e-mosty

Issue 04 / 2017 December 2017

Movable Scaffolding Systems. Formwork Travellers.

Bowstring Overhead MSS
with Organic Prestressing System
Turkey

Front Cover: Movable Scaffolding System - BERD, Turkey
Back Cover: Atlantic Bridge, Panamá. Photo: Rúbrica Engineering

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Chief Editor: Magdaléna Sobotková

Contact: info@professional-english.cz

Editorial Board

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Velká Hraštice 112, 262 03
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Dear Readers

*The December 2017 Issue of our magazine e-mosty specialises in **Movable Scaffolding Systems (MSS) and Formwork Travellers**.*

*António Póvoas describes **evolution and development of MSS** and describes projects where various MSS were utilised, with focus on two significant High Speed Rail Bridges in Spain – the **Almonte River Viaduct** and the **Tagus River Viaduct**.*

*It is followed by an article about a **Bowstring MSS with Organic Prestressing System** and their development and utilisation – at this moment they are operating in Turkey and Colombia.*

*Next, you can read about the **MSS for a bridge across the Vistula River in Warsaw** in Poland. The article was written by Aquilino Raimundo, with photos of its ongoing assembly by Tony Chellingworth.*

***Formwork travellers** for the **Atlantic Bridge in Panamá** are presented in an article written by Paula Rinaudo from Rúbrica Engineering.*

*I am happy to announce that the company **Rúbrica Engineering has become a partner of our magazine e-mosty**.*

*Finally, Thanos Bistolas and Brian Duguid have prepared an article about the **Ordsall Chord** on the occasion of its completion and opening to traffic.*

Thank you all very much for perfect cooperation. You all and your companies bring development, ingenious technical solutions and accomplishment to bridge engineering and construction, and I am very happy that we can present it all in this issue. I also thank to members of our Editorial Board who helped me with this issue: Richard Cooke, David Collings, Ken Wheeler and Peter Paulik.

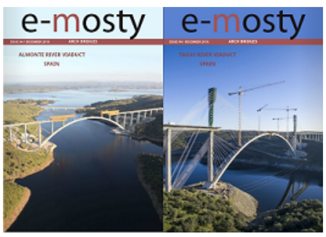
*The magazine also brings information on our **Editorial Plan for 2018** and information on our Partnership Program. The price and extent of cooperation is negotiable with the aim to provide you the best promotion and presentation of your companies.*

In 2018 we will continue our cooperation with Bridges to Prosperity and provide them our medial support.

*For the **e-mosty March 2018** edition about **Naeem Hussain** I am preparing an interview with him. I would welcome any questions that you would like me to raise on your behalf – I think it might be interesting to ask him for his thoughts on topical bridge matters and for some of you to be part of such an interview. Please send them to my company e-mail: info@professional-english.cz by 15 January. Thank you.*

Thank you all for great cooperation in previous years and I wish you all the best in 2018.

Read more about design and construction of both Almonte and Tagus Viaducts and about the Ordsall Chord in our e-mosty December 2016 (click on the picture):



Magdaléna Sobotková

e-mosty

3rd Bosphorus Bridge (Yavuz Sultan Selim) | Izmit Bay Bridge (Osman Gazi Bridge) | Delaware Memorial Bridge | Queensferry Crossing | Forth Road Bridge | Almonte River Viaduct | Mersey Gateway Bridge

The magazine „**e-mosty**" is a quarterly issued, peer-reviewed, interactive (electronic) international magazine about bridge engineering.

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

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

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

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

The magazine was founded in May 2015 and its first issue was released in June 2015.

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

Editorial Board: e-mosty.cz/editorial-board

The number of **readers** and **subscribers** is increasing fast worldwide.
The readers are mainly bridge engineers, designers, constructors, managers of construction companies, university lecturers, students, or people who just love bridges.

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

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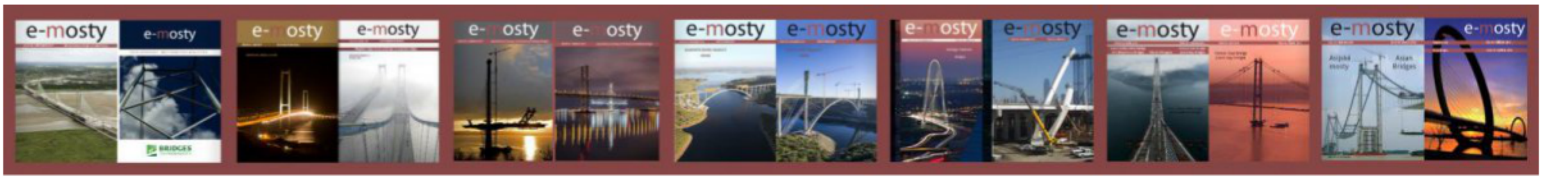


Partnership and promotion of your company in our magazine e-mosty for the year 2018

Our preliminary **Editorial Plan for 2018** covering 4 issues is as follows:

March 2018:
Naeem Hussain: Bridges

June 2018:
American Bridges.

September 2018:
Maritime Vessels and other equipment used for Bridge Construction.

December 2018:
Asian and Australian Bridges.

Basic price for Annual Partnership is **990 EUR a year plus VAT**. For this money you will get:

- A **logo on the main page** on our website.
- 1 page interactive **presentation of your company in every issue.**
- Your logo and / or the name of your company on **every publication and output we release.**
- In compliance with our Editorial Plan we can also publish one **technical article** during the year (which we can help you prepare).

Additional Information

The magazine e-mosty ("e-bridges") is an **international, interactive, peer-reviewed magazine about bridges published quarterly on www.e-mosty.cz.**

It is **open access with a possibility to subscribe**.

It was established in April 2015 and its first issue was released on 20 June 2015 as a bilingual Czech – English magazine aimed mainly for Czech and Slovak bridge engineers. Very quickly it reached an international readership. In 2016 we extended the already existing Czech editorial board by two bridge experts from the UK, and in 2017 two colleagues – from the USA and Australia – joined us.

Since December 2016 the magazine has been published solely in English.

The readership is increasing very fast and we have **readers worldwide**. We already have almost **200 subscribers** who receive new issues automatically – achieving this number after only six months (We started offering free reader subscriptions in Spring 2017).

Each issue now has **hundreds of readers, downloads and very positive feedback.** Many of our readers share the magazine in their companies and among their colleagues so the final number of readers is much higher. Generally the readership has reached over **6000 in two years.**

Most importantly the **readership covers our target segment** – managers in construction companies, bridge designers and engineers, universities and other bridge related experts. We also know that the readers usually go back to older issues.

www.e-mosty.cz

THE EVOLUTION OF MOVABLE SCAFFOLDING SYSTEMS AND THEIR APPLICATION IN CONSTRUCTION OF THE SPANISH HIGH SPEED TRAIN LINE

Antonio Póvoas, AP- Bridge Construction Systems – Portugal, Ltd.

Figure 1: Almonte Viaduct – Approach of nose MSS to central span

Introduction

The evolution of pre-stressing technology has allowed bridge designers to face the construction of bridge decks using continuous spans and increasing their length, aiming to reduce the cost and duration of bridge construction. Movable equipment for the construction of the decks are evolving according to this tendency and sometimes preceding it, allowing larger spans to be built in shorter periods.

The mobile equipment for building bridge decks are basically divided into two main groups:

- Precast decks or segments
- Cast "in situ" decks or segments

For building decks with precast beams, segments or the entire deck there are special equipment that we shall not discuss in this article.

For building decks "in situ" there are basically three groups of movable equipment:

1. Movable formwork tables
2. Movable Scaffolding Systems (MSS)
   - Underslung
   - Overhead
3. Travellers (not analysed in this article)

1. Movable formwork tables

Traditional formwork supported by shoring is made of formwork blocks supported by beams placed over propped shoring or beam shoring (Figure 2).

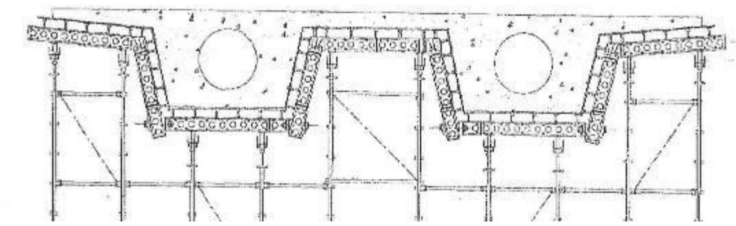


Figure 2: Example of traditional propped shoring formwork

The movable formwork tables - Figure 3 - are normally made of a steel structure which is stiff enough to hold the form work panels that can be transported, lifted and slipped laterally as well as longitudinally, over a fixed supporting structure, making a modular block that normally is called *movable formwork table*.

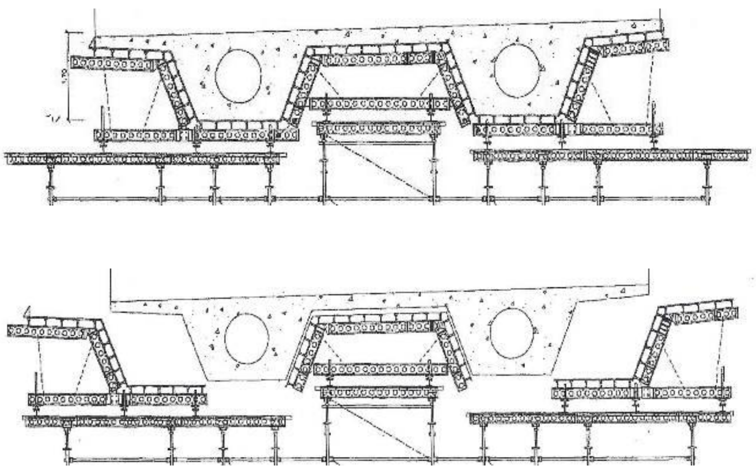


Figure 3: Example of movable formwork tables – casting position (above) moving (below)

The formwork tables can normally be moved in the three directions of space:

Vertically – allowing moulding and demoulding of the deck

Laterally – allowing the table to pass the pier of the current span

Longitudinally – allowing the table to move to the following span.

The fixed supporting structure can be made with traditional shoring with multiple columns or by other structures such as longitudinal beams or trusses placed directly over their own foundations (on very low bridges) or supported over columns directly placed over the bridge piers foundations.

To use this system, it is recommended to have 2 sets of supporting structures so that the following span supporting structure can be installed while building the previous deck.

When the movable tables are released from the concrete they are longitudinally moved over the waiting supporting structure to prepare next span casting.

This system also requires the preparation of the ground: for multi shoring; accesses of trucks and cranes to erect and dismantle *n* times the supporting structures; and initial assembly and final disassembly of the movable tables.

This system obviously requires lots of man power and auxiliary machinery such as cranes and trucks for the repetitive operations of assembly, disassembly and movement of supporting structures and tables.

The movable formwork tables are an easy construction system for low decks with a short number of spans, when a more sophisticated method is not necessary.

The cost of using this method is similar to the cost of traditional propped shoring systems, but with better efficiency achieving cycles of one span every two weeks, for spans between 25 m and 36 m.

2. Movable Scaffolding Systems – MSS

2.1 Underslung

The system of movable formwork tables was the origin of underslung Movable Scaffolding Systems, where it is the supporting structure that can move itself in the 3 main directions, carrying the outer form to the following span.

The primitive underslung MSS were made of independent structures placed under the level of the deck, with some parts being dismantled and replaced on the next span by auxiliary machinery such as trucks and cranes, as shown in Figure 4.

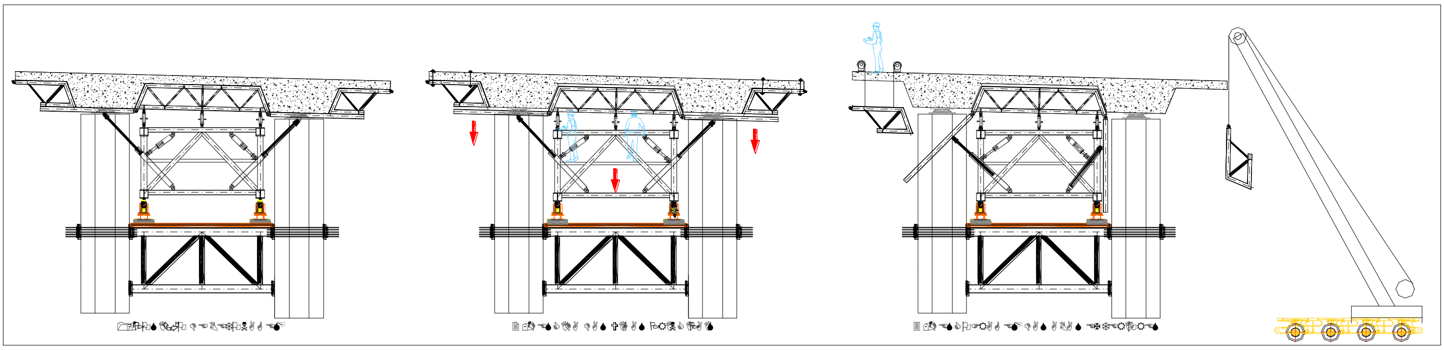
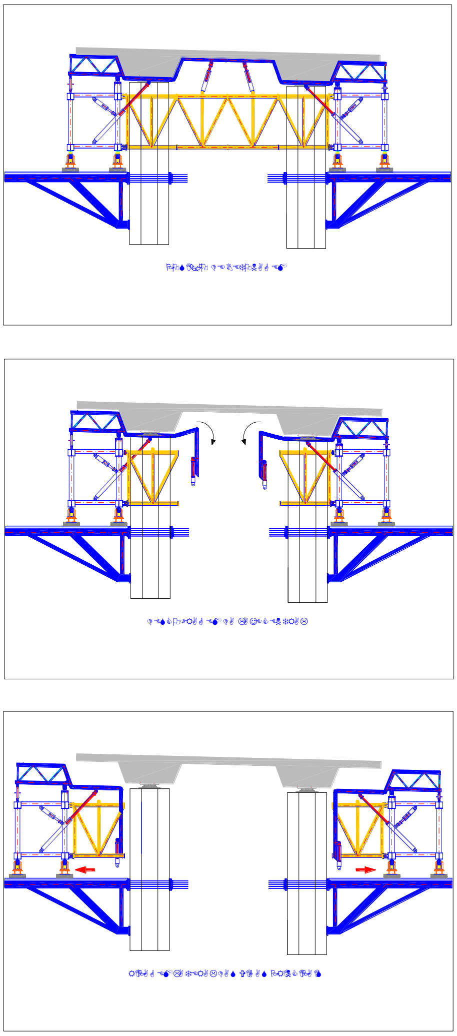


Figure 4: Example of primitive underslung MSS based on movable formwork tables system

2.2 Evolution of underslung MSS

The underslung MSS first evolved in the way that all parts of the outer form are carried by the supporting girders (Main Girders - MG) and are assembled in 2 longitudinal blocks - one left and one right - with the full length of the span rigidly fixed to the MG (Figure 5).

These 2 blocks can be folded together with bracing elements and shifted outwards to allow the 2 MG to pass outside of the piers.



The normal underslung MSS were very dependent on auxiliary cranes, telescopic platforms and trucks for installing the pier supports and the rebar. This dependence can significantly increase the cost of using those machines.

Therefore, when estimating the global cost of using these MSS it is necessary to consider the costs of using auxiliary trucks, cranes and telescopic platforms as well as the construction of supplementary roads to access the piers and some ground platforms under the MSS or around the piers.

Over water or in high bridges, this dependence and corresponding costs penalize and normally exclude those dependent MSS.

Commonly these extra options are not included in initial prices and can be supplied later as extra costs, being very annoying expensive surprises for the client.

← Figure 5: Underslung MSS schematic drawings with folded inside form and its respective movement towards the supporting brackets

↑ Figure 6: Underslung MSS – with foldable inside form and MG over supporting brackets

With the competition of autonomous overhead MSS that can auto assemble and disassemble the pier supports as well as carry or lift the rebar, the underslung manufacturers were forced to make their machines also capable of auto install the pier supports and the rebar.

Nowadays there are also autonomous underslung MSS. These machines use auxiliary travelling gantries to carry rebar from the previous deck to the one under construction.

They also use a travelling gantry running along their nose that can carry the support brackets to the next pier.

Even though, if the front pier supporting brackets can only be released after pre-stressing the previous deck, the time for moving the brackets to the front pier and its assembly will be on the critical path of the construction schedule.

The most efficient way to install front pier brackets off the critical path is to use a set of brackets not necessary for pouring the concrete of the previous span.

Underslung MSS are very popular with some contractors because their use is very similar to traditional scaffolding, enabling similar methods for the subcontractors for rebar and pouring the concrete with truck pumps placed along the bridge side or over the previous decks.

The most current underslung MSS are formed by a pair of main girders each one under one side of the bridge (left-right).

Each main girder is composed by a central load body made of closed box girders and two noses, one front nose and one rear nose. Noses are normally made by trusses, as in Figure 6 and Figure 7.

Using large cranes these MSS are easy to assembly because they are made of rigid blocks, around 12 m long that are connected by plate cover joints unions.

Using the main girders under the formwork, and below the bridge deck, the height of the Main Girders is an important limitation when bridges are close to the ground or when they cross over existing roads, railways or other facilities due to the lack of space for main girder plus the height of the pier supports.

Figure 7: Underslung MSS – first span using the MSS without the rear nose (left) and abutment allowing whole MSS to pass

Therefore, for the underslung MSS there is always a compromising situation to define the optimal height in order to have enough inertia ($I=Sh^2$), to take in account the limitations due to MSS transportation and to have space for the MSS to fit below the deck.

For these reasons underslung MSS main girders are normally much heavier than overhead MSS that can be higher and therefore can reach the same inertia using larger webs and less material.

The use of rear and front noses sometimes carries problems for the first span such as those seen in Figure 7 - left, that can be avoided by designing abutments that allows a full assembly of the rear nose behind the abutment and the use of the MSS for the first span of the bridge as in Figure 7 - right.

Figure 8: Underslung MSS – pier supports for pile-piers and double T deck

The optimal use of any bridge construction equipment requires a close cooperation between the bridge designers and the equipment suppliers as happened in the bridge shown in Figure 8.

Pier supports for underslung MSS are sometimes complex due to the piers shape.

In Figure 6 - right - the pier is a single column and the piers supports are made of two brackets that can transfer horizontal loads from side to side through the pier compensating each other.

In Figure 8 the pier is made of 2 different piles and a more complicated solution to hold the brackets was necessary because the pile-piers cannot resist horizontal actions. Supplementary horizontal connections had to be used to connect both piles equilibrating horizontal loads from both pier supports.

Almost everything can have an engineering solution, but in bridge construction the simplest solutions are the cheapest and faster to use. Therefore, it is very important in the preliminary work to optimize the superstructure design regarding the construction equipment.

Underslung MSS apparently look easier to use but their efficiency depends a lot on the design of the abutments and of the piers so that the machines can be used in all bridge spans and can be fully assembled on the first span.

Complex pier supports such as shown in Figure 8 take a lot of work and time to install increasing the bridge cost.

2.3 Overhead MSS

Some construction companies started using main girders of beam launchers to launch and support formworks for casting decks "in situ" using flexible suspensions such as dywidag bars. These were the first overhead MSS.

This preliminary use of existing launchers as Main Girders for MSS, also created the common mistake of calling LG – Launching Girders as Movable Scaffolding Systems - MSS.

As we can see in Figure 9, using dywidag bars as main suspensions implicates that they had to be placed vertically, which has serious limitations on the suspended formwork design and its continuous adjustment when building viaducts with large longitudinal and transversal slopes changing along the length of the viaduct.

