e-mosty

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Movable Scaffolding Systems. Formwork Travellers.

Bowstring Overhead MSS
with Organic Prestressing System
Turkey

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.

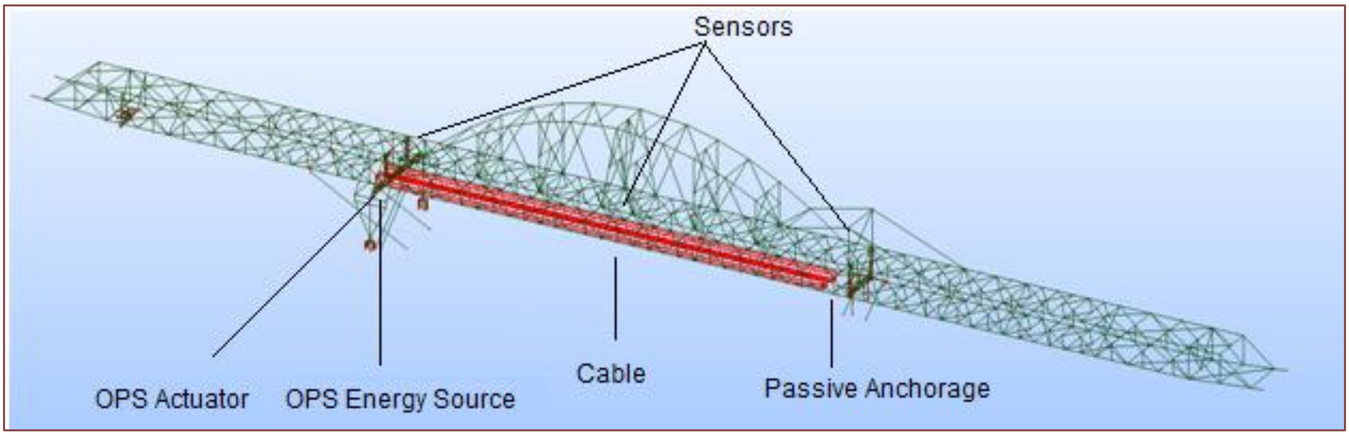


Figure 2: A typical MSS with OPS

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.

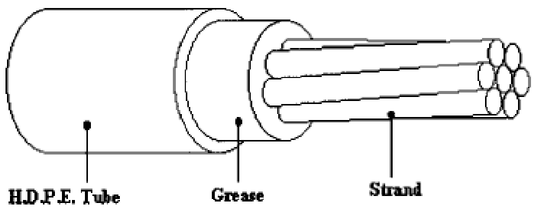
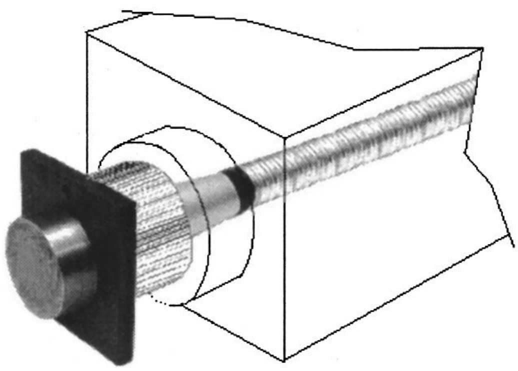


Figure 3: Unbonded Tendon

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.

