e-mosty

ISSUE 03/2020 September

VESSELS AND EQUIPMENT FOR BRIDGE CONSTRUCTION

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Photos: Front Cover: *´I Lift NY´* raises the final westbound girder assembly, weighing more than 700 tons.
Photo Credit: NY State Thruway Authority

Back Cover: Sőderstrom Railway Bridge Replacement Photo Credit: Sarens

International, interactive magazine about bridges e-mosty ("e-bridges").

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Dear Readers

*This special issue focuses on **Vessels and Equipment used for Bridge Construction**.*

The first article provides an overview of projects in which the floating crane ´Left Coast Lifter´ was used in the USA. Three bridge structures are described: the Oakland Bay Bridge, the Governor Mario M. Cuomo Bridge, and the Spuyten Duyvil Bridge. Additionally, the main facts and technical specification of the crane are provided.

In the next article, Sky Bridge Installation in Hong Kong Airport is described. The article was prepared by Mammoet which transported and installed the Bridge. The article is accompanied with drawings illustrating the process.

The third article of this issue was prepared by Sarens and it brings information about the Söderstrom Bridge replacement in Sweden, and it is also accompanied with drawings of the process.

The last article looks back at the Apollo Bridge Installation in the Slovak Republic. The main bridge structure was built on the river bank and then rotated into its final position over the River Danube.

*I would like to thank all authors and companies involved for their cooperation; **Khurram Saeed** (NY State Thruway Authority), **Kleopatra Kyrimi** (Sarens), **Denise Chiew** (Mammoet), **David Leon Shaw** (Mammoet) for their assistance, **Richard Cooke** for reviewing this issue, **William Day** for cooperation, **and Guillermo Muñoz-Cobo Cique** (Arup) for his final check.*

*I would also like to **thank our partners for their continuous support**.*

On behalf of the organizers and as a media partner, we would like to invite you to two conferences:

- **IABSE Symposium Wrocław 2020** on **October 7-9, 2020**,
- **EXPO & MULTI CONFERENCE infra BIM Gliwice on October 13 – 15, 2020.**
  Both conferences will be held virtually.

More information can be found on pages 43 and 45.

Next e-mosty magazine will be released on 20 December.

Magdaléna Sobotková

Chief Editor

e-mosty

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

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

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

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

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

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

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

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

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e-maritime

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

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

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

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and show the grace and beauty of the vessels and structures as well.

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FLOATING CRANE ´LEFT COAST LIFTER´ USED IN US BRIDGE CONSTRUCTION

Hans Tompot, Naval Architect

Figure 1: ´I lift NY´ arrives at the Tappan Zee
Photo Credit: NY State Thruway Authority

INTRODUCTION

The ‘Left Coast Lifter’ is a USA-flagged floating crane which was built for the American Bridge Fluor joint venture.

This company was contracted for the self-anchored suspension eastern span replacement of the San Francisco–Oakland Bay Bridge.

The barge was built in 2008 as a deck barge by the shipyard US Barge (now named Vigor Industrial) of Portland Oregon, USA as yard number 2.

The crane equipment was ordered from the Chinese company Shanghai Zhenhua Port Machinery Co. Ltd (ZPMC).

For this reason, the barge was transferred to Shanghai, China, where the conversion to ’Crane Barge’ / Crane took place.

In March 2009, the ‘Left Coast Lifter’ arrived back in the US on board the Chinese vessel ‘Zhen Hua 22’, one of the dozens of semi-submersible heavy-lift ships belonging to the Zhenhua subsidiary, Shanghai Zhenhua Marine Engineering Service Group Co., Ltd.

The ‘Zhen Hua 22’ vessel has a free deck space of 151.55 x 32.20m and can carry 32,292 tons of cargo.

Figures 2 and 3: Latest views of the Oakland Bay Bridge. Photo Source: baybridgeinfo.org

SAN FRANCISCO-OAKLAND BAY BRIDGE

The San Francisco-Oakland Bay Bridge - locally called Bay Bridge - is a large bridge spanning San Francisco Bay. It connects the California cities of Oakland and San Francisco in the western United States.

The original bridges were designed by Charles H. Purcell. The bridge opened on November 12, 1936, six months before the Golden Gate Bridge.

Motor vehicles paid tolls only when crossing the bridge from east to west, or in the direction of San Francisco.

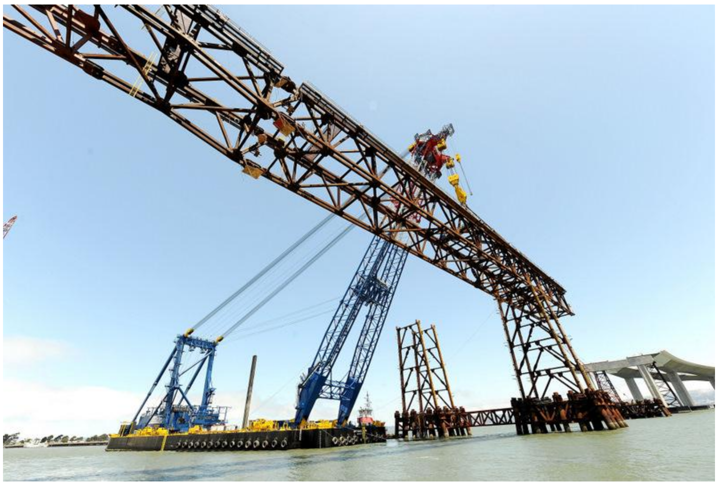
The bridge consists of two parts, which are separated by the Yerba Buena Island (with the artificial island of Treasure Island attached to it).