2.4 Evolution of AP MSS

AP Bridge Construction Systems started designing and supplying MSS in 1993/1994 with specific equipment designed for motorway bridges in Portugal. The first two were made for A4 motorway (Porto – Amarante).

One of those two and another three similar new ones were used for Vasco da Gama bridge construction in Lisbon (1995-1996). Vasco da Gama's South Viaduct had 88 spans of 45 m with cast in situ decks.

Their weight was about 250 kN/m and as it is shown in Figure 10 the required distance between MSS supports was 46 m due to the bridge expansion joints concreting 54 m at once, 45 m between piers plus 9 m of cantilever ahead of front pier.

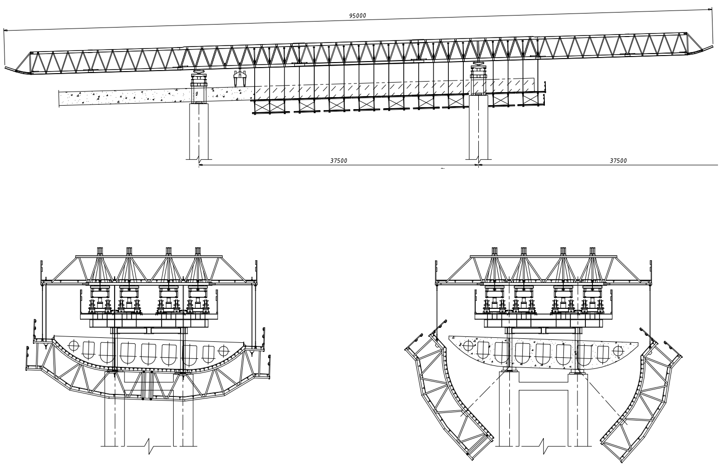


Figure 9: Launcher with suspended formwork using individual modules and dywidag bars as suspensions

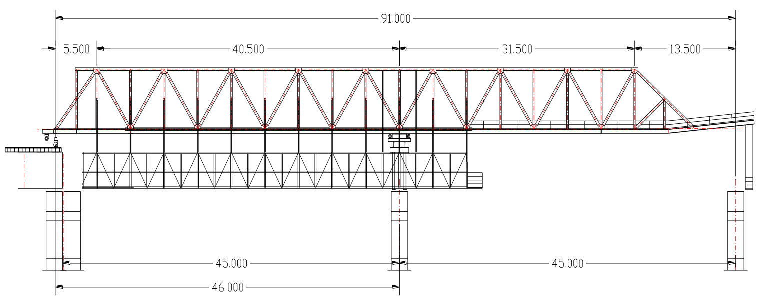


Figure 10: Vasco da Gama Bridge – rear support location at construction joint

This case showed that the same MSS could be used for longer continuous spans by placing the rear support over the cantilever of previous span and the front support on front pier. This way the total span, between piers, could be 54 m.

In this bridge the innovations already used in A4 Motorway were:

- Hanging from the main girder the pre-assembled rebar beams during launching.
- Having the front nose extended over the next pier to allow the assembly of next support from the nose.

The first innovation represented a gain of one/two days compared to assembling the rebar beams in situ.

The second innovation removed the assembly of the front support from the critical path by using the MSS nose as a crane while other tasks were being done.

Until then the assembly of the front support was done by using extra cranes and trucks or boats. In long bridges such as Vasco da Gama these innovations made possible an average construction cycle of one week. Some spans were even done in five working days.

In 2004, adding more capacities to the overhead MSS, a new concept was presented gathering the following principles:

- Maximum security.
- Capacity of unloading the trucks that feed the materials to the MSS (rebar + pre-stressing cables).
- Capacity of carrying the rebar and the pre-stressing cables when launching.
- Full autonomy for assembling and disassembling their own supports.
- Easy adaptation for different spans or girder weights.
- Easy suspension of different shapes of formwork.
- Reversibility for parallel viaducts – i.e. the capacity of building one side of the bridge in one direction and coming back doing the other side in the opposite direction.
- Minimal man power.
- Maximum of automation of all main tasks.
- Radio control for all motion operations.
- Transformability to become a launcher of pre-fabricated decks or pre-fabricated beams.
- Capacity of hanging prefabricated deck segments using span by span method.
- Minimal storing space when disassembled.
- Easy transportation overseas – all parts are designed to be packed inside normal 40 feet containers.

The inclusion of so many features, when designing these MSS, was done to give them have all the skills required to optimize the costs for the first and subsequent jobs, enabling the owners of such machines to have more adaptable and versatile machines and not one-job-only machine.

Obviously, the price of such overhead MSS, including so many extra skills, may become a bit more expensive for the first bridge than simpler MSS, but that will be balanced because this MSS can be easily reused in the following bridges, bringing larger savings in the future.

The main goal of any construction company, when choosing a MSS, is to find one autonomous MSS that won't bring expensive surprises such as needing extra cranes, trucks or boats as well as the need of building access roads in order that the MSS can work properly.

Often some inexperienced site engineers only look to the initial price of the machine itself, disregarding the necessary extra equipments and auxiliary works that the chosen MSS will necessarily require. Once a wrong choice has been taken there is no much left to the constructor than to pay the extra bills.

A common extra cost arises when using a short nose MSS supported on segments previously built by the contractor over the piers to allow the MSS to use simple slab supports over them, instead of steel structures directly over the pier.

These preliminary segments are very expensive as they require extra equipments to build them and it is an obvious extra cost for a client that has bought a machine that should have the formwork required for the full length of the deck, and finally must pay for extra equipments to build the segments over the piers, what it is obviously a duplication of costs.

2.4.1 Cornella viaduct

For the Cornella Viaduct construction in Barcelona (2004-2005) a new MSS for heavy loads was designed, as the viaduct had 11 spans with different lengths of 27 – 35 – 36 - 40 m, with a deck weight of 512 kN/m near the piers and a current weight of 368 kN/m.

Main contractor - Construcciones RUBAU SA.

The launching operations, over the motorway, were done mostly during night periods. A record of 2 hours and 15 minutes to open the formwork, launch the girder and close the formwork was then reached, after performing it several times in 3-4 hours.

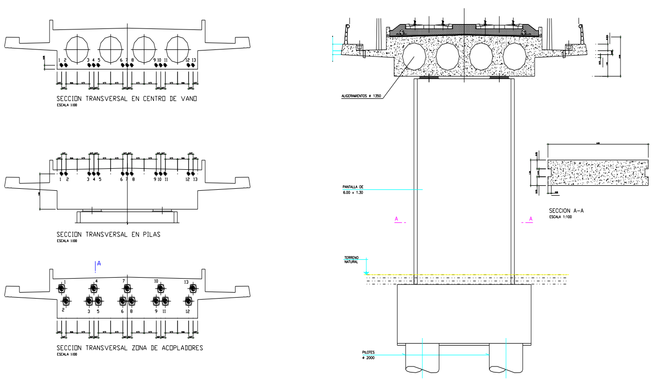


Figure 11: Cornella Viaduct cross section (left) and MSS (right)

2.4.2 Llobregat Viaduct

In 2005, AP Bridge Construction systems designed another MSS for the Llobregat Viaduct construction in Barcelona for a heavier U-shape concrete girder with 4.2 m high walls, 16.8 m maximum width and 14 m usable width (Figure 12:).

Main contractor - Acciona SA.

The 50 m span deck had a self-weight of 337 kN/m, but considering local reinforcements the average weight was 400 kN/m. Due to the high walls and the slab beams, the formwork weighed about 50 kN/m, even though the MSS could open the formwork in 10 minutes and do the complete launching in 3 hours.

These two heavy railway bridges were built by a new MSS model - AP2005 - with the capacity of hanging 400 kN/m concrete deck load plus the necessary inner and outer formwork, concreting spans of 50 m always in one stage only. This also showed that it would be easy to adapt them for larger spans with lighter deck's self-weights, such as those used for roadway viaducts.

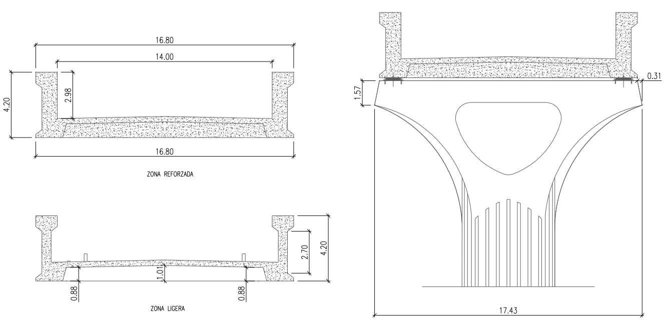


Figure 12: Llobregat Viaduct sections (left) and MSS (right)

This MSS model - AP - 2005 was used in:

- Vila Pouca de Aguiar Viaduct (2016), Portugal – Main contractor: Spie Batignolles Europe – a motorway bridge with 60 m span between piers
- Toxa Viaduct (2009), Spain – Main contractor: U.T.E. Tecnosa + Sisocia + Cyopsa + extraco – high speed railway bridges with 55 m span between piers
- Martixe Viaduct (2009), Spain – Main contractor: U.T.E. Tecnosa + Sisocia + Cyopsa + extraco – high speed railway bridges with 55 m span between piers
- Del Sar Viaduct (2011), Spain – Main contractor: – Ferrovial S.A. – high speed railway bridges with 55 m span between piers
- Esla Viaduct (2011), Spain – high speed railway bridges with 55 m span between piers
- V3 Viaduct (Venta de Baños) (2015), Spain – Main contractor: Ferrovial S.A. – high speed railway bridges with 55 m span between piers

On those viaducts MSS was supporting 280 kN/m of concrete weight plus 60 kN/m of formwork weight, with its supports 54 m apart (concreting span). All those models could easily fly over 63 m distances between piers (flying span).

After building bridges for the Spanish High-Speed Train Line with 55 m span between deck piers but with 54 m concreting span another challenge was arriving – overcoming the mythic frontier of casting 70 m span in one stage.

2.5 MSS Design criteria for large spans

MSS must be designed to sustain the formwork and the concrete load during pouring and must be able to launch itself for the consecutive decks.

The capacity of a MSS is measured by:

- The admissible live load during pouring (but including self-weight of the MSS and its form)
- The distance between concreting supports of the MSS – concreting span
- The distance between launching supports of the MSS – flying span

Although it could appear that the concreting span would be the worst load combination case for a large span MSS, in fact all launching stages can bring more important stresses to the MSS structure and become determinant for its design.

In large spans, due to the reactions over central MSS supports, the lower chords achieve very high shear stresses during launching therefore MSS resistance depends a lot on the flying span and the carried loads.

With the AP standard MSS, it is possible to build decks with 80 m span between deck piers, if the construction joint is at 1/4th of the span (20 m) and the rear support is placed 63 m behind the front pier (Figure 13: below - Launching).

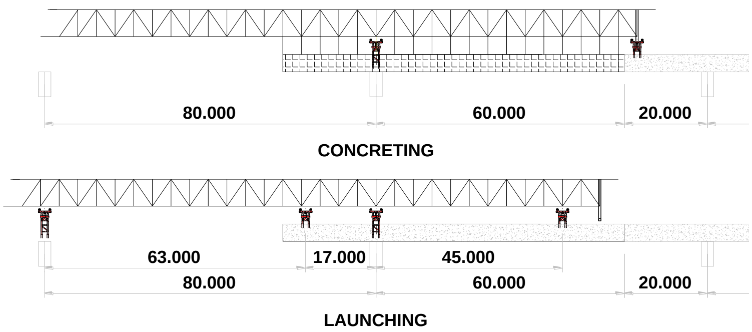


Figure 13: Concreting and launching 80 m span viaduct

Any experienced MSS supplier can design one MSS for very large spans (80 m -120 m, for ex.), the main problem is not to design it, but to make a machine that can be reused (if it is not possible to have it paid by that project).

The bridge design engineers must be aware that the state of the art of MSS engineering can provide them any tool they may wish for designing multi-span large bridges with larger spans that they are doing for the moment.

In Spain this MSS model - AP2005 brought to the high-speed railway bridge engineers more and more trust to design their new bridges with larger and larger spans, and they already are designing railway bridges with 68 m span between piers.

2.5.1 Engano Viaduct - MSS for 72 m span in one casting stage

The original design of Engano viaduct in Galicia (2010) considered 13 spans of 55 m and two end spans of 37.5 m, where most of the spans would be built over the water and 14 piers had submerged foundations. Main contractor: COPASA S.A.

2.5.1.1 Final design of the bridge

After knowing that the MSS model AP-2005 could build bridges with 63 m concreting span, the possibility of using 70 m deck spans was investigated, which would reduce the number of bridge piers and respective submerged foundations from 14 to 10 as well as the construction time.

The final layout has now 9 spans with 70 m and two end spans, one with 41 m and other with 50 m.

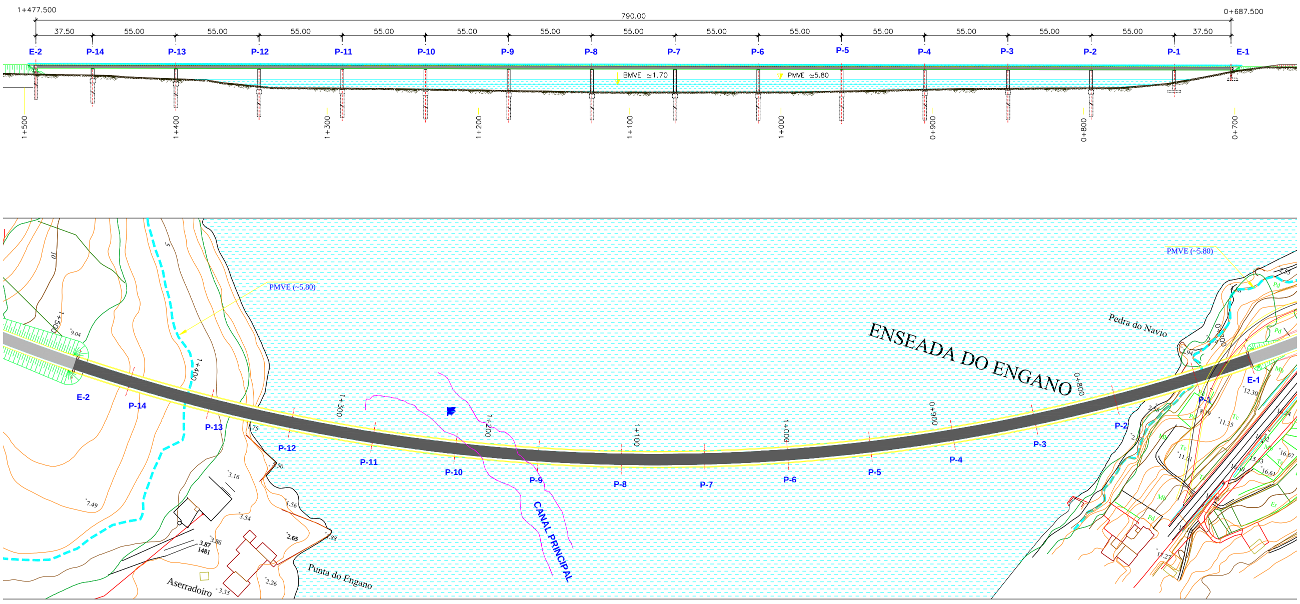


Figure 14: Engano Viaduct initial layout

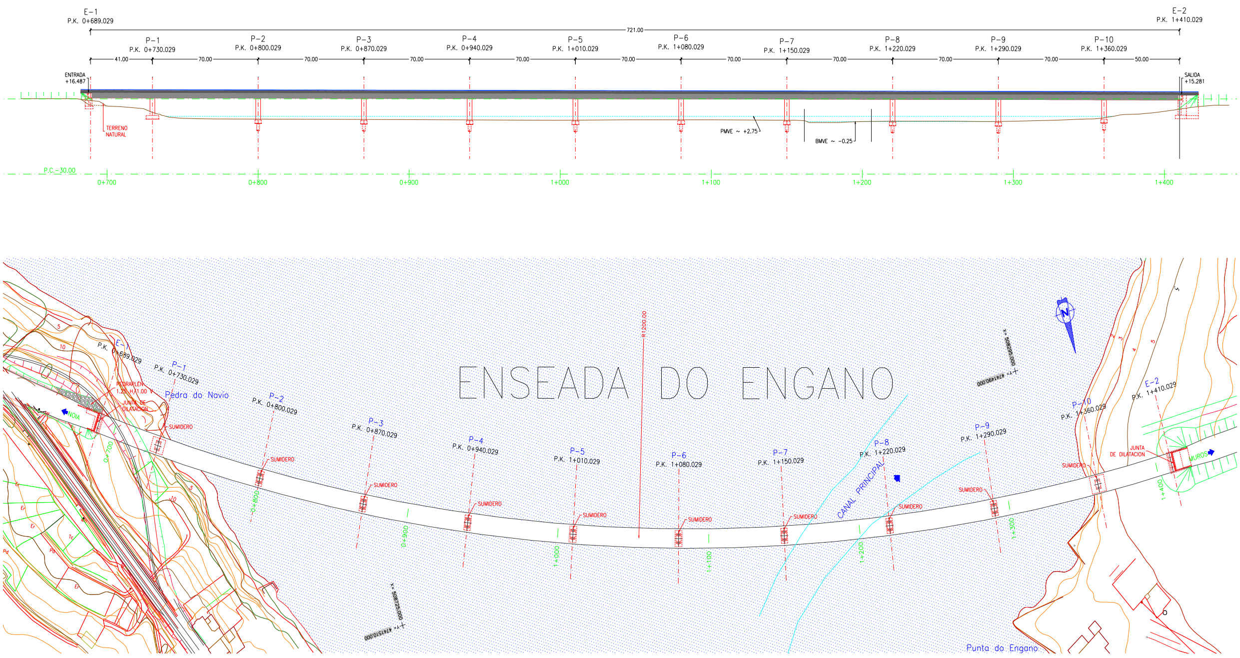


Figure 15: Engano Viaduct final layout

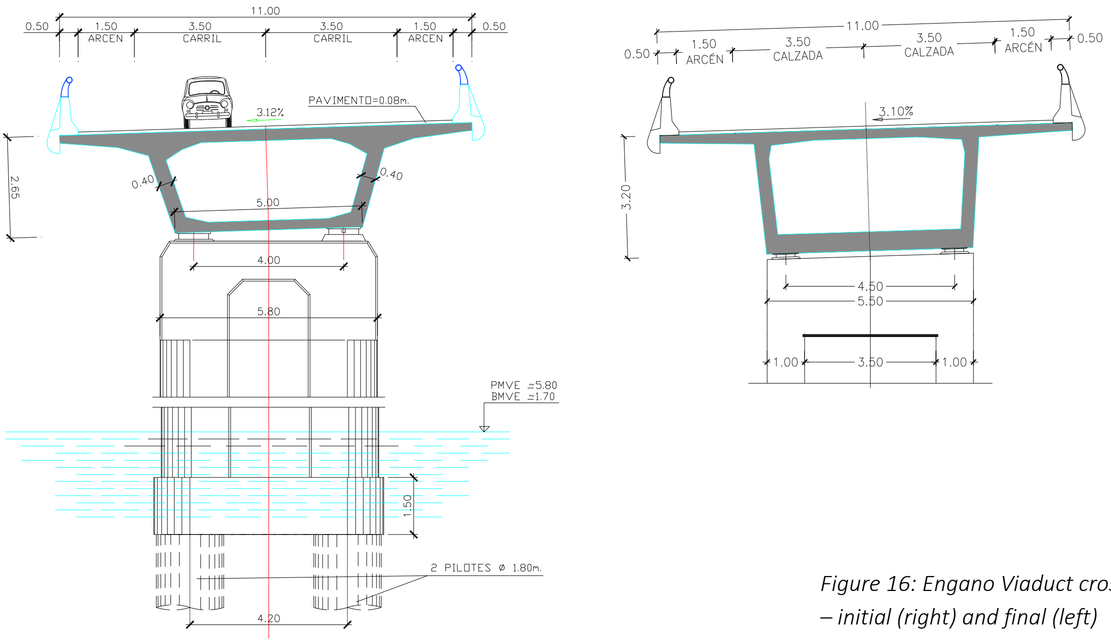


Figure 16: Engano Viaduct cross sections – initial (right) and final (left)

To overcome a larger span, the height of the box girder was raised from 2.65 m to 3.20 m which didn't penalize much the weight of the concrete girder since the design was optimized to the new geometry – Figure 16. The final concrete section was only 5% heavier than the one from the initial design. This difference was highly compensated by the reduction of the number of piers.