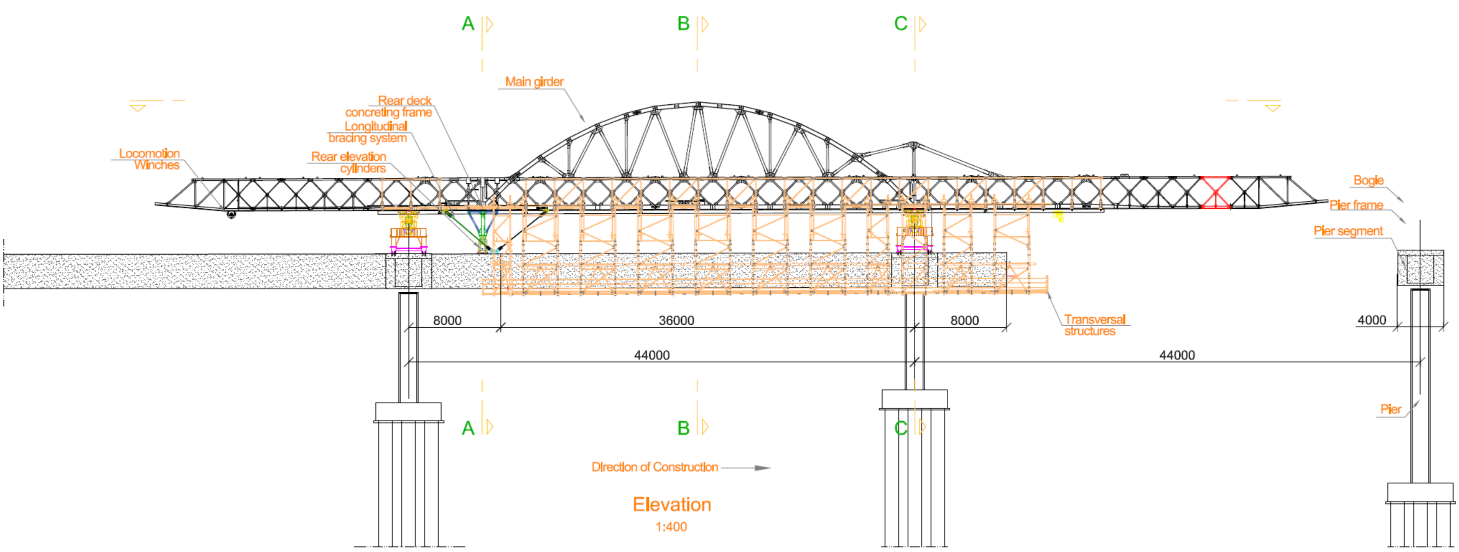


Figure 6: MSS M45-S Elevation

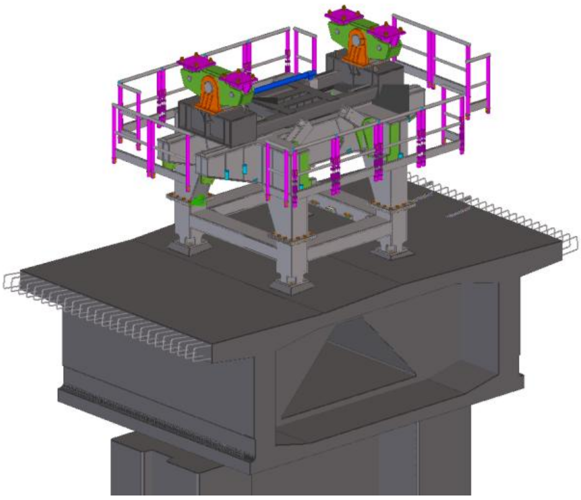


Figure 7: Pier Frame with Bogies

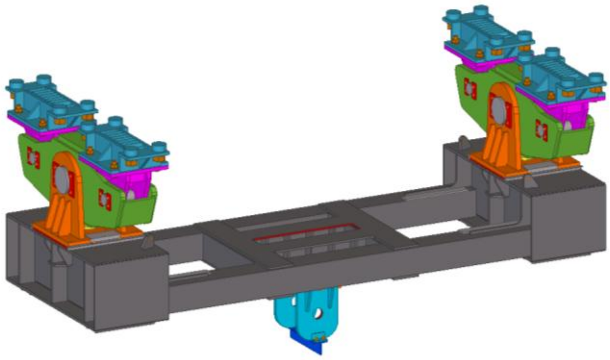


Figure 8: Bogies – each bogie contains two lines of support for the two rails in each inferior chord of the girder

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.

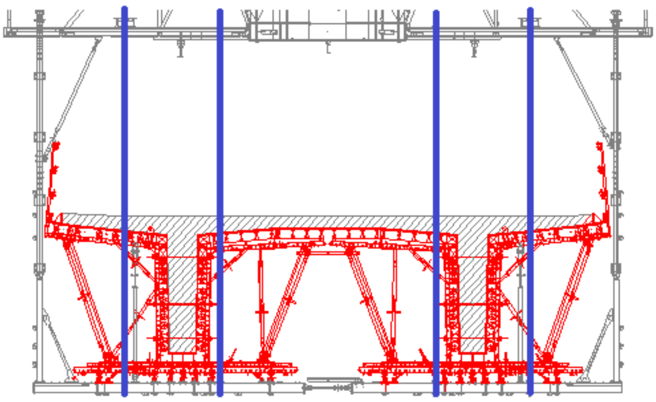


Figure 9: Formwork (red) with suspension rods (blue)

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.