The western section connects this Yerba Buena Island to San Francisco and consists of two separate suspension bridges, each with two pylons, attached to a central concrete anchor.

The eastern section connects Oakland to Yerba Buena Island, and consists of a steel truss viaduct, five smaller steel truss bridges, and finally a large truss bridge.

The eastern span of the Bay Bridge was damaged during the 1989 Loma Prieta earthquake when a section of the bridge's upper deck collapsed onto the lower deck.

While the damage to the bridge was relatively minor, its structural failure underscored the seismic vulnerability of this major transportation link for the San Francisco area.



Figures 4 and 5: Truss Installation
Photo Credit: Fluor

The traffic on the truss bridges was on two levels: the top deck was for traffic to San Francisco, the bottom deck for traffic to Oakland. About 274,000 vehicles a day travelled across the bridge.

The bridge was replaced by a new design bridge – a single tower, self-anchored suspension bridge.

The length of the bridge is 625m. A single cable is anchored on one end of the bridge, crossing over the top of the single tower at a height over 150m, looping under the span's opposite end, and crossing back over the tower top to the other side.

The 'Left Coast Lifter' was used to place prefabricated falsework truss sections and the 28 box girder deck segments.

These deck sections were also fabricated by Shanghai Zhenhua Port Machinery Co. Ltd (ZPMC), builder of the crane installation of the 'Left Coast Lifter'.

The project employed 3,000 workers who built the main bridge tower and completed the 28 bridge segments.

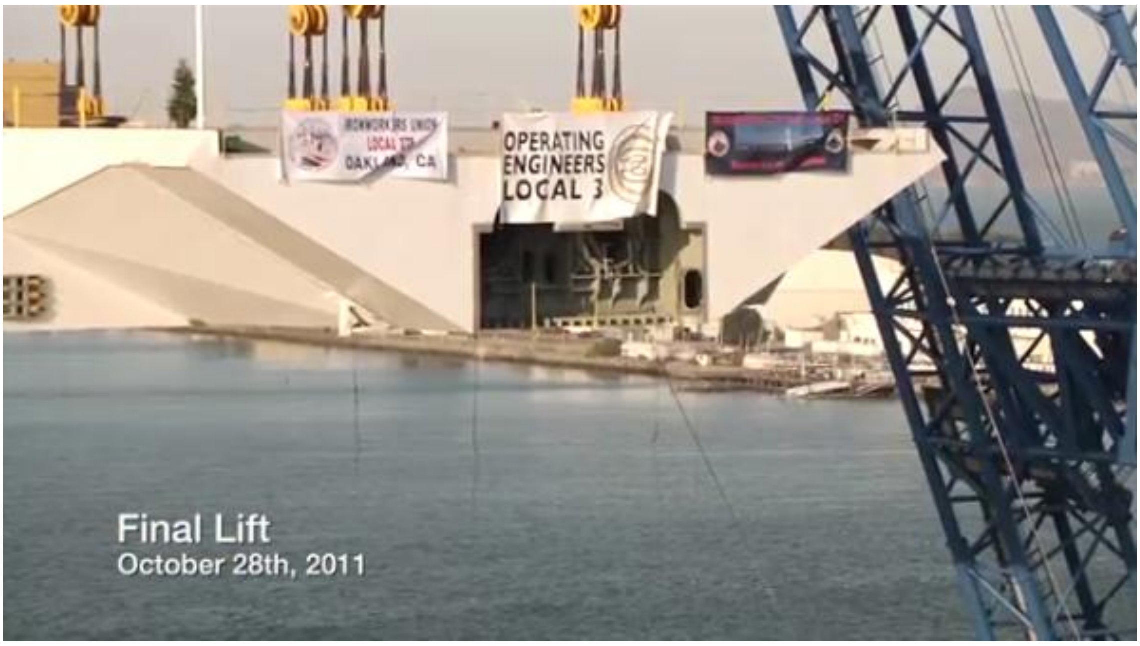
The first deck section was lifted in February 2010 and the last deck section was lifted in October 2011.

The bridge opened to traffic on September 2, 2013.

SALVAGE OPERATION

Before the heavy deck sections for the San Francisco-Oakland Bay Bridge were lifted, the 'Left Coast Lifter' was also engaged in a salvage operation.

The crane raised the 1941-built former US Navy tug 'USS Wenonah (YT-148)' from San Francisco Bay. The American Bridge/Fluor Joint Venture was contracted by Global Diving that was commissioned by the US Coast Guard to recover the vessel to prevent oil pollution.