The heaviest section has now 8.05 m^2, which corresponds to a slab weight of 201.3 kN/m. The layout of the viaduct is curved, with a constant radius of 1200 m and a constant transversal slope of 3.1 %.

The pre-stressing was designed considering the execution of the viaduct from abutment E-2 (right side on Figure 15) to E-1 (left side on Figure 15), an initial span of 50 m, 9 consecutive spans of 70 m and a last span of 41 m.

Considering the construction joint always 17.5 m ahead of the corresponding pier, allowed the MSS rear support to be placed 16 m ahead of the rear pier in all spans, which corresponds to 54 m concreting span (Figure 17).

Figure 17: Difference for 1/4th and 1/5th of the span joints

2.5.1.2 Design requirements for the MSS

The initial design of the MSS was done considering that the construction joint would be at 1/5th of the span, with 14 m cantilever ahead of the pier, and the MSS should have a front support on the span pier and a rear support over the cantilever, 63 m behind (Figure 18).

The MSS was then designed with a total length of 148 m considering a concrete span of 63 m (Figure 18). This MSS configuration allowed it to perform 70 m span between concrete piers.

Meanwhile, the engineer who designed the bridge performed some calculations using 1/4th of the span construction joints, instead of 1/5th, considering the concreting span of at 63 m, 58.5 m and finally 54 m.

These calculations were done taking into consideration the reduction of the MSS length and self-weight as well as corresponding reactions.

After a global cost analysis for pre-stressing + concrete + MSS final cost, the client finally decided to use 1/4th of the span joints and it was achieved a 9 m shorter MSS with 54 m concreting span (Figure), what became a cheaper global solution to build the viaduct shown in Figure 20.

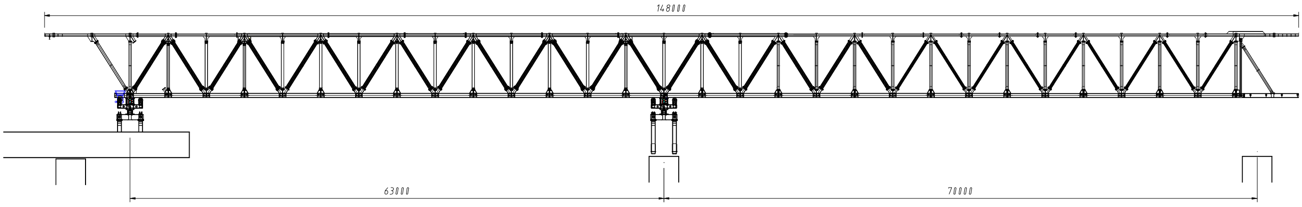


Figure 18: MSS 148 m long with 63 m concreting span

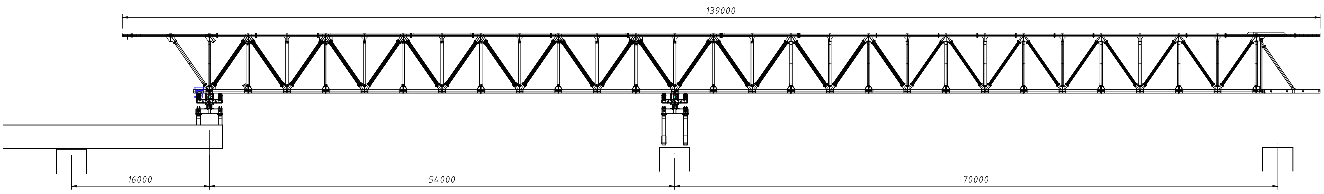


Figure 19: MSS 139 m long with 54 m concreting span

2.5.1.3 Relevance of the construction joint location

The global cost studies made for Viaduct do Engano brought very important conclusions concerning the interaction between the bridge design and the construction equipment design for large span viaducts.

A very important conclusion is that the location of the construction joint may have a big impact on the final bridge cost showing that it is worth giving it high relevance during bridge design.

The gain of weight in the MSS steel girder was about 70 tones by lowering its concreting span and consequently reduce the total length of 9 m, what corresponded to around 300.000 €.

The increase in pre-stressing steel due to this solution for the whole bridge was only half of that amount but in the end, there was a total save of about 150.000 € to the client.

Figure 20: Overall view of the Engano Viaduct with the MSS at the last span

2.6 Building the World Largest High-Speed Train Arch Bridges with AP MSS

In this part, the utilization of fully autonomous MSS for building the largest HST arch bridges in the world is described – Tagus River Viaduct (central span 324 m) and Almonte River Viaduct (central span 384 m), where MSS were used for the construction of the multi-span access viaducts with spans of 60 m and 45 m respectively, and were also used to build the decks over the arches.

2.6.1 Tagus River Viaduct

The North access of Tagus Viaduct near Caceres (2015-2018) of 642 m has a first span of 45 m, 9 spans of 60 m and one of 57 m. The South access viaduct of 522 m has a first span of 45 m, 7 spans of 60 m and one of 57 m. Viaduct has a central zone of 6 spans of 54 m over the arch of 324 m (Figure 22). Main contractor – U.T.E. Canaveral.

The deck of this viaduct is a box girder type, with an upper slab with 14 m wide and 3.6 m depth in the girder center line. The same section is used all along the Viaduct. The deck self-weight was optimized to 250 kN/m.

The concreting span was 54 m on the access viaducts and 40.5 m on the central viaduct. The construction joint of the deck was made at 1/4th of the span.

2.6.1.1 Deck section – Arch section

The deck of this viaduct is a box girder type, with an upper slab 14 meters wide, and with a height of 3.6 m on the centerline of the box girder. The same section is used all along the Viaduct. The deck self-weight was optimized to 250 kN/m.

The arch is a single box girder with a variable section starting with a width of 12.0 m and a height of 4m, finishing with a width of 6 m and a height of 3.5 m (Figure 21).

The arch was built using form travellers. Pylons were placed on top of piers P11 and P17 to hold the cables that anchored the arch girder to the pylons and piers (Figure 23).

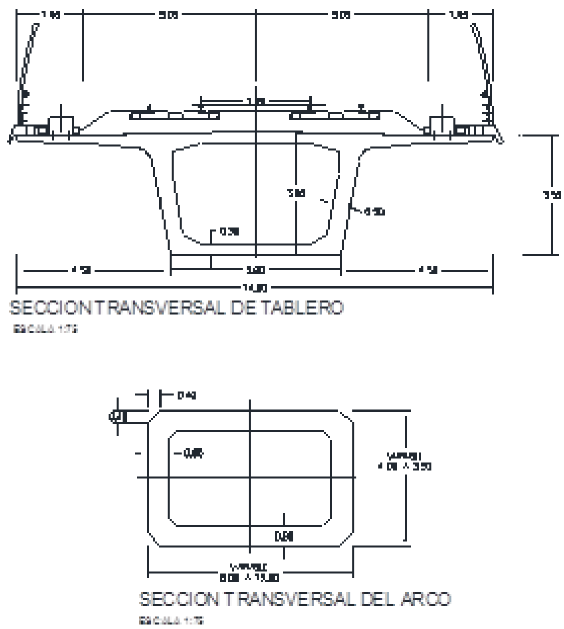


Figure 21: Tagus Viaduct – Cross sections of the deck and of the arch

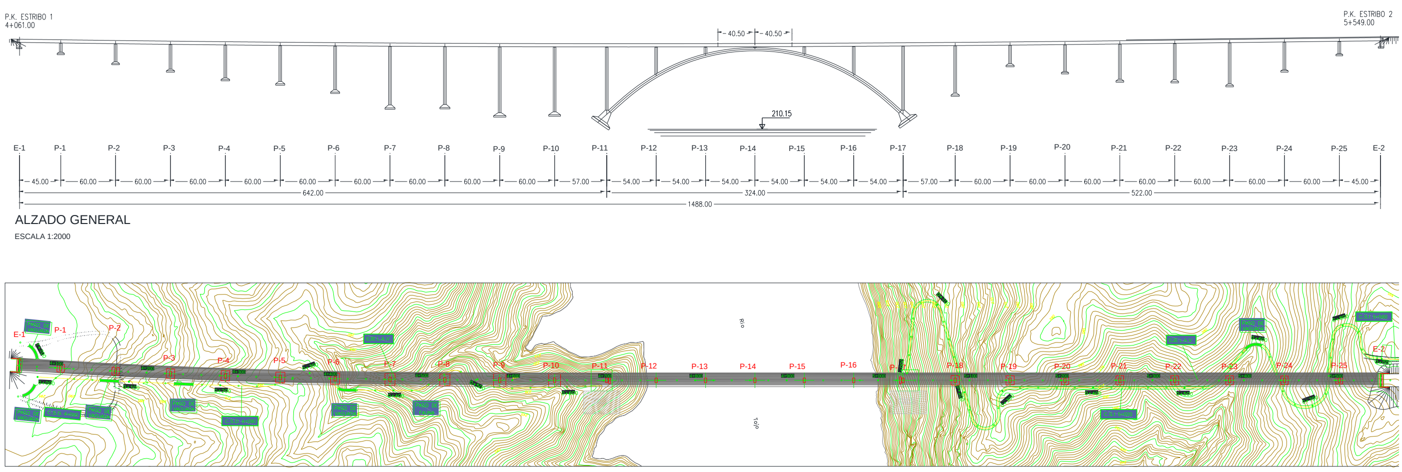


Figure 22: Tagus viaduct

Figure 23: Tagus Viaduct – Construction of the arch

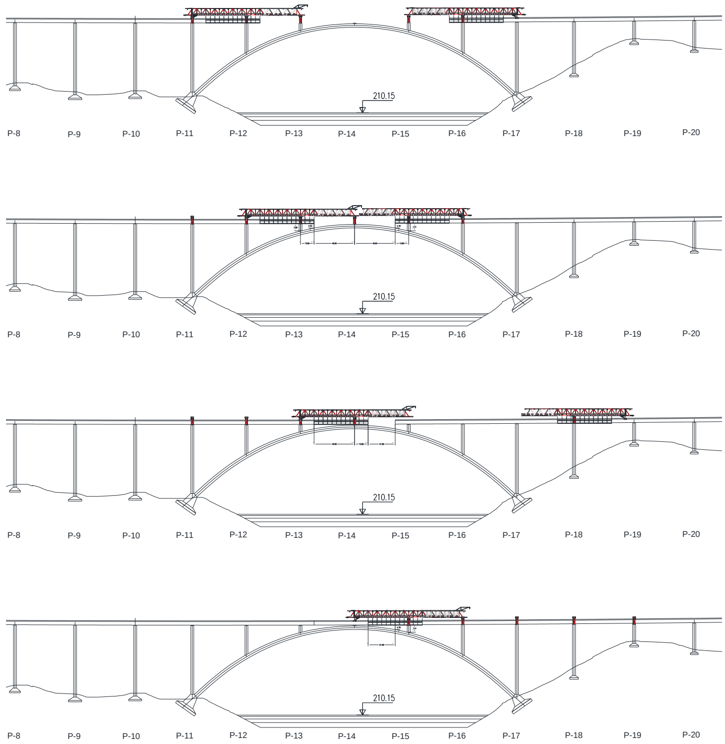
2.6.1.2 <u>Access viaduct construction</u>

The access viaducts were built with one MSS from the first to the last span just before the arch (Figure 25).

The same MSS was used for both sides, achieving performances of casting one span per week in most of the 60 m spans.

2.6.1.3 <u>Construction of the decks over the arch</u>

The decks over the arch were built by two MSS that cast simultaneously the first two spans in each side (Figure 26).



↖ *Figure 24: Tagus Viaduct – MSS on North Viaduct Access*

← *Figure25: Tagus Viaduct – MSS finishing North Access Viaduct deck*

↑ *Figure 26: Tagus Viaduct – MSS construction of deck over the arch*

2.6.2 Almonte River Viaduct

Almont River Viaduct near Caceres (2013-2016) has a central zone with 2 spans of 45 m and 7 spans of 42 m over the arch of 384 m that were constructed by two Overhead MSS. Approach viaducts have spans of 45 m, 6 spans on North side and 8 spans on South side (Figure 27). Main contractor – U.T.E. Alcântara – Garrovillas (FCC Ciudadanos + Conduril S.A.).

The deck of this viaduct is a box girder type and the same section is used all along the Viaduct. The distance between pouring supports of the MSS is 45 m on the access viaducts and 40.5 m on the central viaduct decks. The construction joint of the deck is made at 1/5th of the span. The deck weight is 256 kN/m.

Piers 6 and 15 are fully solid in their upper part due to the heavy loads brought by the suspension cables of the arch that pass through the piers and the vertical reaction of the pylons during arch construction.

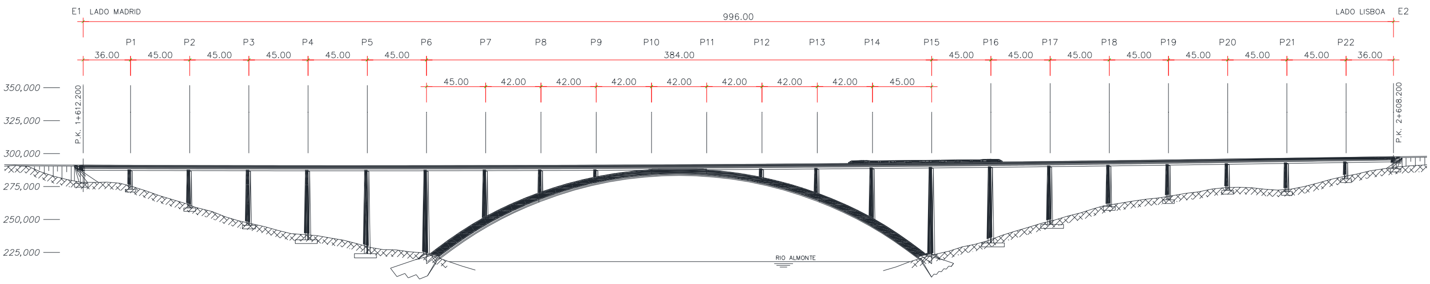


Figure27: Almonte Viaduct

2.6.2.1. Access viaducts construction

The access viaducts were built with an MSS from the abutment to the span just before the arch.

Two equal MSS were used. The formwork for the access viaducts were replaced by different formwork for the spans over the arches.

The supporting structure over piers 6 and 15 was strongly conditioned by the size of deck supports leading to the use of the complex structure shown in Figure 29.

Figure28: MSS on last span of South Access Viaduct

Figure 29: MSS supporting structure over piers before the arch

Figure 30: Almonte Viaduct – Arch construction

Figure 31: Almonte Viaduct – 2nd deck over the arch

2.6.2.2 Arch construction

The arch was built by form travellers. Pylons were placed on top of piers P6 and P15 to hold the cables that anchored the arch girder to the pylons and piers (Figure 30).

2.6.2.3 Construction of the decks over the arch

The decks over the arch were built by 2 MSS working almost simultaneously (Figure 31).

Each MSS travelled to the beginning of the decks over the arch (P6 and P15). Then they were launched for the first span on the same day.

The decks were concreted separately, one in one side, another one on the other side, to compensate the horizontal forces transferred to the arch and the consequent deformations Figure 31).

That MSS then poured the center span, reduced to 30 meters (Figure 32).

Figure 32: Almonte Viaduct – Concreting of last span

Figure 33: Almonte Viaduct – Viaduct completed

2.7. Conclusions

The overhead MSS used in the above mentioned bridges and viaducts proved the importance of some features:

1. The full autonomy of those machines allowed the construction of very high viaducts and viaducts over water without using auxiliary equipment such as: cranes, telescopic platforms, trucks, boats, etc.

2. The standardization of components of the main structure allowed to build several bridges with different spans and different deck loads using the same MSS model – AP2005

3. The list of features indicated in 2.4 above0 is characteristic of those MSS which are the base of those achievements.

4. These machines are bringing to the construction industry solutions to build multi-span bridges with great efficiency and remarkable construction speed.

5. Bridges for High Speed Trains in Spain are already being designed for spans larger than 68 m which is an important step to reduce the cost of some of those viaducts with expensive foundations or very high piers.

6. The site is cleaner by using these machines that don't spread or leave wood parts and small pieces all over the site, a very important issue in what concerns safety and environment protection when working in so well-preserved areas and natural reserves.

7. As described before, when choosing a MSS (either underslung or overhead) it is very important to consider:

    - Autonomy of the machine.
    - Reusability of the machine in future jobs.
    - Total weight of the machine and its transportation cost from site to site.

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BOWSTRING MOVABLE SCAFFOLDING SYSTEM WITH ORGANIC PRESTRESSING SYSTEM (OPS)

Magdaléna Sobotková

Figure 1: MSS in Turkey

1. Movable Scaffolding System (MSS) with OPS

1.1 Development of the MSS

The Bowstring Movable Scaffolding System with Organic Prestressing System (OPS) was developed between 2007 and 2009.

OPS, which was developed back in 1999, is a concept inspired by the behaviour of an organic structure found in nature: a muscle. It is an active control prestressing system which allows for an “optimized” prestressing, because permanent undesirable stresses are avoided and prestressing time-dependent losses are greatly reduced.

OPS permits the design of lighter and more slender structures with the same structural materials and is particularly efficient in situations with high “live load/dead load” ratio.

A very simple methodology was first developed for simply supported beams. An effective control system was achieved, where the main objective of ensuring no tensions (or even low compressions) could be generated at predefined control cross sections.

Later, after numerical simulations, it was concluded that the concept would be particularly useful for application on large bridge construction equipment – usually known as Movable Scaffolding Systems or shortly MSS.