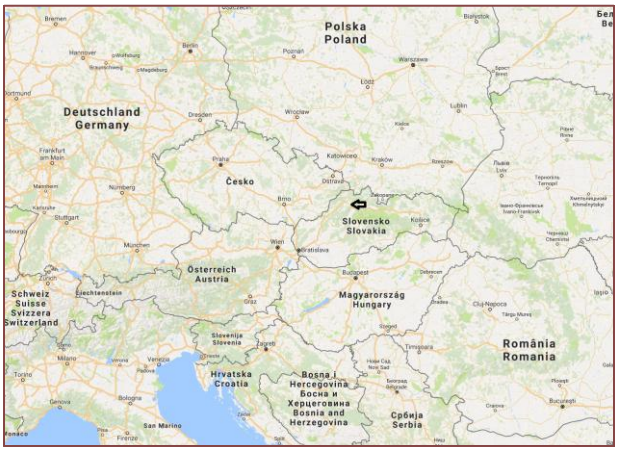


Figure 12: Location of the bridge
Source: Google Maps

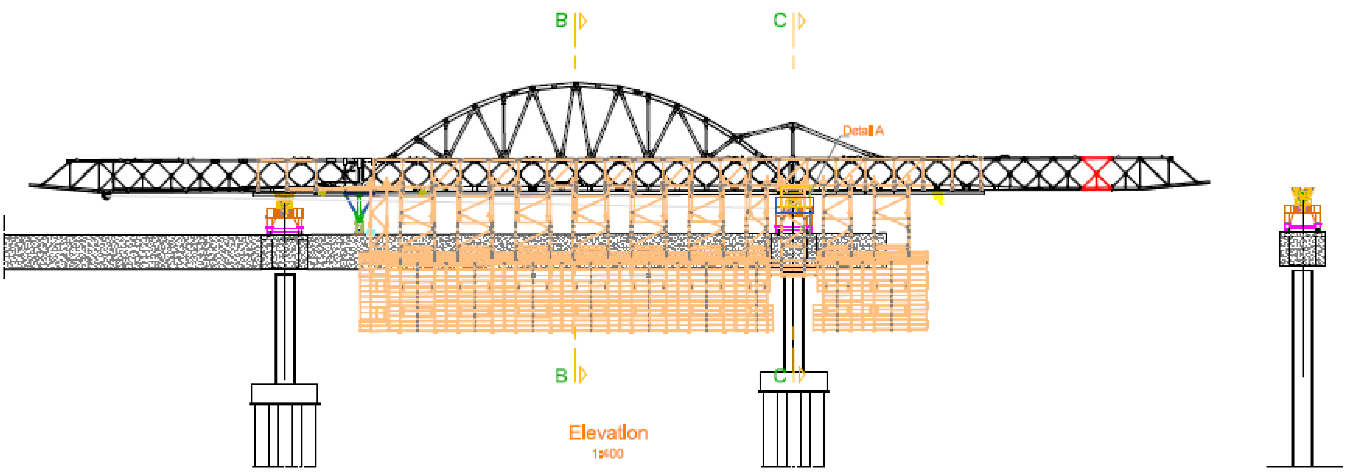


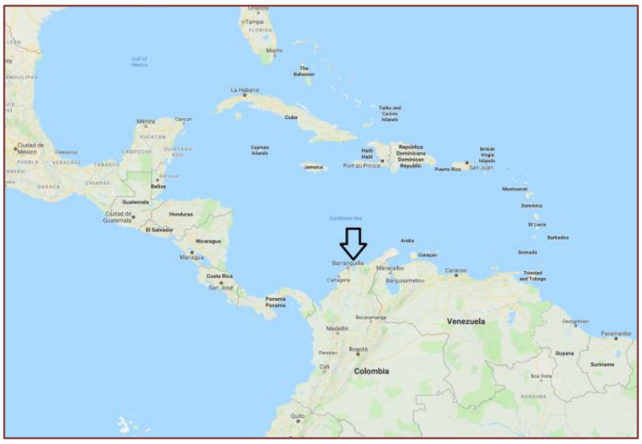
Figure 13: The MSS is ready for launching

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.

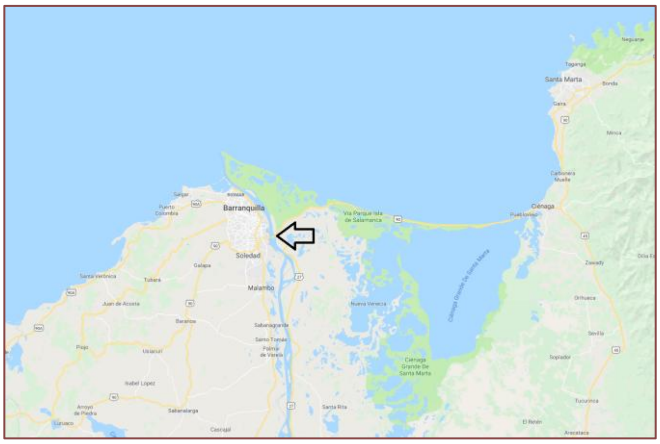


Figure 17: Rendering of the bridge Source: SACYR

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

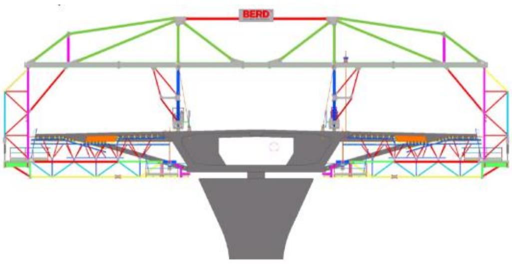


Figure 18: Completed Section

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).

