating equipment with 57 m draft and 66 m air draft.

Regarding the depth of the Strait, we studied bathymetric reports within the vicinity of the bridge construction and understood that the depth of the water was changing between 55 to 90 m.

We designed a route to keep the rig travelling safe with 57 m draft in the sea. We navigated in a channel like the water depth is not less than 75 m deep.

It was a true challenge, but we made it.

Figure 6: Preparation for the submerge operation  
Figure 7: Submerge operation
Figure 8: Pull out preparation
Figure 9: Pull out completed

Figure 10: Proceeding towards the Bridge
Figure 11: Passage

Figure 12: Passed
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References:
- Bahia de Cadiz, Spain
- Hochmoselübergang, Germany
- Osman Gazi Bridge, Izmit, Turkey
- Mainbrücke Randersacker, Germany
- Millau Viaduct, France
- Rheinbrücke Schierstein, Germany
- Rion Antirion, Greece
- Russky Island Bridge, Vladivostok, Russia
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