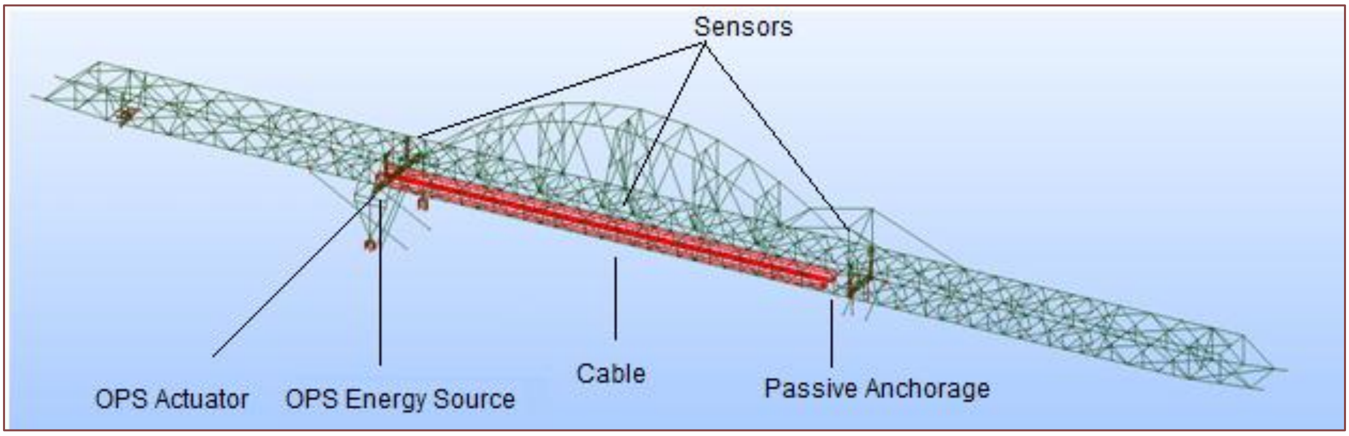


Figure 2: A typical MSS with OPS

This revolutionary invention was put into practice by BERD, a company founded in 2006 in Porto, a City of Bridges. Just over a decade has been enough time for the company to become a model and a global leader, carrying out projects worldwide and receiving various prizes and awards in the sector.

1.2 OPS Description

The OPS System is mainly formed by the following elements: the actuator in the organic anchorage, the unbonded tendons (cables – Figure 3), and electronic circuit.

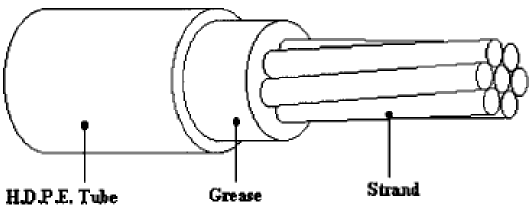
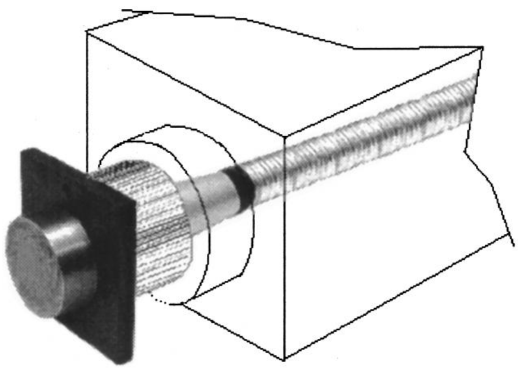


Figure 3: Unbonded Tendon

Organic anchorages (see Figures 3 and 4) are anchorages with servo-hydraulic systems incorporated. That means that the hydraulic jacks permanently stand between the anchorage and the structure and became structural elements themselves. The electronic circuit includes sensors, electric cables and electronic components (controllers), similarly to common active control circuits.

The prestressing cables are actively controlled and stressed progressively in the concrete-pouring stage when the structure is loaded with the weight of the deck fresh concrete to reduce deformation and minimise stresses.

During the MSS launching stage (in which the MSS is self-launched from the previously constructed span to the next concrete pouring position), the cables are not active and the MSS acts like a steel truss with variable section.



← ↑Figures 4 and 5: Organic Anchorage

The OPS solution leads to minimal compression values but it is necessary to pay attention to fatigue damage in organic cables, fretting fatigue, deformations and vibrations.

The prestressing losses are greatly reduced because in OPS the permanent prestressing forces are of a small value. Other losses can be partially compensated by increasing the stressing values on the OPS cables.

Deformation in the central part of the MSS is measured with sensors installed in strategic points of the structure. The information from them is transmitted and processed according to the control algorithm to maintain or change the intensity of prestressing.

The system also comprises safety measures such as monitoring and alarm warnings. Structures with OPS are designed for accidental limit states which comprise system breakdown so, in case of malfunction of the OPS, the structure remains safe.

Due to the improved waste management and adaptive strength of the intelligent OPS system, critical savings are generated by allowing for faster construction cycles, the creation of significantly lighter and safer structures, and a reduction in the consumption of steel, energy, fuel, and consequently, CO_2 emissions.

1.3 Further Development of the System

In its early days, BERD anticipated that, in the near future, lighter structures enabled by the intelligent OPS system would make it possible to work with spans of up to 100 metres, thereby expanding construction with Movable Scaffolding Systems to a dimension never seen before.

This is what is currently happening in Turkey where MSS M1-90-S is used for construction of high-speed railway viaducts. It allows to extend the maximum span of 70 metres of its predecessors to 90 metres in multi-span bridges.

1.4 MSS General Description

1.4.1 Main Truss

The most important structural element of the MSS is the main truss. It holds the beams that support the transverse structures where the formwork is placed. It is constituted by the front nose, the main body with the arch, and the rear nose.

During the concrete-pouring stage, when the load achieves its maximum value, the main girder is supported by two elevation hydraulic cylinders per supporting section: on the deck concreting frame (the girder rear support) and on the pier frame (the girder front support).

During the launching stage, the main girder is fully supported by the rollers on the bogies (Figure 8) that are assembled over the pier frames. They transmit both vertical and horizontal loads to pier segments which are properly connected to the pier.

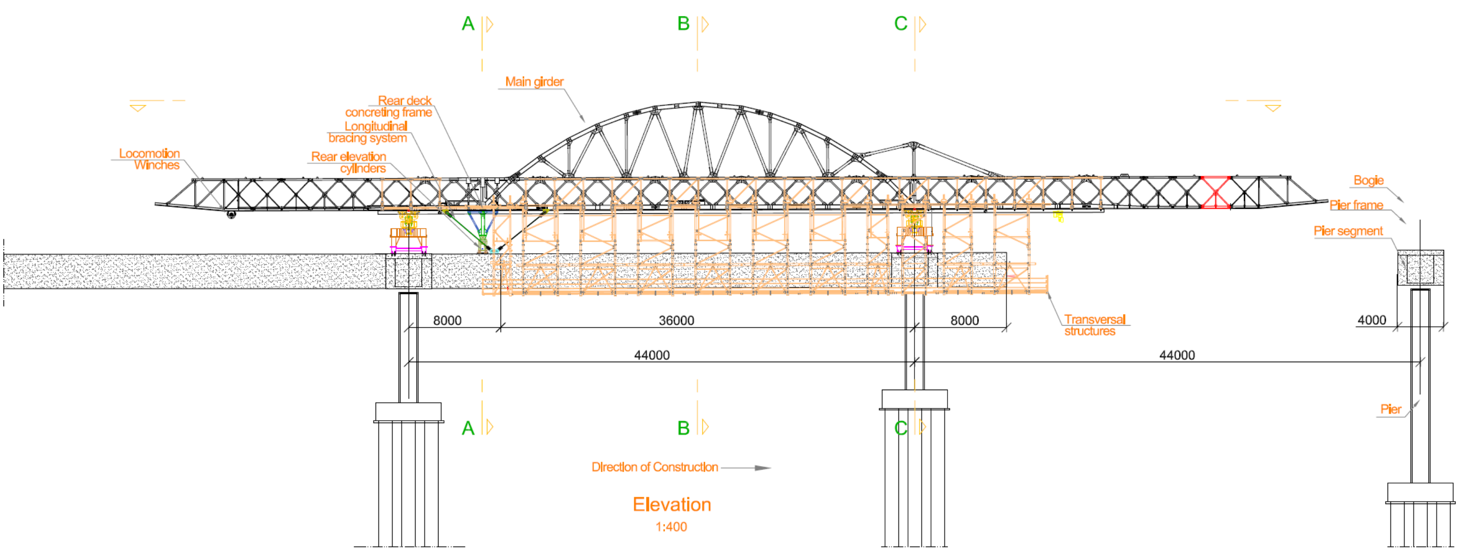


Figure 6: MSS M45-S Elevation

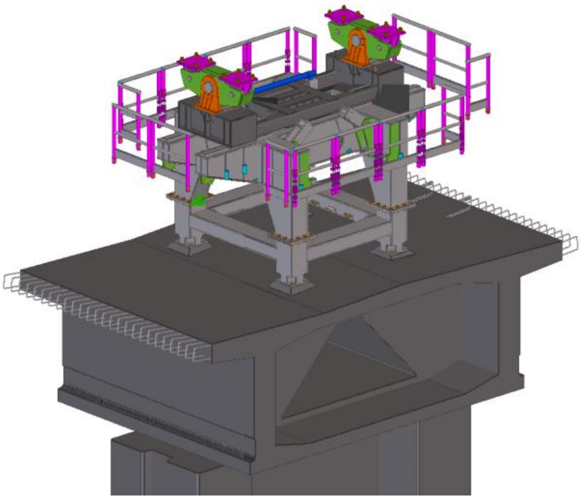


Figure 7: Pier Frame with Bogies

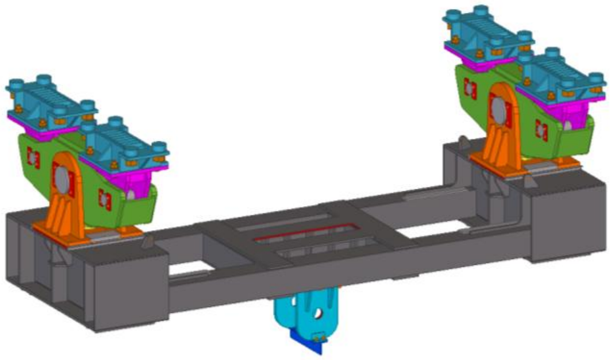


Figure 8: Bogies – each bogie contains two lines of support for the two rails in each inferior chord of the girder

1.4.2 Formwork

Generally, the formwork is made of plywood and timber beams. It is assembled onto the inferior part of transverse structures - steel trusses, which are suspended from transverse support beams on the level of the main girder.

All formwork panels are adjustable to the deck geometry. The formwork panels are opened and closed by rotation of the inferior metallic structure and consequently the formwork.

Each formwork panel has normally 8 suspension rods (2 in each of the 4 longitudinal alignments, half exterior to the deck webs and half interior to the deck webs). The panel that surrounds the pier is usually different.

Each exterior rod is composed of two sections that are connected at mid-height during concreting and are disconnected when formwork and inferior part rotate for the launching stage. Interior rods have 3 parts and the middle one is disassembled during the launching stage and transported individually.

1.4.3 Transverse Structures

The superior part of the transverse structures is constituted by transverse vertical trusses (which are connected to the main girder) and a horizontal diaphragm joining adjacent vertical trusses that works like a platform. On the front part there is a system for rotation to accomplish the plan curvature of the bridge. The rotation is performed by means of two hydraulic jacks in each half of the transverse structures.

Lateral parts hang from the superior part and they are connected to the inferior part. They have several adjusting devices that allow changing the formwork position.

Inferior parts constitute a "ground" for the formwork. During concreting phase they are also supported by suspension bars (rods). Between the inferior parts and the formwork there are power screws and a grillage structure that allow for changing the longitudinal slope of the formwork.

The MSS is provided with locomotion winches and various hoists (central, lateral etc.) for material transportation.

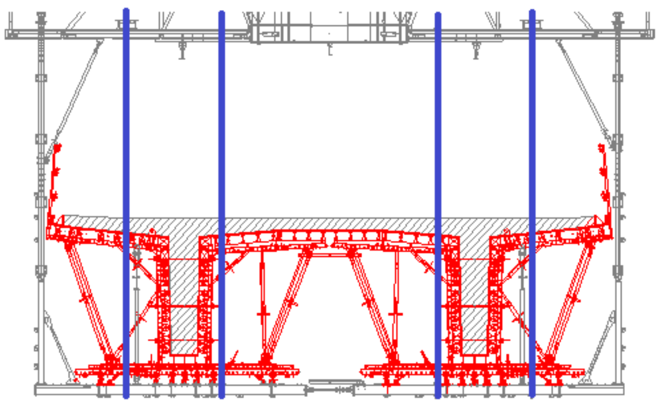


Figure 9: Formwork (red) with suspension rods (blue)

Figure 10: Opatovický Kanál

Figure 11: Sokolov – Tisová Viaduct

2. Projects

2.1 MSS M45-S, Slovak Republic

The MSS M45-S was developed for the construction of a motorway viaduct between Sokolov and Tisová and for a bridge across Opatovický Kanál, both in the Czech Republic, and again later for the construction of viaducts between Poprad and Prešov in the Slovak Republic. In 2017 it was also used for a motorway viaduct on the D3 highway between Strážov and Brodno in the Slovak Republic.

2.1.1 Description of the MSS

It is an overhead MSS with an organic prestressing system (OPS) for spans of max. 45m and max. deck width of 14m. It comprises a steel truss with a top arch. Typical performance cycle is 10 days.

Formwork for this project was modified in cooperation with its supplier due to the proximity of the decks and the radius of curvature on plan (low and variable).

The construction period was 48 weeks. The MSS allowed the client its reuse.

2.1.2 Bridge across the River Váh's Reservoir Hričov, section Žilina-Strážov - Brodno, Slovakia

The bridge is part of the D3 motorway project near the city of Žilina. The twin bridge with a total length of 1.5km is formed by a continuous structure of span lengths from 30.5 to 110m. The left viaduct has 9 spans of 44m. The right viaduct has 8 spans of 44m, 1 span of 38.3m and 1 span of 27m.

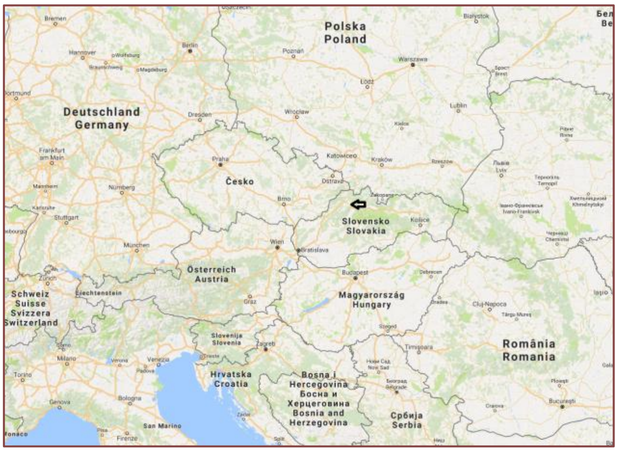


Figure 12: Location of the bridge
Source: Google Maps

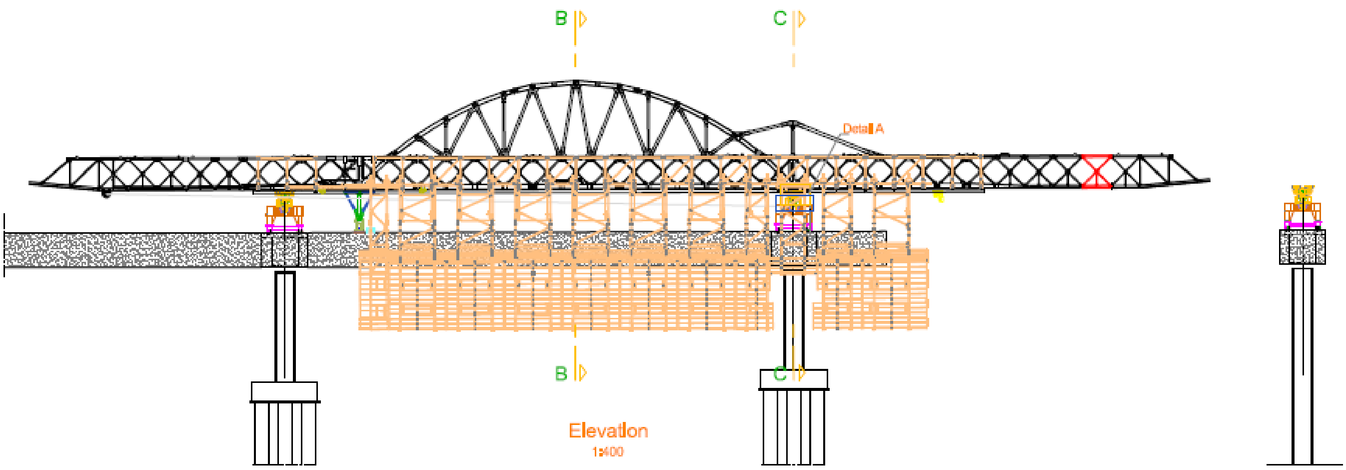


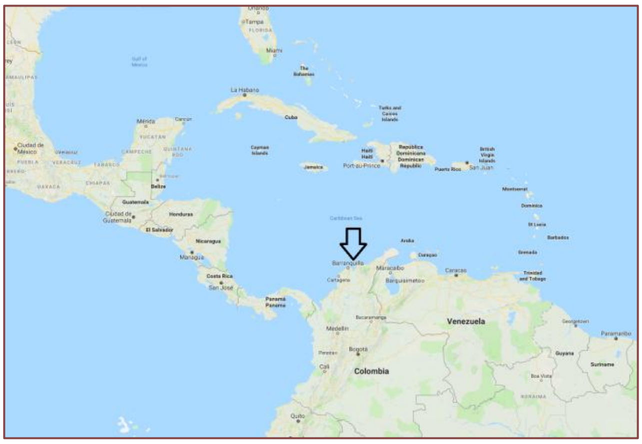
Figure 13: The MSS is ready for launching

Figure 14: MSS M45-S used for a bridge construction, Motorway between Strážov and Brodno, Slovakia. Photo Credit: Peter Paulik, Slovak Technical University

The central spans bridging the River Váh are formed by a box girder of a variable depth, from 3 to 6m, which were segmentally cast in symmetrical cantilevers. The remaining spans have a double tee cross section of a constant depth of 3m. These spans were cast span-by-span on stationary or movable scaffolding.

Client: Národná diaľničná spoločnosť, a. s. (National Motorway Company), Slovakia

Alternative and detailed designs were provided by the company SHP (Stráský, Hustý and Partners). Contractor: Consortium Diaľnica D3 Žilina (Strážov) – Žilina (Brodno), EUROVIA SK-HOCHTIEF CZ-SMS



Figures 15 and 16: Location of the bridge on the map
Source: Google Maps

2.2 Pumarejo Bridge, Barranquilla - Santa Marta, Colombia

The Pumarejo Bridge will provide a comprehensive solution for crossing the Magdalena River in Barranquilla, enabling large vessels to pass as well as increasing user convenience and improving traffic conditions, particularly that of heavy vehicles travelling in both directions. The bridge will also further increase the safety and the level of service provided to users of this busy road.

It will be the country's longest bridge (2,250m) and the biggest public work project carried out in Colombia. The cable-stayed bridge will span 380m between the 132m high pylons. The deck will be 38.2m wide in the cable-stayed section and 35.1m wide in the access sections. The deck will have three lanes as well as a pedestrian area (2m) and bike path (1.5m) on both sides. The clearance for the passage of vessels will be 45m.

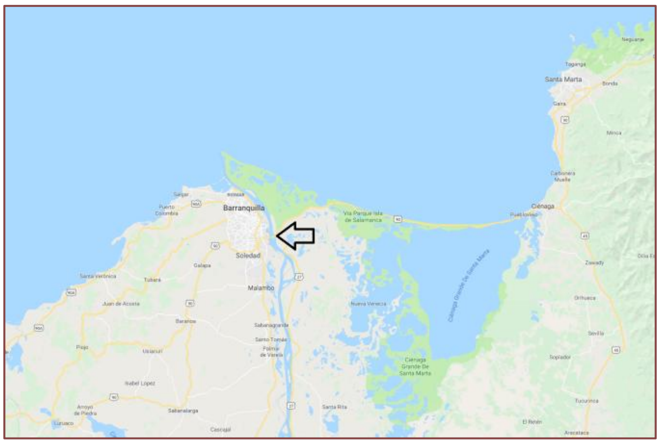


Figure 17: Rendering of the bridge Source: SACYR

The viaducts are 990m long and comprise 17 spans. A typical span is 70m long.