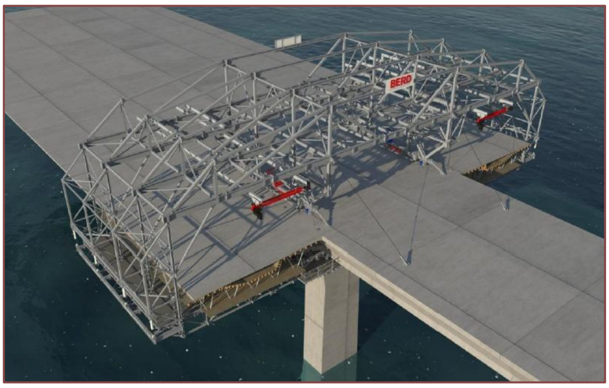


Figure 19: Cantilever Machine

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.

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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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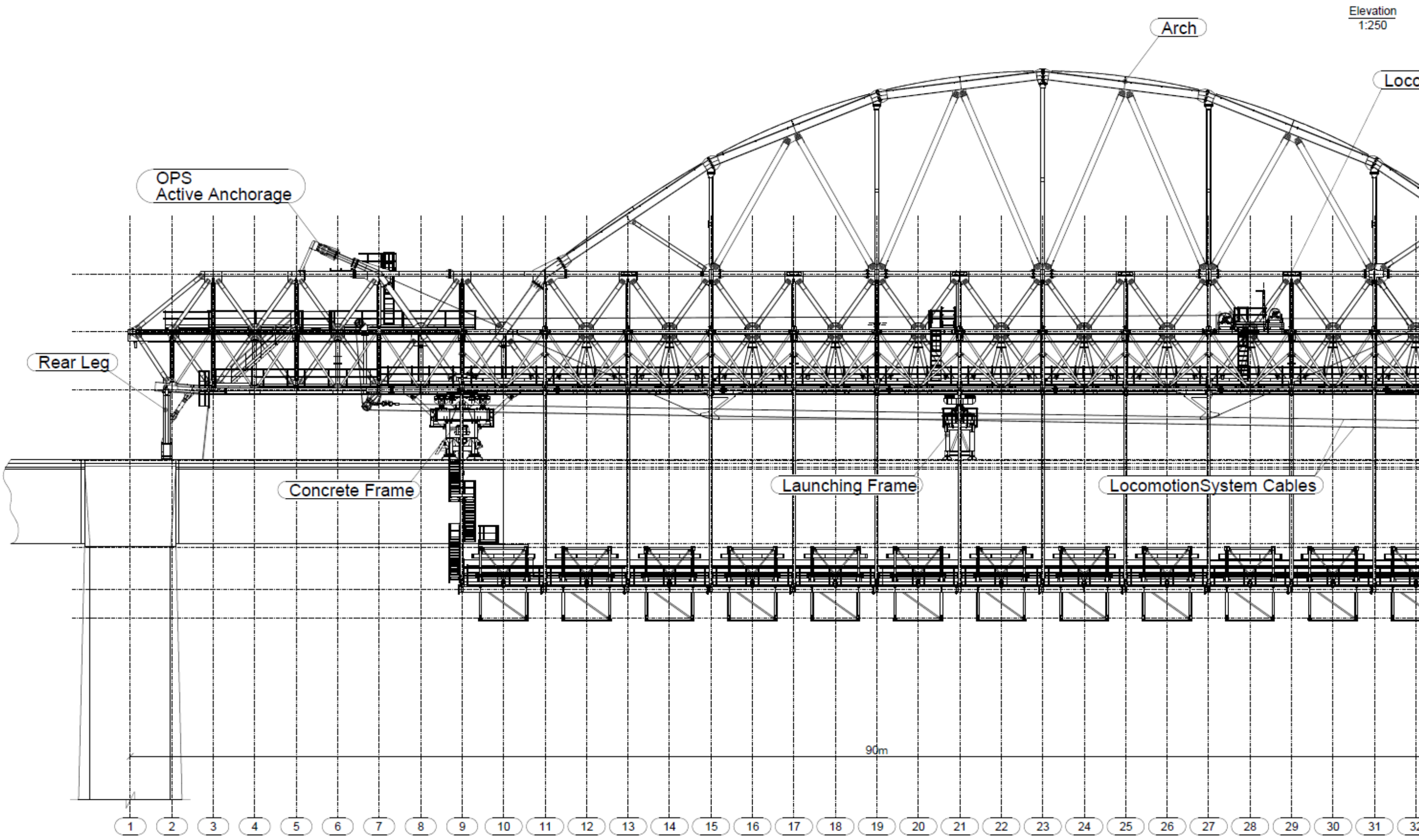
MSS M1-90-S