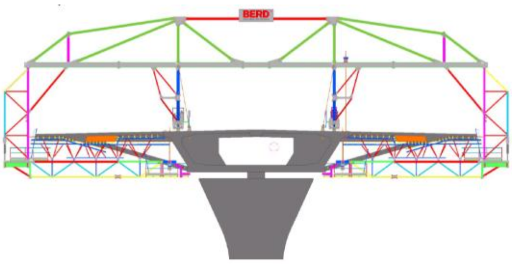


Figure 18: Completed Section

As the bridge deck is very large (38.2m), two equipments will be working on this project: the Overhead MSS M1-70-S, constructing 70m long and 16m wide spans, and auxiliary cantilever machines that build the remaining width of 22.2m (11.1m on each side).

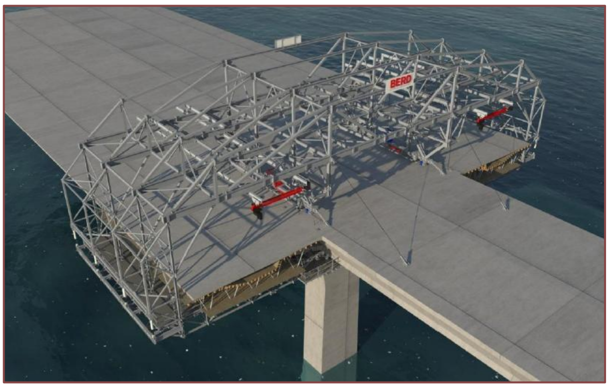


Figure 19: Cantilever Machine

The cantilever machines will execute 15m long segments. The MSS is expected to perform 14-day cycle for each span.

As the construction is across the water, the equipment is fully autonomous. The material is supplied on the previously built deck.

Client: Colombia's National Roads Institute (INVIAS - Instituto Nacional de Vías)

Contractor: SES Puente Magdalena consortium (formed by Sacyr Construcción Colombia SAS, Sacyr Chile and Esgamo Ingenieros Constructores).

2.3 MSS M1-90-S, Turkey

Part of four high-speed railway viaducts with a total length of 6,151m is now being built by two MSS: M1-90-S = 4,454m (with typical span 90m) and M55-S = 1,697m (with typical span 45m). The deck with a typical box cross section is 12.7m wide.

Of the 13 viaducts required for the section of railway between Ankara (Kayas) and Kirikkale Arasi, 4 of them are being erected by unique and groundbreaking equipment that represents revolutionary and critical advancement in the field of bridge engineering - M1-90-S. But what exactly is it that makes the M1-90-S so special?

2.3.1 Operation of the MSS

The way in which this model functions is similar to what we have seen in BERD’s predecessor MSS models, but at a larger scale.

In order for the MSS to advance, the launching to the next span begins with the lowering of the entire machine. This movement allows to release the formwork from the recently constructed deck. Once this movement is completed the suspension bars are disassembled and the formwork tables slide apart, creating the necessary free space to cross the pier. During the forward movement of the MSS a set of 3 support frames are strategically positioned, ensuring that the machine is secured during the whole movement.

The movement of the machine is performed with a set of 4 winches that are radio controlled - the display shows the force developed by each winch as well as other relevant information about the system.

This ensures higher levels of safety during launching operations. After the first 30m launching the front nose of the overhead MSS reaches the next free pier. At this position the supporting frames are repositioned with the overhead cranes integrated in the MSS. This feature makes this equipment fully autonomous with no need for external cranes to assemble its supports. During these operations two plane trusses positioned at each end of the main girder play an essential role in order to guarantee the stability of the machine. Once the support frames are repositioned, the MSS is able to perform the final 60m launching.

As soon as the launching operation is completed, the entire machine is elevated using hydraulic cylinders, the formwork tables are closed and the suspension bars assembled. With these steps finalised, the MSS is ready to start the construction of a new span.

The construction of the new span starts with the positioning of preassembled steel reinforcement cages over the formwork. Once again the overhead cranes play an essential role, enabling lifting, transportation and positioning of these heavy loads.

The post-tension steel strands are assembled inside the ducts that were previously and accurately positioned inside the steel cages. Before the concrete operation starts, it is still necessary to assemble the internal formwork panels that will give the desired shape to the deck section.

The concrete pouring of the deck is divided in two stages. In the first stage the bottom slab and webs are poured creating a U section. In this operation 690m^3 of fresh concrete is poured over the formwork. The concrete is transported from the concrete plant to the back of the MSS in concrete mixer trucks. The trucks deliver the concrete into static pumps that are responsible for pumping the concrete through metallic tubes to the concrete distributors. There are 3 distributors strategically placed over the formwork in order to reach the full length of the deck. During the concrete pouring operations, the OPS is continuously monitoring and actively controlling the structure. According to the load applied to the structure, the OPS automatically adjusts the tension of the MSS prestressing cables, which reduces deflection and minimises tension. Once the 1st stage of the concreting operation is finished and the concrete has hardened, the internal formwork panels are dismantled and the top slab formwork is put into position. Then, the top slab reinforcement steel is assembled and the system is ready for the 2nd concrete pouring stage, in which 460m^3 of concrete are cast. Once this operation is finished the entire section of the deck is completed.

When the concrete becomes hard enough the post tensioning cables installed inside the concrete are tensioned, which gives the necessary strength to the deck. Once more, during post tensioning the OPS is monitoring the structure and releasing the tension in its prestressing cables while the weight of the deck is being gradually self-sustained.

Post tensioning operation marks the end of the span construction, meaning that a new cycle is ready to begin.

The M1-90-S was conceived to achieve construction cycles (i. e. one span) of 14 days.

The Client: Yuksel Kappa

3. Conclusion

The first application of the OPS system has defined a new era in the field of bridge construction. Its innovative technology has enabled reaching new limits of optimized dimensions, allowing for higher quality construction with better control and savings both in time and costs.

References:

PACHECO, Pedro – FONSECA, António: Organic Prestressing. Journal of Structural Engineering. March 2002. DOI: 10.1061/(ASCE)0733-9445(2002) 128:3(400)

PACHECO, Pedro: Multi-span large decks – the organic prestressing impact. Taylor & Francis Group, London, 2015. Pp 103 – 124. ISBN 978-1-138-02757-2

Construction Manuals, drawings and other information provided by BERD

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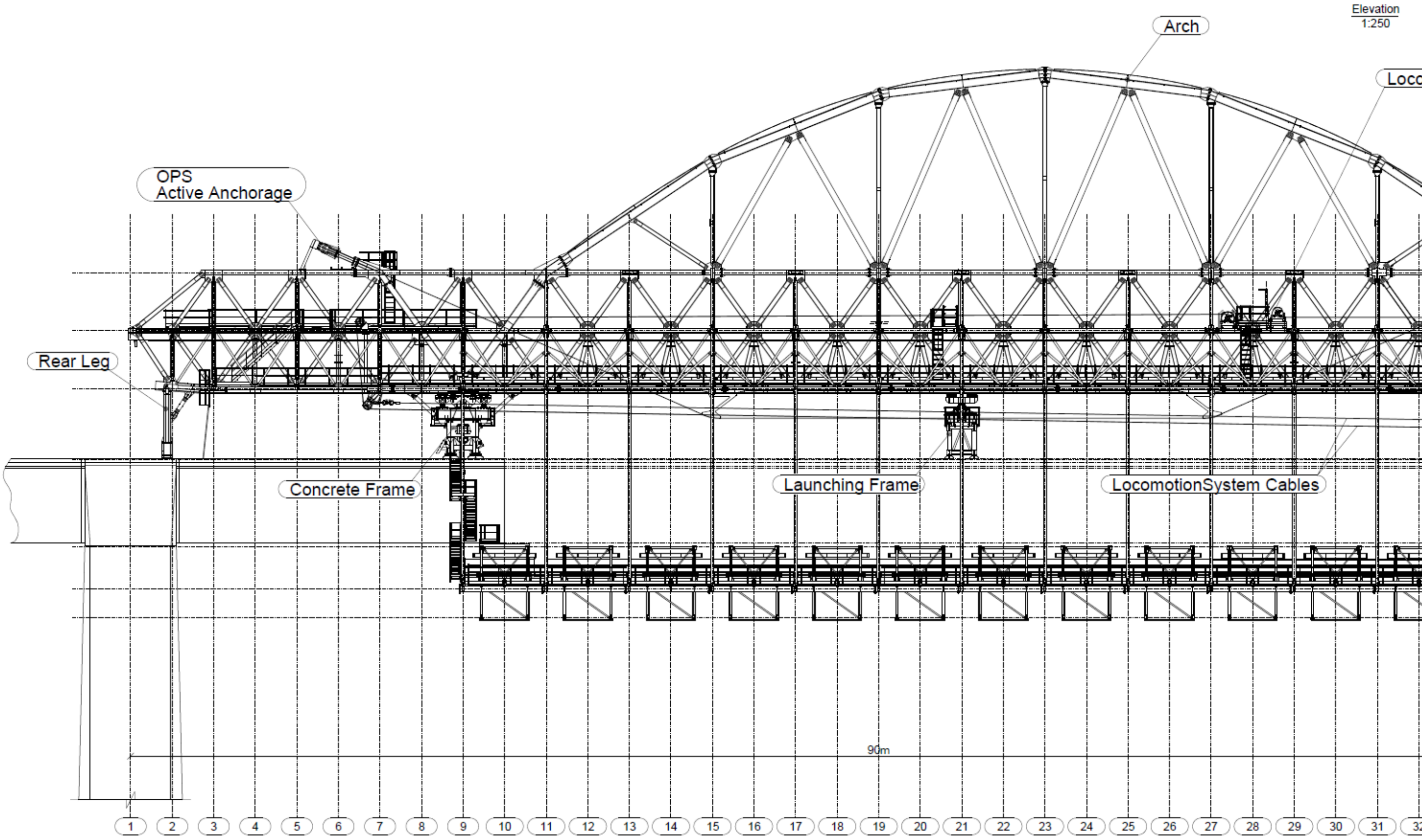
André Resende, Project Manager, BERD
Brigitte Rouquet, Marketing Director, BERD

MSS M1-90-S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Concrete Frame
Launching Frame
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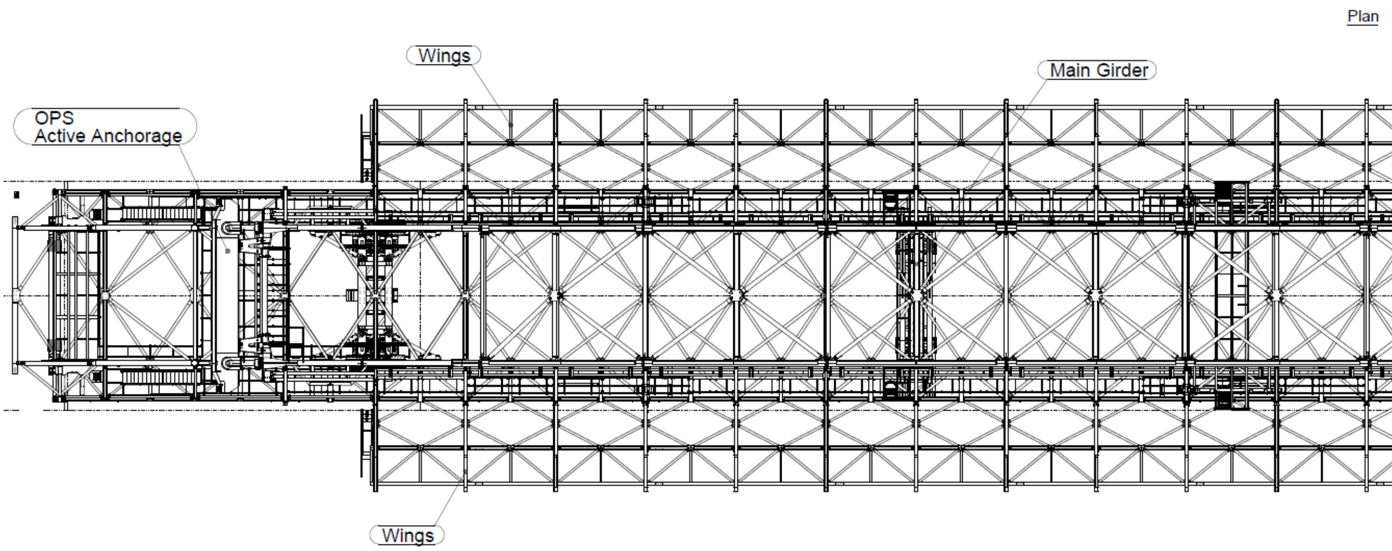
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Main Girder
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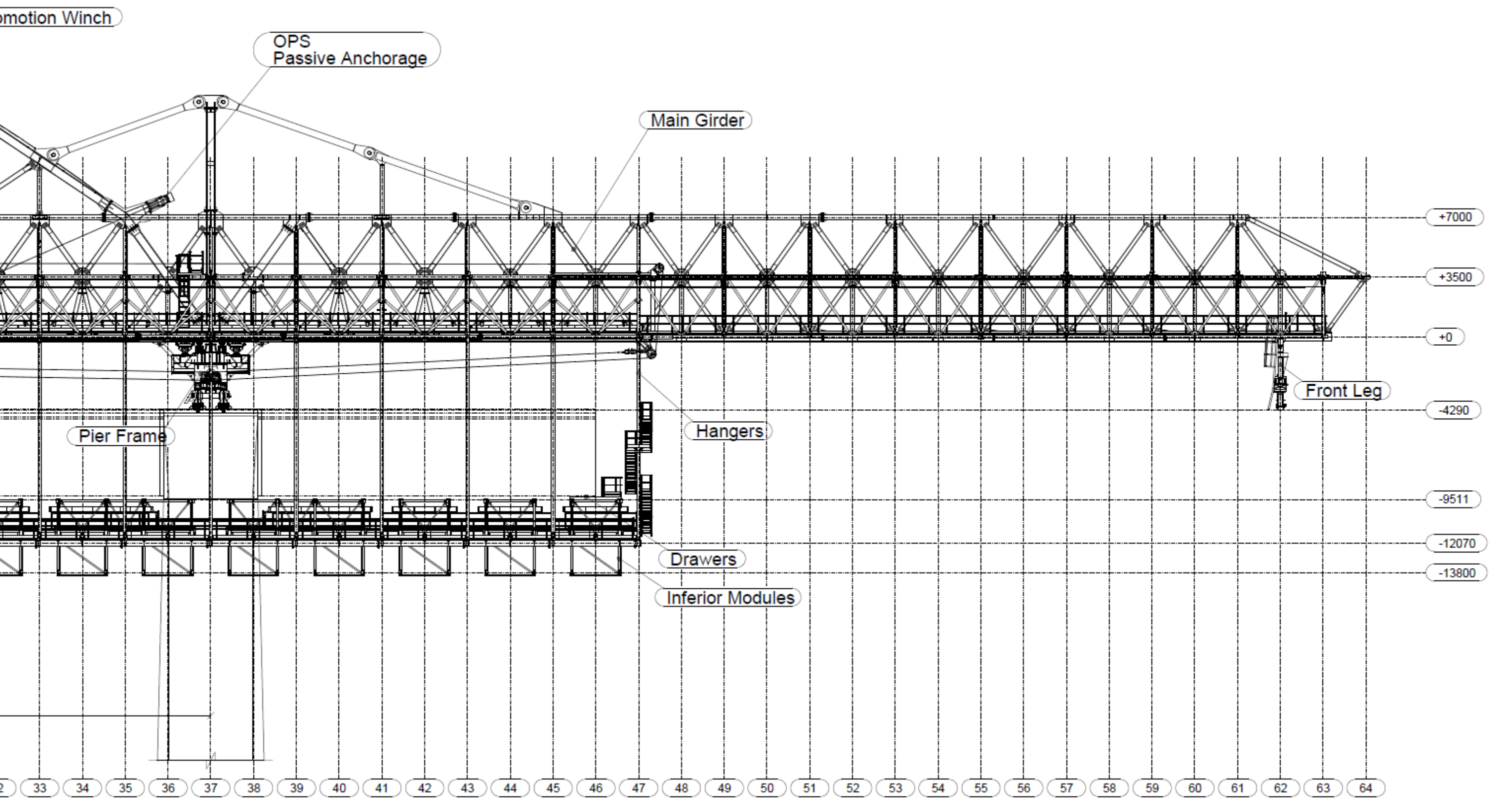
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Front Leg
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Pier Frame
Hangers
-9511
-12070
Drawers
-13800
Inferior Modules
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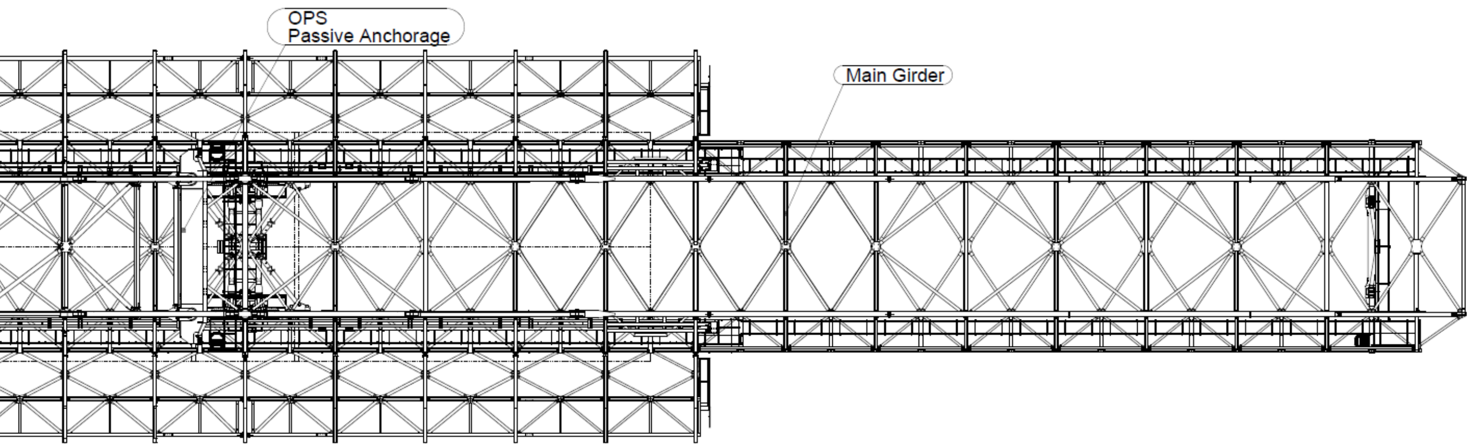
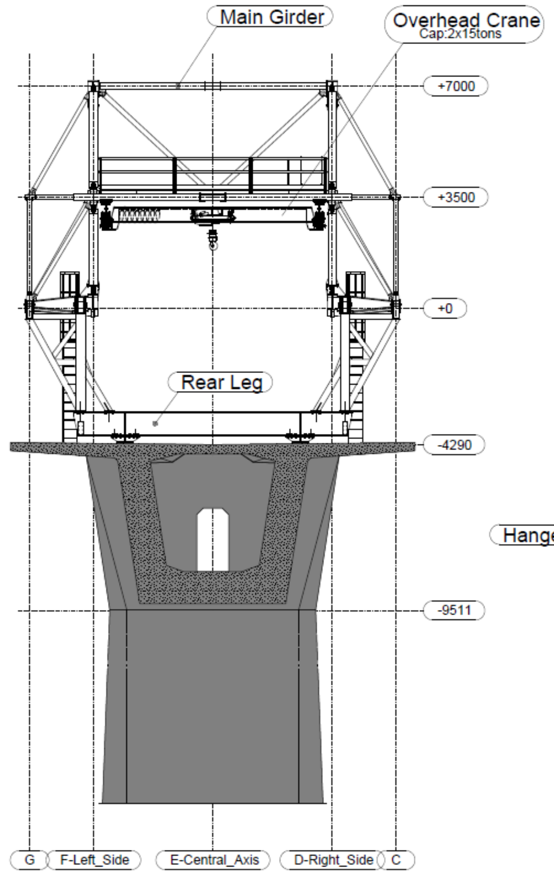
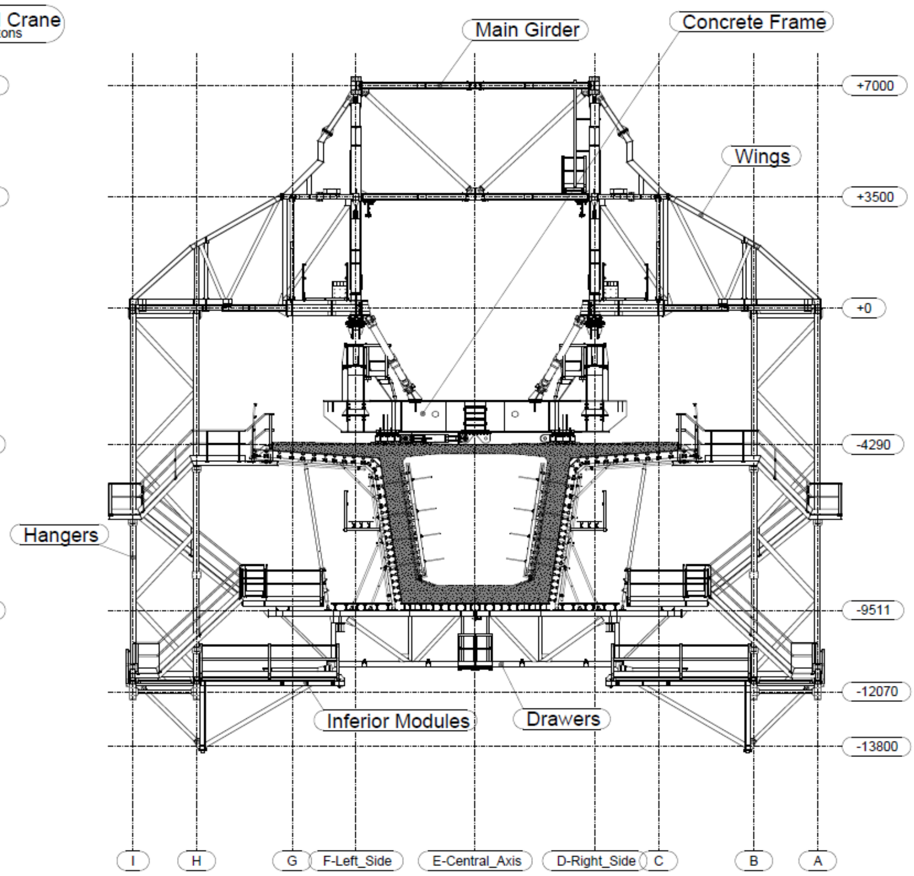