Elevation
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Launching Frame
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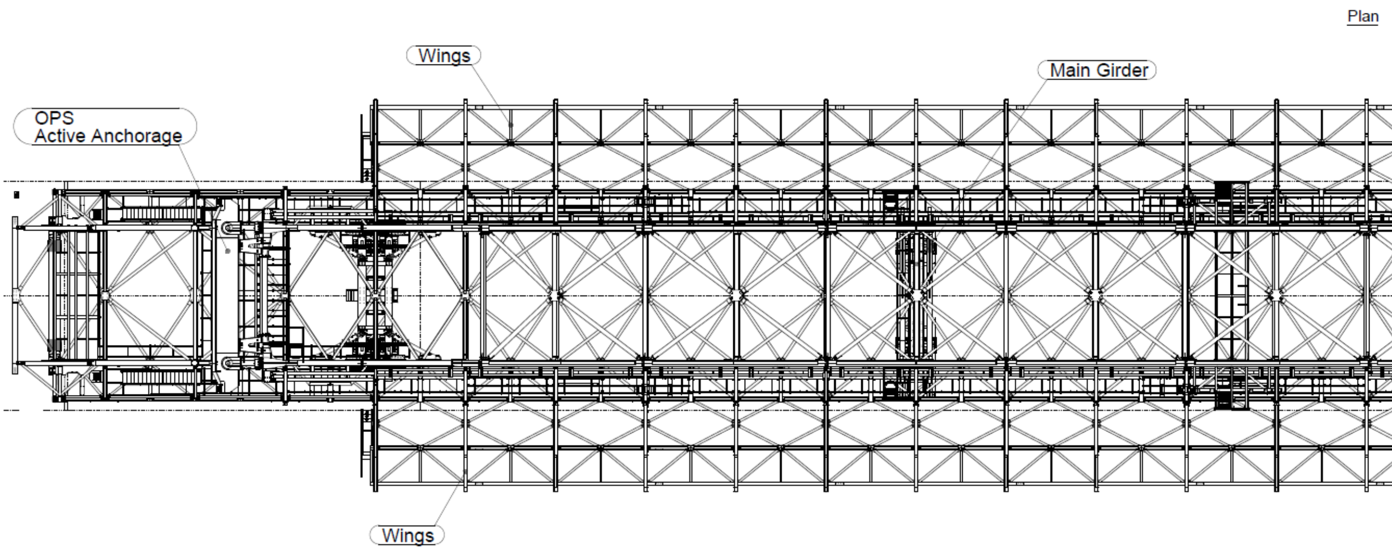
Plan
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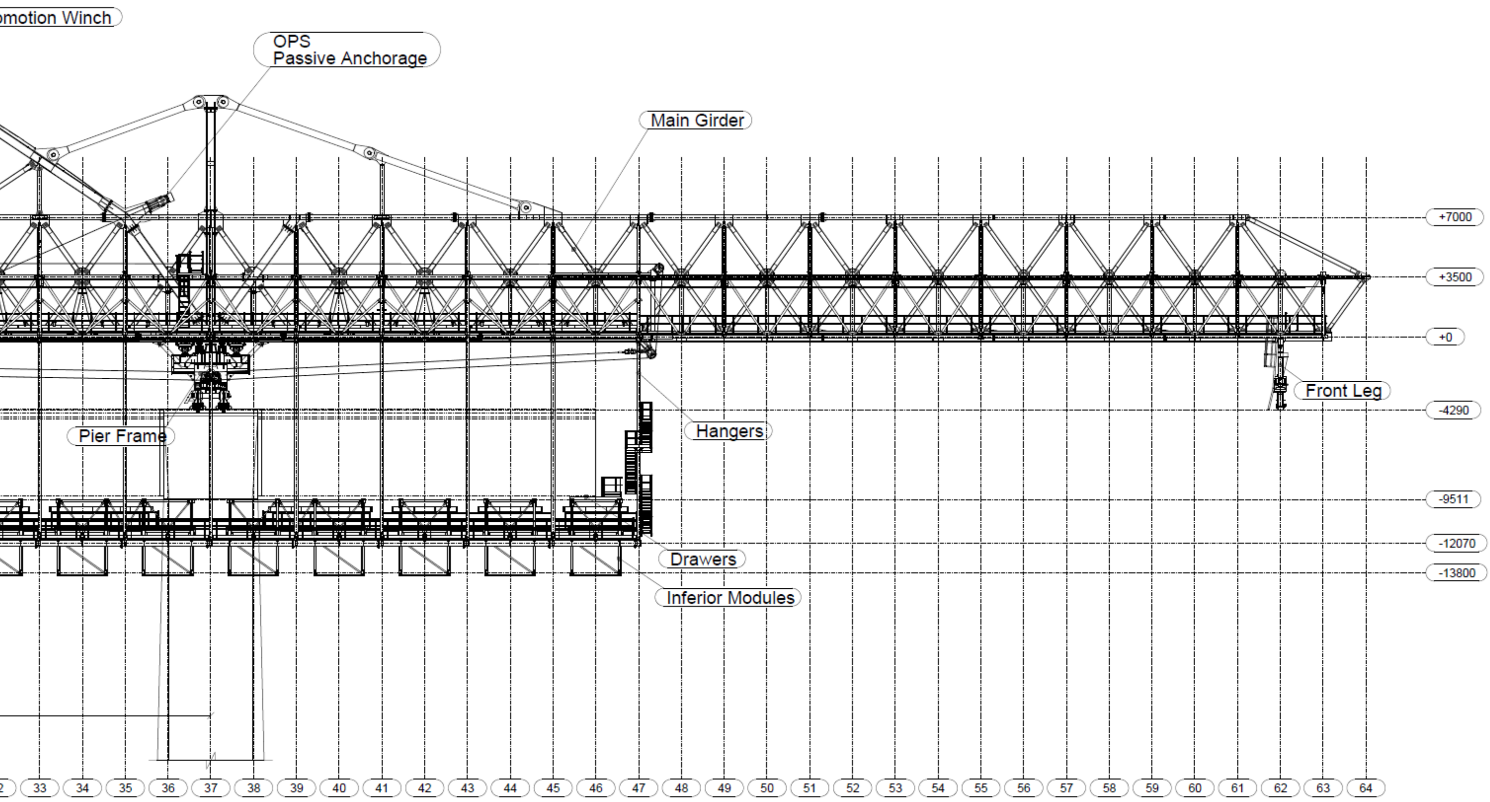
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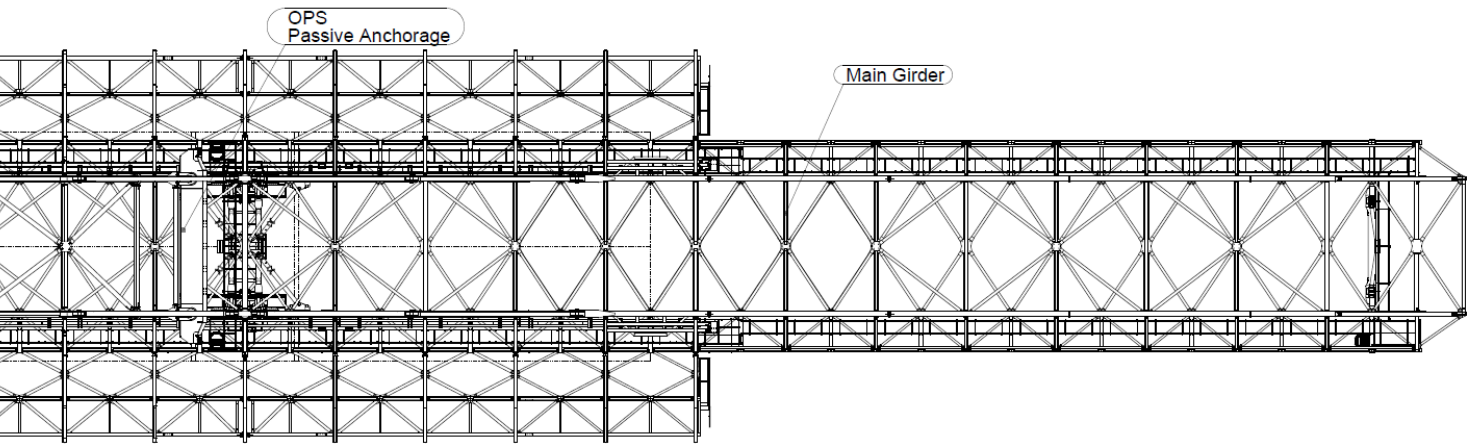
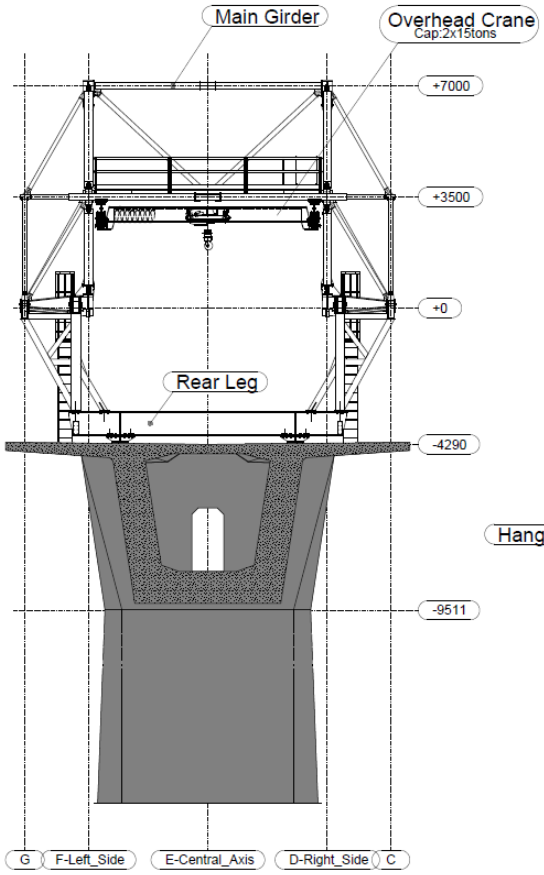
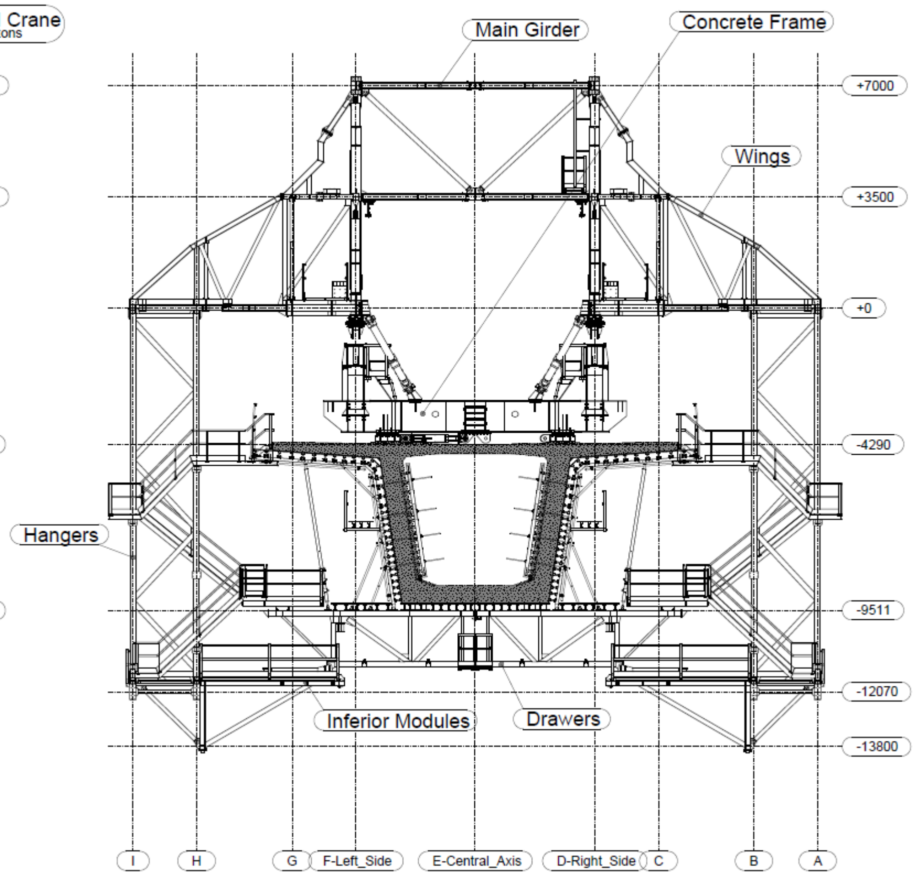