OPS
Passive Anchorage
Main Girder

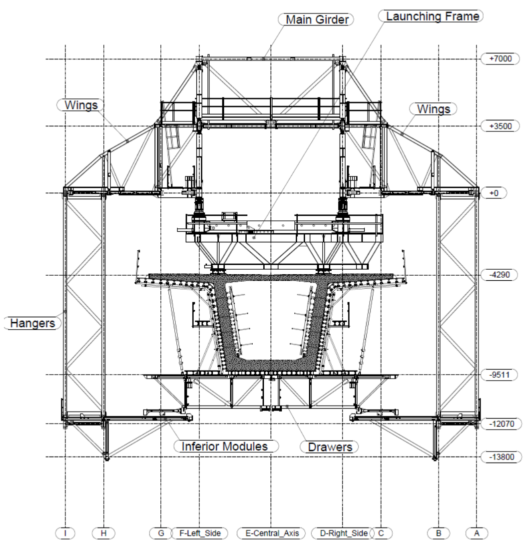
Rear Leg
Aligment 2



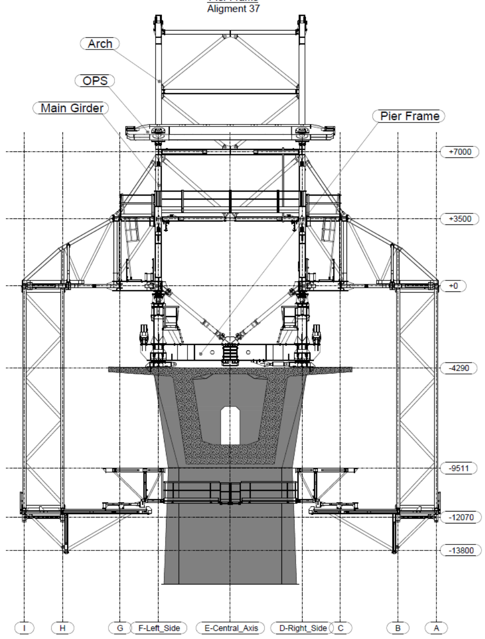
Deck Concrete Frame
Aligment 9



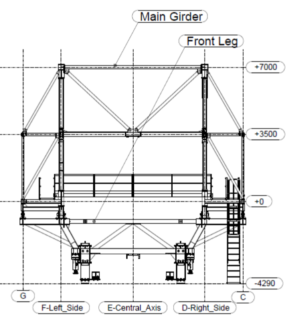
Launching Frame
Aligment 21



Pier Frame
Aligment 37



Front Leg
Aligment 62



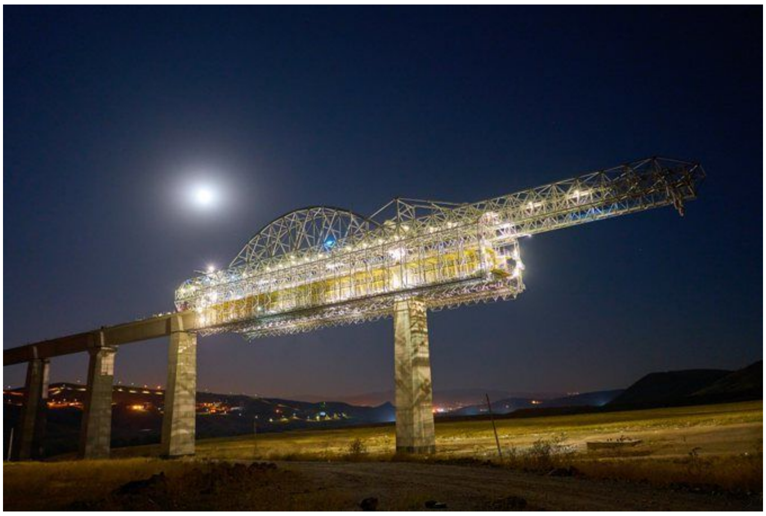
MSS M45-S Strážov - Brodno, Slovak Republic




MSS M70-S Pumarejo Bridge, Colombia

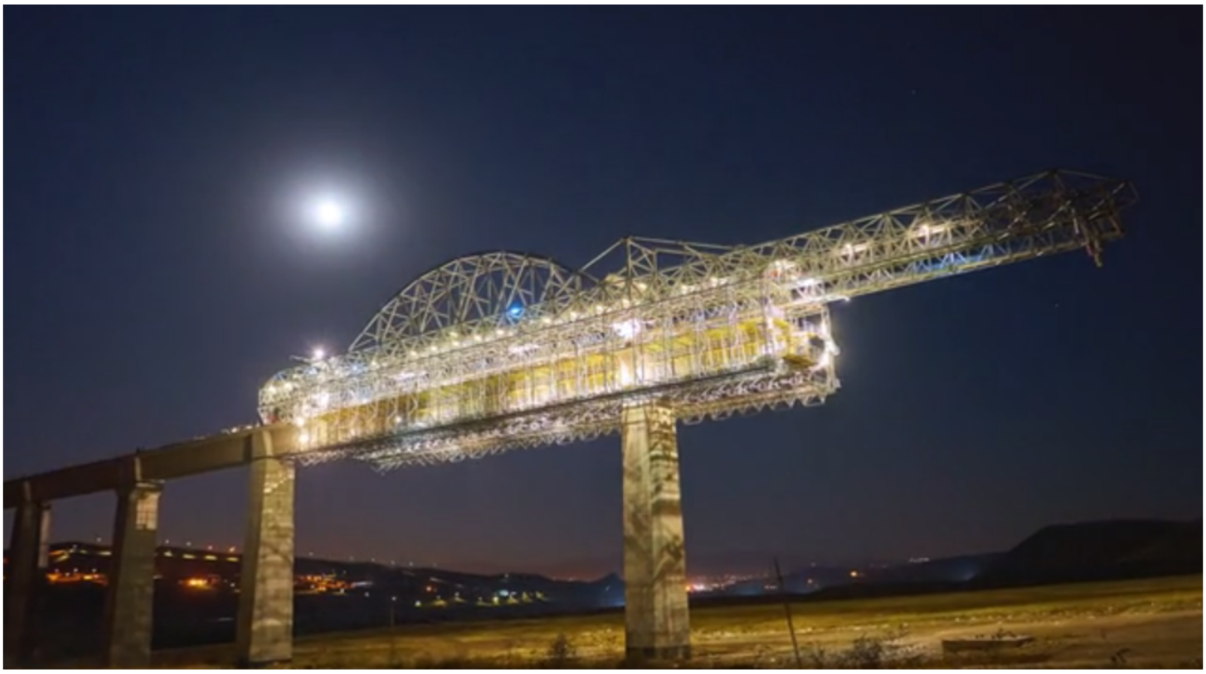



MSS M1-90S, Turkey



VIDEOS - Click on the picture

Launching the MSS in Turkey



MSS in Turkey - Movie Trailer

A Movable Scaffolding System for the Vistula River in Warsaw

Aquilino Raimundo, Strukturas as

Figure 1: OHMSS General view

I. Introduction

The Vistula River, which extends over 1000 km, is one of the few major European rivers that is not completely regulated, thus preserving its wild nature. As it passes through Warsaw, the waters of the Vistula River vary in depth by as much as 8 meters, varying from a mere 0.5 meters deep to 8.5 meters during the flood season. With a width of almost 1.5 km when the water level is at its highest, the Vistula is a serious obstacle to building bridges and viaducts over its channel during the flood season.

The development of solutions for equipment used to build the bridge decks under such conditions led to identifying a broad range of technical requirements that were specifically considered during the Movable Scaffolding System (MSS) design phase.

II. General Project Description

Construction of the S2 Expressway is one of the most significant investments underway in Warsaw, completing the outer ring of the city and improving the citizens' mobility.

The new Vistula crossing integrated into the S2 Expressway and consists of two parallel decks with the following lengths:

- Central bridge MG04-02 measuring 536.5 m per deck;
- MG04-01 and MG04-03 access viaducts with a total of 970 m per deck.

→ *Figure 2: Location of the bridge on the map*
Source: Google maps

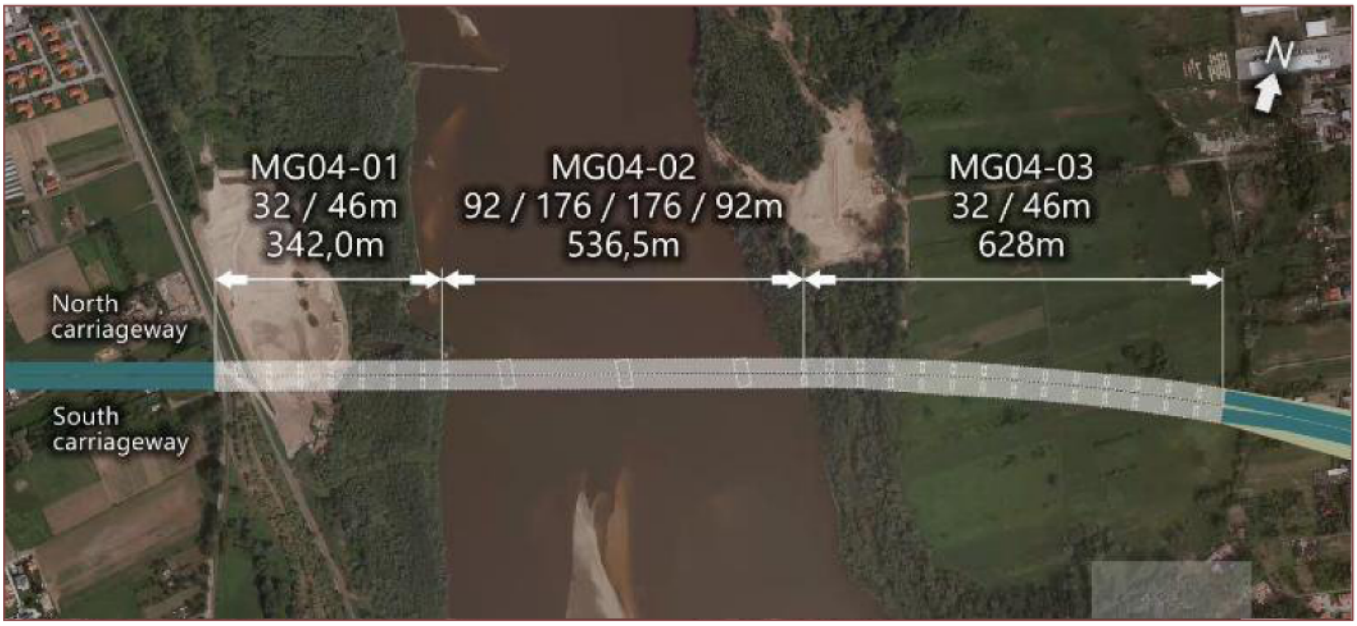


Figure 3: Vistula Bridge general plan view

III. Main requirements of the equipment used to build the decks

Taking into account the conditions of the location of the crossing, the type of structural solution for the deck and the organization of the intended work cycle, the solution that was deemed most advantageous was the one that integrated the Overhead Movable Scaffolding System (OHMSS) combined with a Wing Formtraveller (WFT) for onsite concreting of the decks of the access viaducts.

The OHMSS is used for concreting the central deck box and the WFT used to install the pre-fabricated struts and concrete the wings.

The broad range of technical requirements used during the design and dimensioning phases of the OHMSS included the following features:

- the outer formwork of the OHMSS must be possible to open when free distance to the ground is only 3.0m;
- the outer formwork must be able to pass in the closed position over the existing railway without reaching a height of more than 0.7 m (see Figure 3);

Figure 3: OHMSS opened external formwork

- the rebar U-cages (bottom slab and webs) of the deck must allow for assembly in 12 m sections and in the final position using the transport devices that equip the OHMSS;
- the sections of the rebar U-cages of the deck must allow for lifting from ground level or as an alternative, be transported over the deck that has already been built and later moved through the inside of the OHMSS main structure through its rear support;
- the deck shall be concreted in two phases, the first phase involving the concreting of the central box using the OHMSS, the second phase involving the installation of the pre-fabricated struts of the deck wings and the concreting of the wings itself using the WFT;
- allow for the OHMSS to move backward to the abutment and proceed with a side-shift to the alignment of the second deck parallel to the first one;
- allow for the passing of the OHMSS through the WFT, after dismantling the OHMSS external formwork and without needing to dismantle the WFT (only its 4 legs are dismantled);
- allow for the forward movement of the OHMSS passing over the deck of the central bridge to the opposite shore of the Vistula River.

Figure 4: OHMSS lifting rebar U-cage from ground

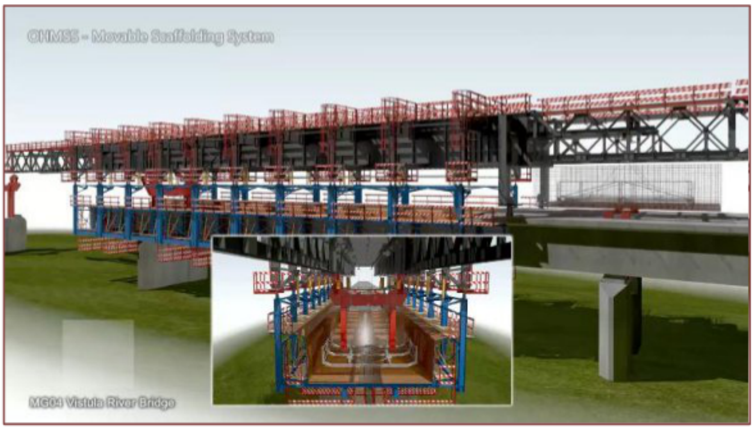


Figure 5: OHMSS rebar U-cage feeding from the deck

IV. General description of the OHMSS

The OHMSS consists of two main symmetric girders with an 'I' section, forming the main part that supports the weight of the deck during the concreting, equipped with sliding rails that allow the OHMSS to slide over the Teflon plates of the main supports mounted on the pillars.

The main girders are also equipped with one pushing rail each that is linked to the launching cylinder mounted on the launching wagons, responsible for moving the OHMSS forward and backward.

Cross-sectionally, the two main girders are linked by transverse beams spaced at regular intervals. The central part of the transverse beams supports the tension bars used during concreting, while the external parts support the external formwork and the hydraulic system that opens and closes this formwork.

The noses are connected to the front and rear extremities of the main girders, equipped with an adjustment system vertically and horizontally, allowing the OHMSS to be used on decks that combine vertical curves with horizontal curves throughout its development.

The OHMSS also includes the pier supports that are responsible for transferring the reactions to the pillars, the launching wagons that are part of the forward, backward and braking systems of the OHMSS, and the rear support positioned at the back of the OHMSS is responsible for transferring the reactions to the webs of the deck at their extremity.

The design of the rear support allows pre-fabricated rebar cages to be delivered to the rear of the OHMSS along the previously constructed deck.

The internal formwork system, internal formwork rolling wagon used in the transport and positioning of the panels of the internal formwork and the external formwork system complete the basic solution of the OHMSS (see Figures 6 and 7 below).

In addition to this basic solution, the OHMSS was also equipped with transverse launching system used during OHMSS side shift, the longitudinal launching support used during OHMSS back launching and OHMSS launching across the central bridge, the rebar handling winches provided to handling the rebar preassembled U-cages and other materials and the rebar cage support frame.

The OHMSS is equipped with various hydraulic systems that allows for all the necessary adjustments.

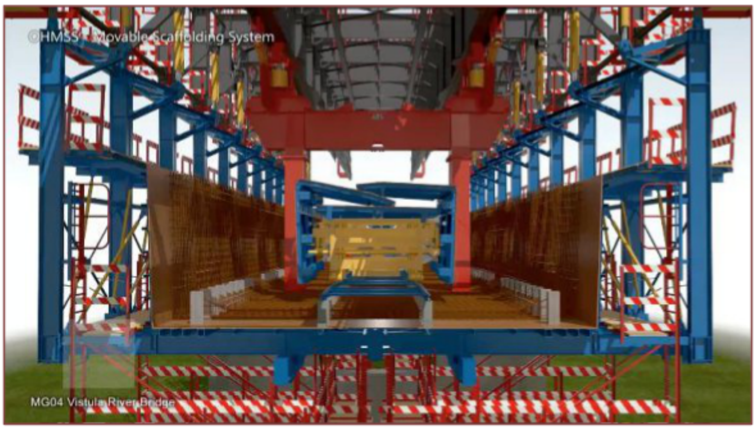


Figure 6: OHMSS internal formwork transport

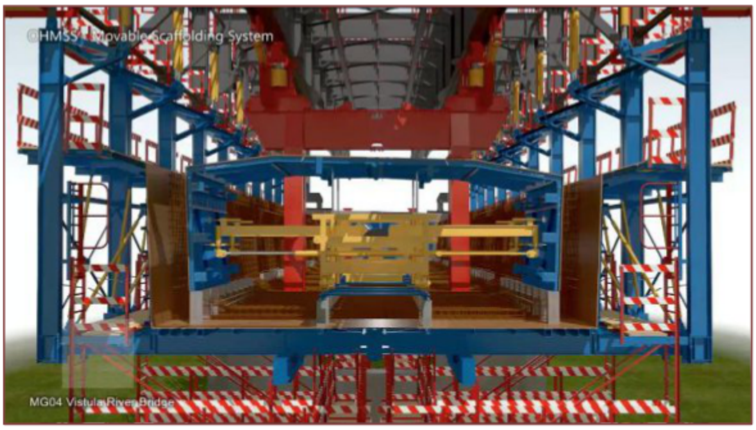


Figure 7: OHMSS internal formwork installation

V. Typical OHMSS Cycle Operations

The typical operations of the OHMSS generally include the following phases:

Phase 1: Lowering the MSS

On the days that follow concreting and before applying the post-tensioning, the pier support pillar is mounted on the front pillar. During this phase, the web formwork tie bars that connect the external formwork to the internal formwork are also dismantled. The formwork of the top end of the deck is dismantled during this phase.

When the concrete reaches the necessary resistance capacity, the post-tensioning is applied. The hydraulic system that opens and closes the external formwork can now be pressurized, the external formwork tension bars dismantled and the OHMSS lowered using the main jacks.

Finally, the external formwork can be opened to pass through the exterior of the pillars during the forward movement of the OHMSS without any collision.

Phase 2: Launch the OHMSS forwards to next span

With the OHMSS supported on the Teflon plates of the launching wagons and the hydraulic cylinders connected to the main girders, the OHMSS can now move forward.

Phase 3: Reinforcement, External formwork and Raising of OHMSS

Once the forward movement of the OHMSS to the next span has ended, the OHMSS is raised to its concreting position. If the decision is made to raise the U-cages from the ground level, that operation is performed during this phase before closing the external formwork.

The rebar U-cages are then suspended and the external formwork is closed, cleaned and adjusted. Finally, the rebar U-cages are lowered to the external formwork.

If the decision is made to transport the rebar U-cages on the already built deck and pass them through the two halves of the main structure of the OHMSS, then the external formwork shall be closed first, then cleaned and adjusted, and only then will it be transported and positioned within the external formwork of the rebar U-cages.

The cambering can be adjusted during this phase.

To allow the U-cages to, in this case, pass through the main support mounted on the rear pillar, the upper part of this main support and the launching wagons must be dismantled, while the four legs remain anchored at the top of the pillar.

Once the mounting of the rebar U-cages has been completed, the upper part of the main rear support is once again mounted, along with the launching wagons. This mounting operation can be performed on the days that follow the concreting of the deck and thus not interfere with the cycle.

Phase 4: Internal formwork, slab reinforcement, concreting

Once the mounting of the rebar U-cages has finally been completed on the whole deck, the internal formwork is repositioned using the respective hydraulic operated transport rolling wagon.

During the operation of the repositioning of the internal formwork the external formwork tension bars are not installed to keep the way clear for the rolling wagon to move with the internal formwork panels folded on top of it.

When the first internal formwork panel is positioned on the next span and connected to the external formwork via the tie bars, the top slab rebar assembling is initiated.

The external formwork tension bars are now mounted, the hydraulic system for opening and closing the external formwork is depressurized and concreting is performed.

Figure 8 on the following page shows the OHMSS casted span.

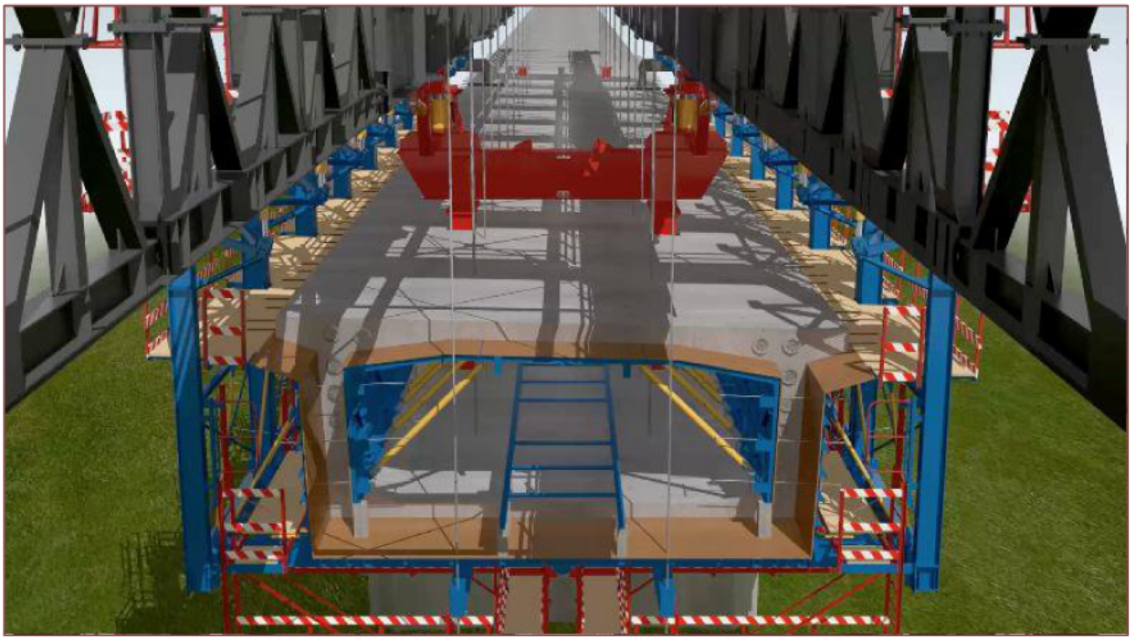


Figure 9: OHMSS casted span

VI. General description of the WFT

Generally speaking, the WFT is made up of an upper structure supported by the deck top slab, from where the formwork of the deck wings is suspended. The opening and closing of this formwork is performed by a hydraulic system included in the WFT. The WFT also includes a hydraulic system for moving forward and a device for transporting and mounting the precast struts, see Figure 10.

The WFT is prepared to remain suspended from the deck when its four legs are dismantled, thus allowing the OHMSS to pass inside of it during the phase of moving backward to the abutment.

VII. Operation and Safety System

The OHMSS is equipped with a full set of working platforms and ladders ensuring access to all locations where routine adjustment for operation needs to be performed. The OHMSS launching device includes a mechanical braking system which always keeps the OHMSS connected to the main support during launching and cylinder piston retracting operation. In addition the OHMSS launching is made on top of Teflon pads located inside the launching wagons instead of using wheels, meaning that existing friction is sufficient to keep the OHMSS stable.

All hydraulic systems like main support cylinders, external formwork folding system and rebar transport electrical winches are equipped with the necessary safety devices.

VIII. Conclusion

The combined OHMSS and WFT solution for the Vistula project, incorporating the necessary functional features in the development of the solution taking into account the constraints of the project, led to a competitive solution that resulted in the improvement by the contractor of the initially planned incremental launching process for onsite concreting.

To keep to the construction programme the use of this hydraulically operated internal formwork transport system and the pre-assembly of rebar U-cages in 12m elements will allow a weekly cycle for construction of each deck.

Figure 10: WFT general view

Lifting of the Main Girders

FORMWORK TRAVELLERS FOR THE ATLANTIC BRIDGE

Paula Rinaudo

Rubrica - Special Projects Coordinator - Ph.D. Civil Engineer

Figure 1: Overall View of the Bridge Construction

The concrete cable-stayed bridge with the longest span in the world

The Atlantic bridge project is located over the Panama Canal near the Gatun locks, which are close to Colon city. The four-lane-road bridge will provide an uninterrupted connection between the east and west side of the province of Colon. It will allow passage of the largest container ships (Post-Panamax), in accordance with the canal expansion programme. It will also allow vehicles to cross the Panama Canal on the Atlantic side, whether or not the locks are in operation.

The cable-stayed concrete bridge has a central span of 530 m and a total length of 1050 m. It will be the longest cable stay concrete bridge worldwide. It has two pylons with a height of 212,5m and a vertical clearance over the canal of 75m.

The owner is the Panama Canal Authority and it is being constructed by Vinci Construction Grands Projects.

Figure 2 + 3: Location of the bridge on the map

To avoid disrupting canal traffic, the works have to be carried out outside the shipping channel, which means the deck has to be cast in place.

The contract also includes construction of access viaducts on either side of the bridge with a total length of 2 km, together with connections to the existing road network.

Figure 4: Rendering of the bridge
Source: vinci-construction.com/en/project/15892/atlantic-bridge-panama

Rúbrica Engineering, which is a Spanish company with more than 20 years of experience in the design and manufacturing of special equipment for civil construction, has designed and supplied four form travellers (two for each bridge pylon) for the segmental construction of the bridge deck.

Additionally, four lifting structures for the lifting of the travellers were also designed and provided.

Both the form travellers and the lifting structures were designed and fabricated specifically for the project.

The form travellers are a system of formwork panels and steel structures that allow casting of an external constant cross section segment of 8m length in order to construct the bridge deck.

This system can be adapted, by removing some panels, to make 7m long segments as required by the client. The inner formwork can also adapt to the different interior cross sections of the segment configurations.

The form travellers are provided with working platforms with steel grated flooring, ladders and guardrails allowing access to different parts of the formwork.

The structure consists of a steel casting cell supported by a grillage of transversal and four longitudinal steel girders. These girders are located under the deck. During casting of each typical segment, each one of the longitudinal girders is supported by four bars anchored to the previous concrete segment working as a cantilever.

During launching, the whole system lies over a pair of rails which incorporate hydraulic cylinders; so that the system weight is carried by the upper part as it moves forward.

The system also includes 2 back support points at the bottom of the previous concrete segment, fitted with rollers.

Figure 5 + 6: Formwork travellers

The construction of the main pylons is almost finished, while the segmental construction of the deck is in the early stages. The two first segments of each pier were cast in autumn 2017.

The first segment of each pylon and of each side of the Atlantic Bridge has the special feature that it was cast using only the front part of the travellers.

The front travellers were lifted with hydraulic jacks from the lifting structure and were fixed on the rear part to the deck and on the frontal part were hung from the lifting structure trough suspension bars.

As a consequence, the front traveller works as a double supported structure during casting of the first segment.

The next step is to move the front travellers down and to assemble the rear parts of the travellers on the ground.

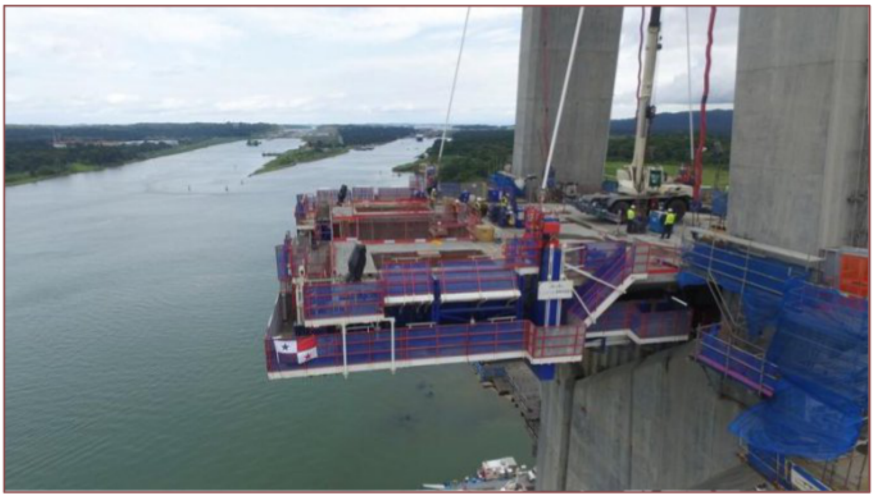
The lifting structures are launched and the complete traveller, that has a weight of 220tn, is hydraulically jacked into place.

After the lifting of the complete form traveller the second segment is cast. From the second segment and the following, the complete form traveller is used to cast each segment.

For each segment, the traveller is launched and then fixed on the previous concrete segment.

Each segment is deliniated longitudinally by two laterals and one central precast diaphragm element. The traveller provides skidding rails and devices to move the precast elements to their position.

The lateral precast diaphragm formwork was also designed and manufactured by Rúbrica.

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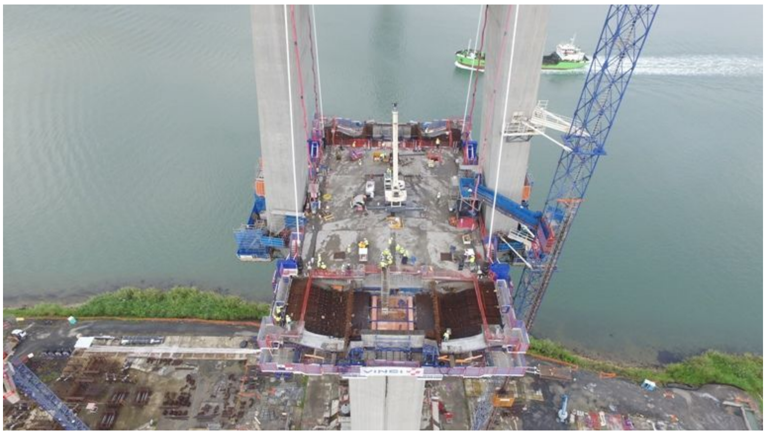

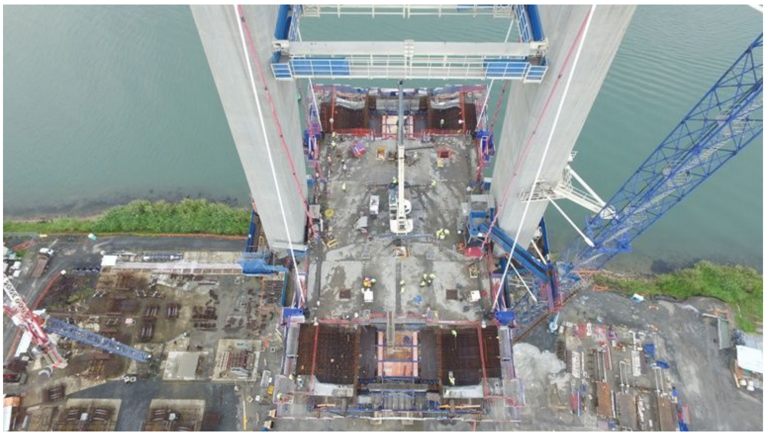


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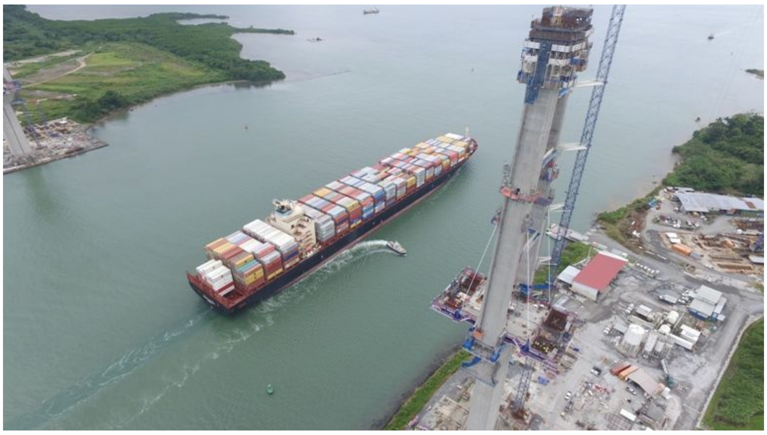

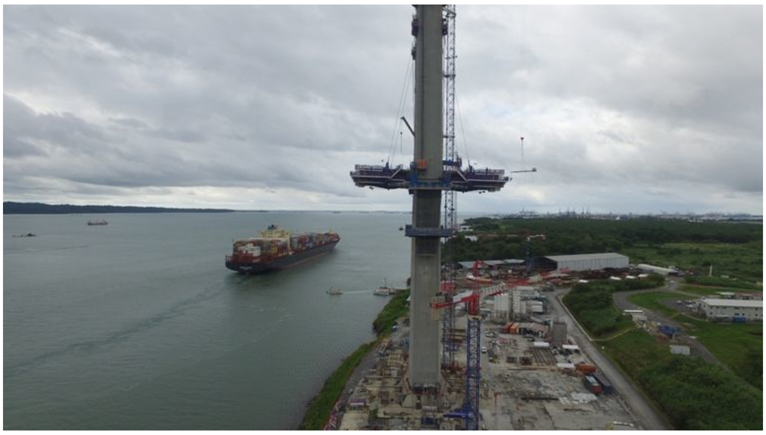

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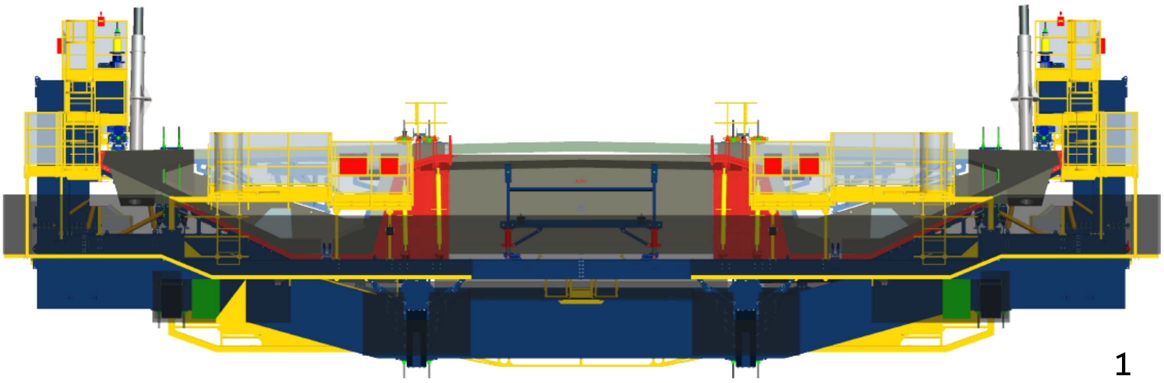

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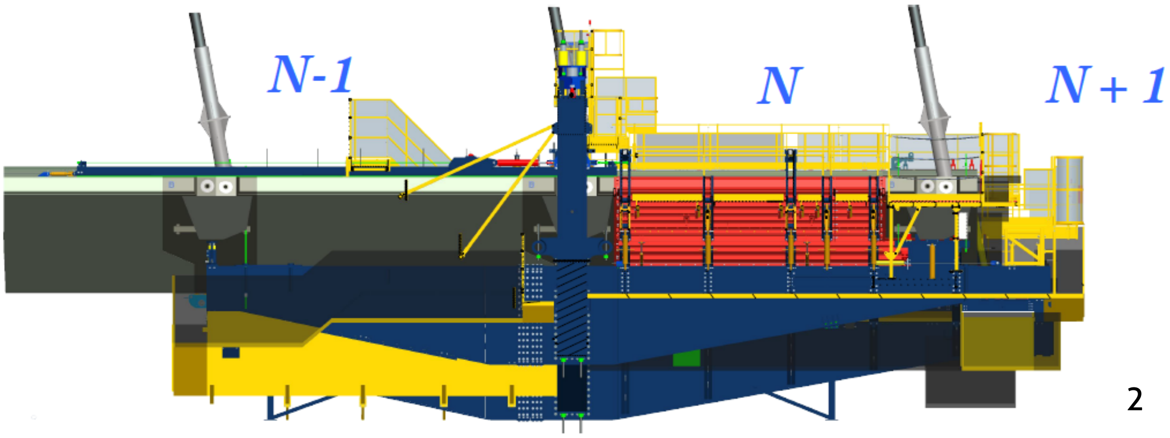