OPS
Passive Anchorage
Main Girder

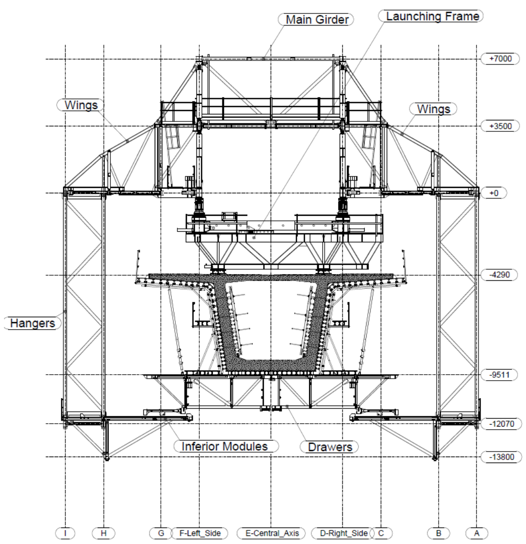
Rear Leg
Aligment 2



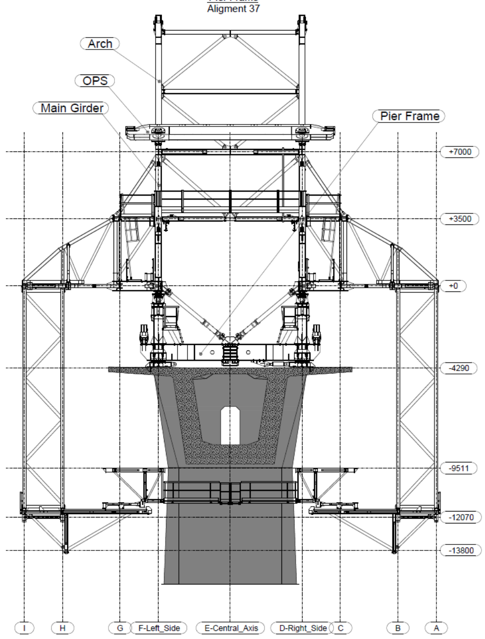
Deck Concrete Frame
Aligment 9



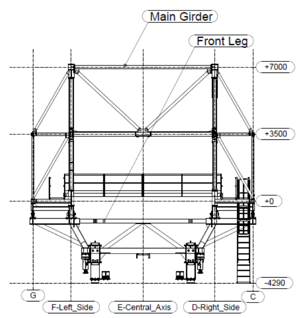
Launching Frame
Aligment 21



Pier Frame
Aligment 37



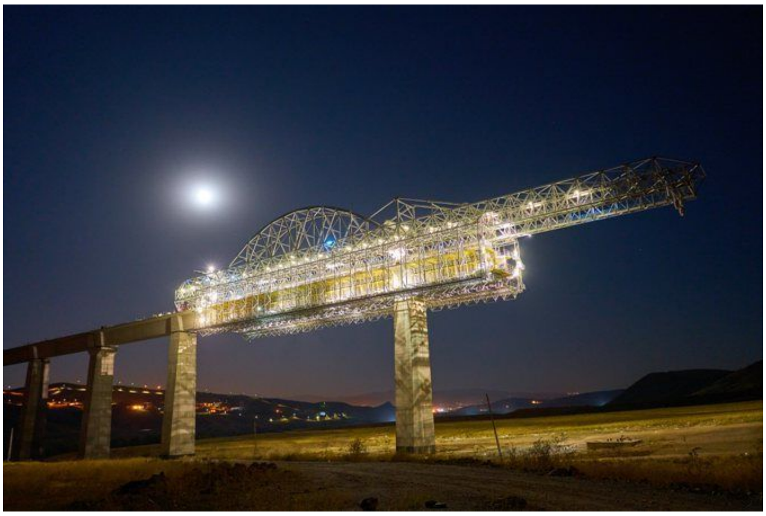
Front Leg
Aligment 62



MSS M45-S Strážov - Brodno, Slovak Republic

MSS M70-S Pumarejo Bridge, Colombia

MSS M1-90S, Turkey



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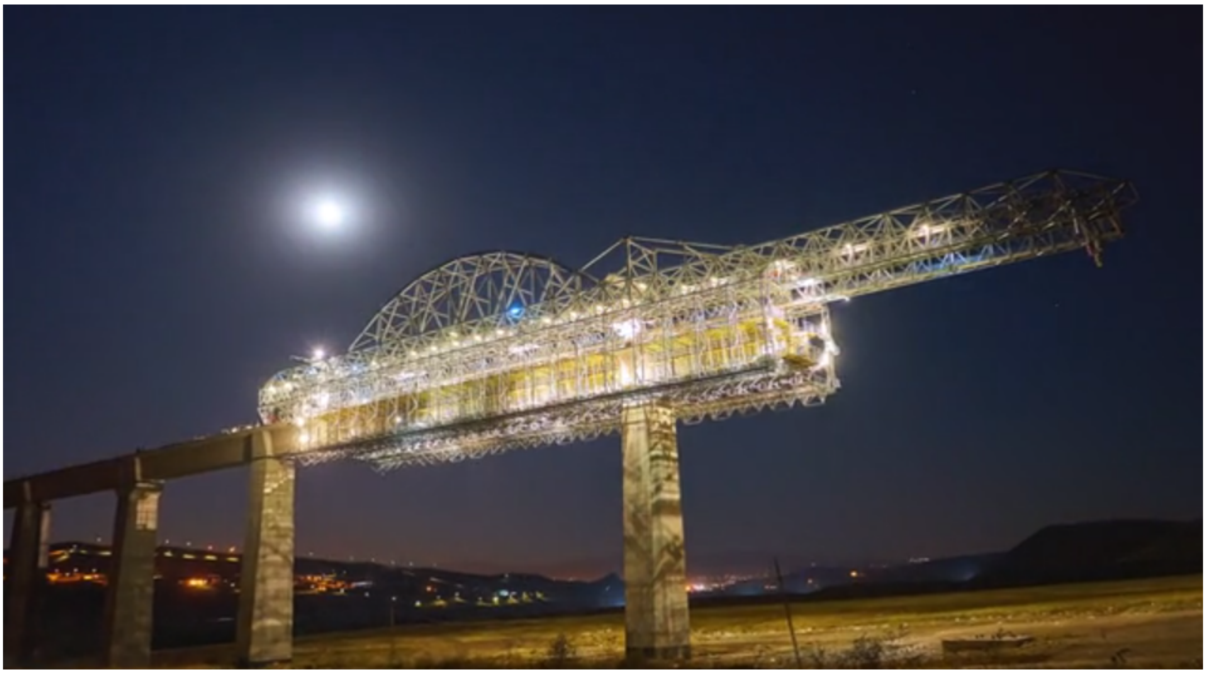
Launching the MSS in Turkey



MSS in Turkey - Movie Trailer