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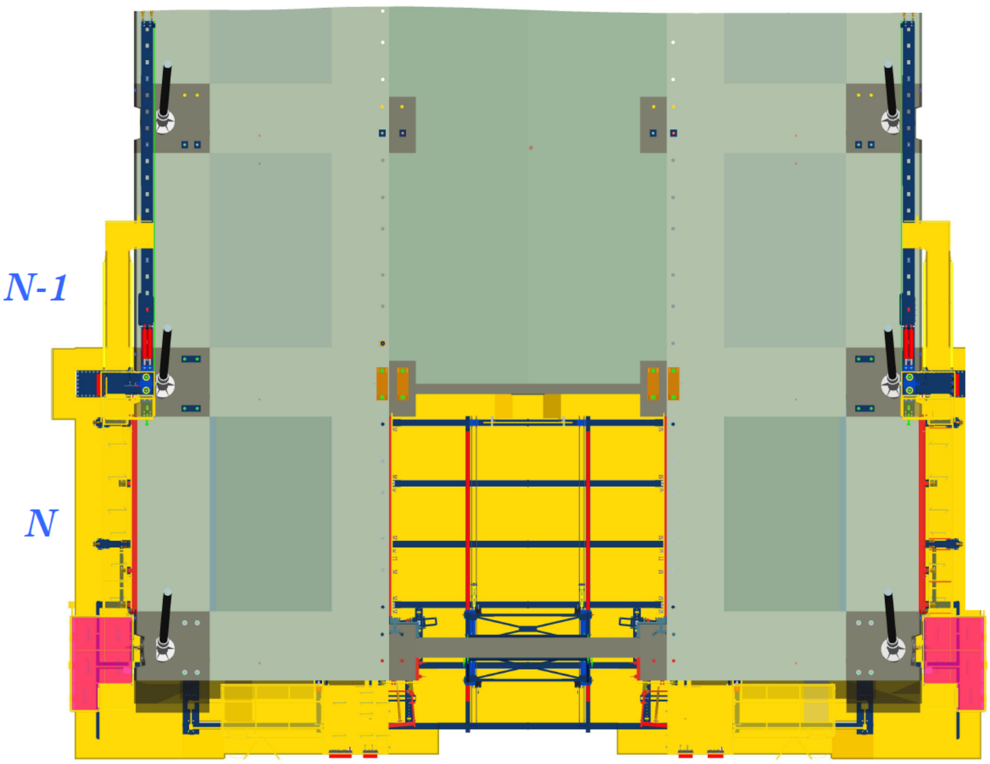
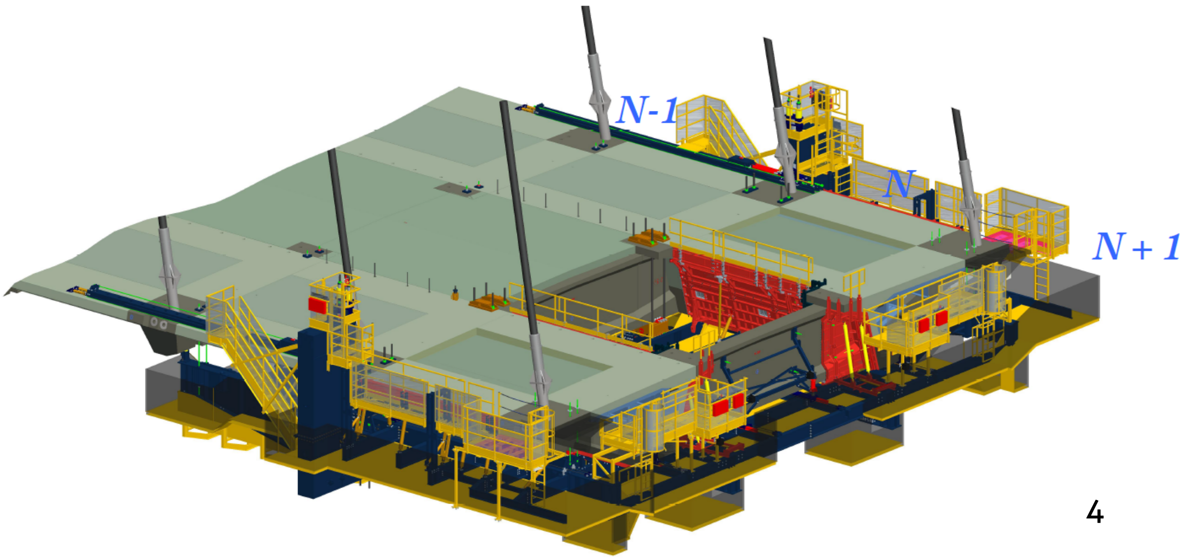


3

1 - 4: First phase (segment N) is cast. Panels are in casting position (not folded). Main anchorages (frontal and rear) are fastened to the segments. Rails are place and fastened in segment N-1.

5: Formwork Traveller lowering - extend rear rollers until they are in contact with the deck.

6: Skidding of the Formwork Traveller


N-1
N
N + 1

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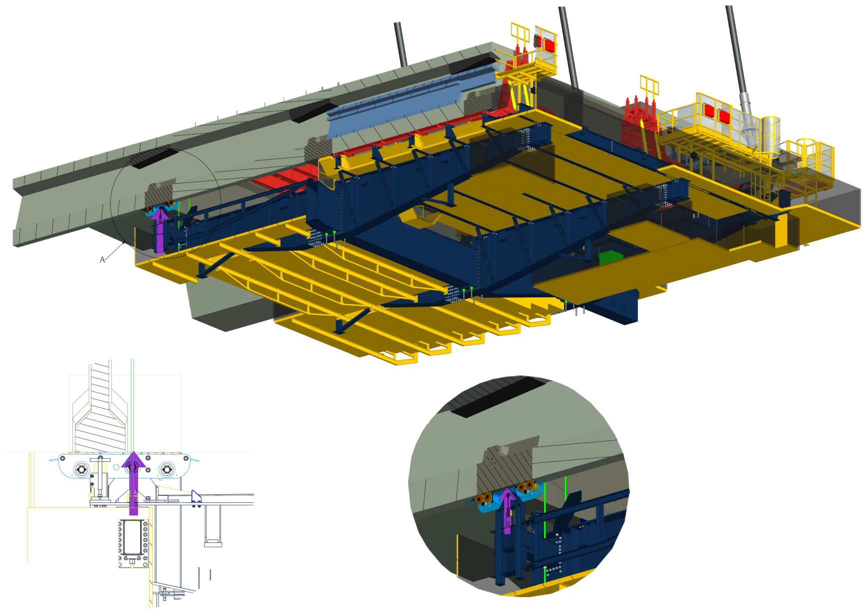
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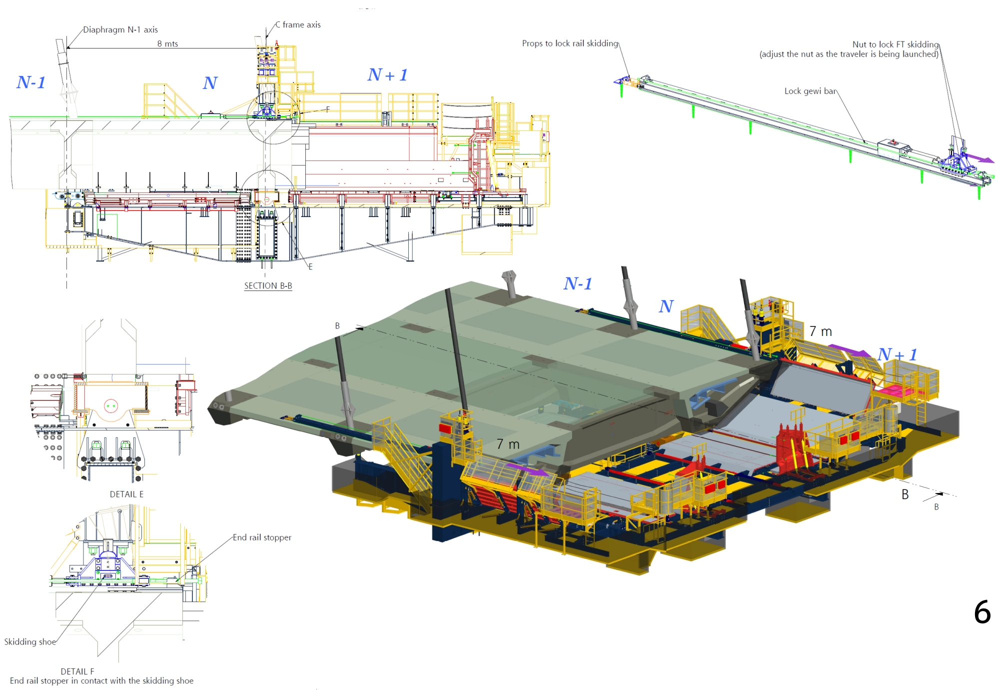
Diaphragm N-1 axis
8 mts
C frame axis
N-1
N
N + 1
SECTION B-B
Props to lock rail skidding
Nut to lock FT skidding
(adjust the nut as the traveler is being launched)
Lock gewi bar
N-1
N
N + 1
7 m
7 m
B
DETAIL E
End rail stopper
Skidding shoe
DETAIL F
End rail stopper in contact with the skidding shoe

6

ORDSALL CHORD

COMPLETED AND OPENED TO TRAFFIC

Thanos Bistolas, Brian Duguid

AECOM Mott MacDonald JV

Figure 1: River Irwell Crossing
© Matthew Nichol Photography

Ordsall Chord, UK

On 9th November, the Ordsall Chord project celebrated construction completion.

The first passenger trains crossed the Ordsall Chord Viaduct on 10th December.

The viaduct carries a new railway line across the River Irwell between Manchester and Salford, connecting Manchester's main railway stations for the first time, reducing rail congestion, and bringing economic benefits throughout the north west of England.

River Irwell Crossing

The River Irwell Crossing is the first network arch bridge to be built in the UK, and the first asymmetric (tapering) network arch in the world. The 90m span, 15m wide bridge incorporates 1156 tonnes of steel.

The composite steel-concrete ladder-beam bridge deck is suspended from weathering steel box girder arches by two networks of solid steel hangers.

There are 46 hangers in each network, with load-monitoring pins installed at the lower end of each hanger.

Temporary trestles were installed in the river with a dual purpose – to support an existing highway bridge while it was demolished in pieces, and then to support the new bridge deck during construction. The new arch tie girders were erected in three pieces each, then cross-girders were installed.

The two arches were welded in sections at ground level, rotated to their correct angle, then connected with cross-bracing and temporary ties and struts.

The double-arch assembly was erected using a tandem crane lift, one 750-tonne and one 1300-tonne crawler crane, the latter being the largest available in the UK.

The Ordsall Chord Viaduct

The River Irwell Crossing is just one of several structures which make up the Ordsall Chord Viaduct.

To the north of the network arch bridge, the viaduct spans Trinity Way, with a 110m long three-span half-through girder bridge comprising 3.0m tall edge girders and a composite ladder-deck.

Two single-span half-through girder bridges were also built across Water Street, both installed using self-propelled modular transporters.

Between the River Irwell Crossing and Trinity Way Bridge, a "king-pier" structure provides resistance to longitudinal railway loads. This structure also supports two giant steel "cascades", the most complex steel pieces on the project, which provide architectural continuity between the structures on either side.

At both ends of the viaduct, existing 19th century brick railway viaducts have been widened using reinforced concrete arch spans.

The concrete arches were precast off site and are supported on cast-in-place concrete piers, and infilled with mass concrete. Due to irregularities in the construction of the existing viaducts, and their curvature in plan, every concrete arch and pier are of a slightly different dimension.

The project also included extensive refurbishment of the historic structures, including the complete reconstruction of one elevation of the two span masonry Stephenson's Bridge.

This bridge holds the highest heritage protection status in the UK, and formed part of the historic 1830 Liverpool to Manchester Railway. After years of damage and neglect, the north elevation has been rebuilt to match its original 1830 appearance.

The project also required construction of a new pedestrian and cycle bridge, Prince's Footbridge, immediately below the River Irwell Crossing.

This is a 50m span steel spine beam structure, with aluminium decking and stainless steel parapets. It is believed to be the first bridge in the UK to be designed and built directly using only the digital design model, without conventional design detail drawings.

Figure 2: Stephenson's Bridge reconstruction
© Matthew Nichol Photography

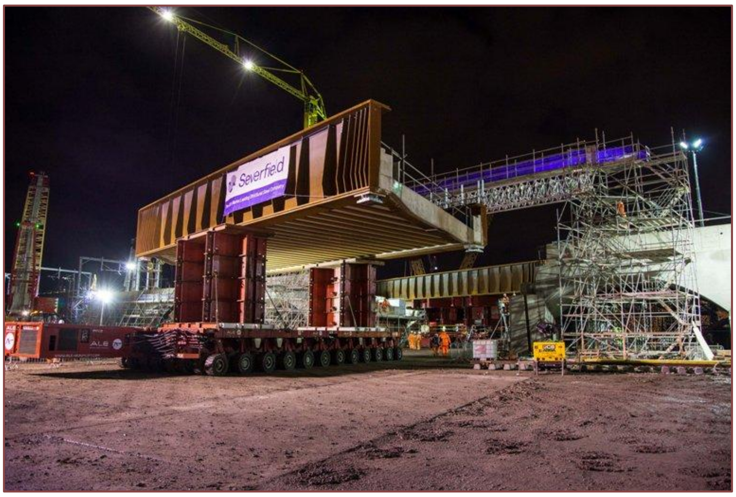

Figure 3: Installation of Water Street Bridge
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Figure 4: River Irwell Crossing, showing cascade steelwork © Matthew Nichol Photography

Project recognition

The project has been presented at events and conferences in Wroclaw, Vancouver, Coventry, London, Manchester, Bath and Leeds, and is described in nine technical papers. It is already the winner of the following awards:

- 2016 Tekla Global BIM Award for Infrastructure
- 2017 Royal Institute of Chartered Surveyors North West Infrastructure Award
- 2017 North West Regional Construction Award for Digital Construction
- 2017 Railway Industry Innovation Awards Major Project of the Year
- 2017 British Construction Industry Awards for Temporary Works

Key quotes

"The steel element incorporating the bridge resembles a single elegant pen stroke from Japanese calligraphy. It combines adventure with subtlety as the Cor-ten steel section narrows from Salford over the river into Manchester. [The bridge] has given excitement to this end of the city centre. It has given it potency and grace too." – Jonathan Schofield, Manchester Confidential

"The transformation of a rubble-strewn tract of land into this impressive feat of modern engineering has been a sight to behold … fingers crossed that in future years, Manchester will look back on this iconic bridge in the same way we reflect now on Stephenson's vision - and the feats of engineering that made it possible." – Charlotte Cox, Manchester Evening News

"Based on what I've seen, the network arch bridge on #ordsallchord will be destined to become a Manchester landmark." – Michael Portillo, TV presenter and author, former Minister of State for Transport

Full project credits

Owner: Network Rail

Delivery organisation: Northern Hub Alliance (comprising Network Rail, Siemens, Amey Sersa, and Skanska BAM JV)

Civil engineering contractor: Skanska BAM JV

Structural steelwork subcontractor: Severfield UK

Lead architect: BDP

Concept design engineer: WSP (formerly Parsons Brinckerhoff)

Preliminary and detailed design engineer: AECOM Mott MacDonald JV

Architectural subconsultant to design engineer: Knight Architects

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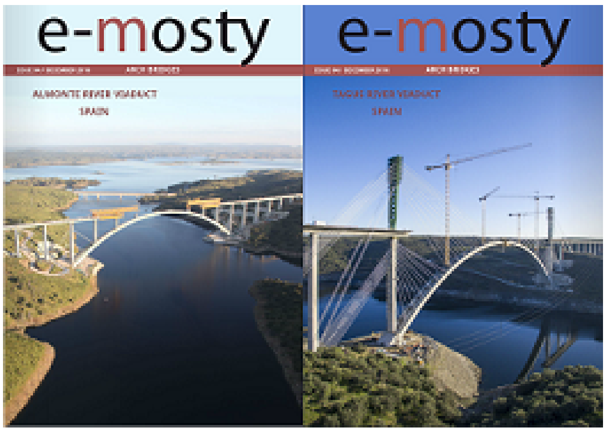
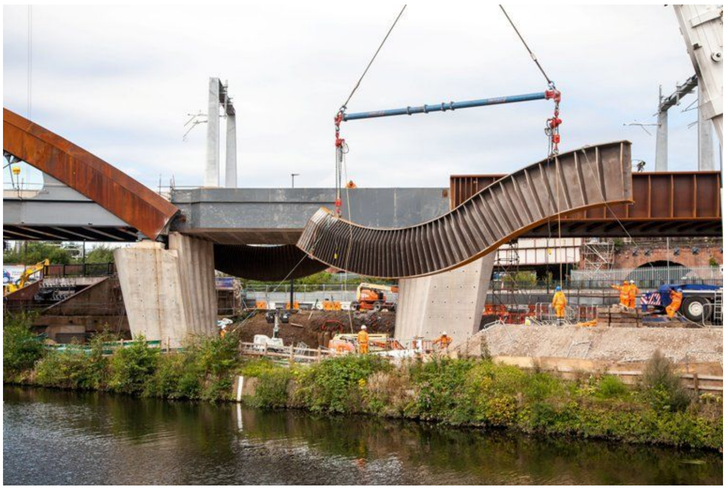
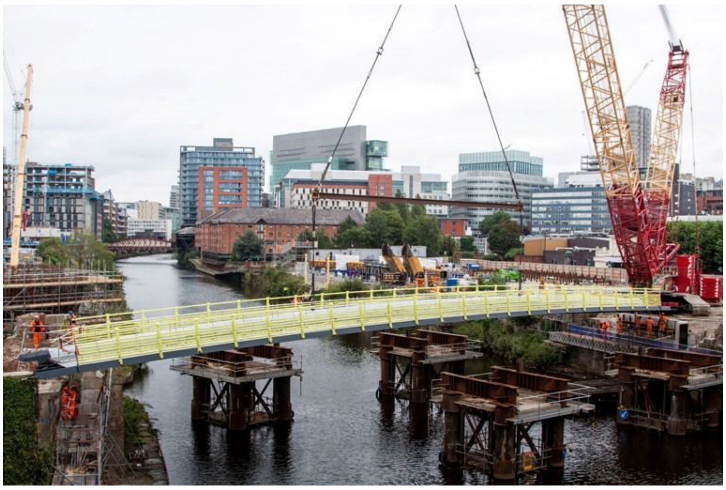
See the magazine e-mosty December 2016, for details of the River Irwell Bridge, the landmark structure at the heart of the Ordsall Chord (click on the picture below).





Installation of steel cascade
© Matthew Nichol Photography



Prince's Footbridge installation
© Matthew Nichol Photography

Prince's Footbridge installation
© Matthew Nichol Photography

River Irwell Crossing and Trinity Way Bridge
© BDP / Paul Karalius

River Irwell Crossing
© BDP / Paul Karalius

Aerial photograph of Ordsall Chord viaduct

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