Video: Final Lift of a deck section and ´Left Coast Lifter´ departing for New York

To play the video please click on the image

THE GOVERNOR MARIO M. CUOMO BRIDGE

The Governor Mario M. Cuomo Bridge is a cable-stayed bridge in the United States, located in the State of New York. The bridge spans the Hudson River at one of its widest points, the Tappan Zee.

Located just north of New York City, the bridge connects South Nyack on the west bank to Tarrytown on the east bank via the New York State Thruway (Interstate 87/287).

The Governor Mario M. Cuomo Bridge has eight general traffic lanes, dedicated bus lanes, breakdown/emergency lanes, a shared bicycle-pedestrian path and a state-of-the-art traffic monitoring system.

A total length of the bridge is almost 5km, the main span is 366m. The westbound bridge is 29.3m wide, while the eastbound span is 26.5m wide.

The cable-stayed main span is supported by eight 128m high chamfered towers. All towers stand at a 5-degree angle. The towers support the deck with 192 stay cables.

The construction of the original Tappan Zee Bridge started in March 1952 and the bridge opened on December 15, 1955.

The 1955-bridge was a combination of a girder bridge and a steel truss bridge as the main span. The bridge was 4,881m long with a main span of 369m.

The bridge deck was a maximum of 42m above the Hudson River. The bridge deck was 24.9m wide and had seven lanes, the middle lane being an alternating lane with a moveable barrier.

In the late 1990s, it became clear that the bridge's condition was deteriorating and that the bridge was not designed to carry current traffic volumes, with its narrow lanes and missing emergency lanes.

Planning for the new bridge started in 1999. After a period of planning, taking into account the costs and various design options, the process to replace the original bridge started in 2012.

Figure 6: View of the complete bridge in 2019

Figure 7: ´I lift NY´passes One World Trade Center on its way to the project site

Figure 8: ´I lift NY´ passes the Statue of Liberty on its way to the project site

The new bridge was designed and built by Tappan Zee Constructors, LLC (TZC), a consortium of design, engineering, and construction firms including Fluor Corporation, American Bridge Company, Granite Construction Northeast and Traylor Bros.

They began construction on the new bridge in 2013.

The 1,700-ton SWL floating crane ‘Left Coast Lifter’, for this project dubbed ´I Lift NY´, was one of the main instruments in the construction of the bridge.

The crane reduced construction time by several months and lowered project costs by more than one billion USD.

The crane arrived at the construction site in early 2014, after a 6,000-mile journey from San Francisco to New York via the Panama Canal.

Before its usage in the project, it had been modified for the specific needs.

After years of planning and preparation, this work included lift testing, precise tuning, careful inspections and installation of a state-of-the-art computer operating system.

This system helped operate the crane with great precision and efficiency.

The crane was used to place the pile caps and pier caps, girders and deck segments.

Figure 9: ´I lift NY´ passes the George Washington Bridge on its way to the project site

Figure 10: ´I lift NY´ passing underneath the old Tappan Zee Bridge

Figure 11: Moments before raising a pair of precast pile caps, each weighing 550 tons

Figure 12: The project site as seen from Rockland County

The huge lifting capacity enabled TZC to pre-fabricate huge sections of the new bridge off-site.

The first operation was lifting a 600-ton concrete segment of the new bridge´s foundations – approach span pile cap upon a group of foundation piles.

Later it helped dismantle the Tappan Zee Bridge. At that time, the crane removed 1,000-ton pieces of the bridge at once, enabling deconstruction to be completed much more efficiently that if it had been carried out by standard-sized cranes.

The north span officially opened to westbound traffic on August 26, 2017, and eastbound traffic temporarily began using the north span on October 6, 2017.

Tappan Zee Constructors then began taking apart the old bridge.

An opening ceremony for the south span was held on September 8, 2018, and traffic started using the new span three days later.

The Tappan Zee Bridge was fully dismantled after the new bridge was opened. The east anchor span of the bridge was lowered via controlled demolition on January 15, 2019.

The super crane departed the project site in October 2019.

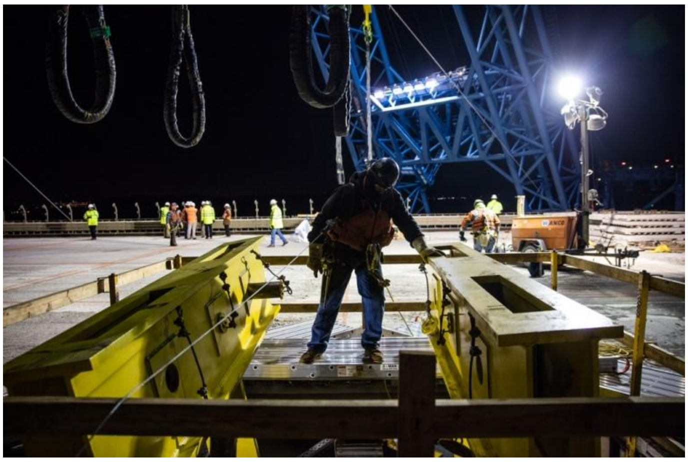


Figure 13: I lift NY´s rigging system is connected to a large section of the old bridge

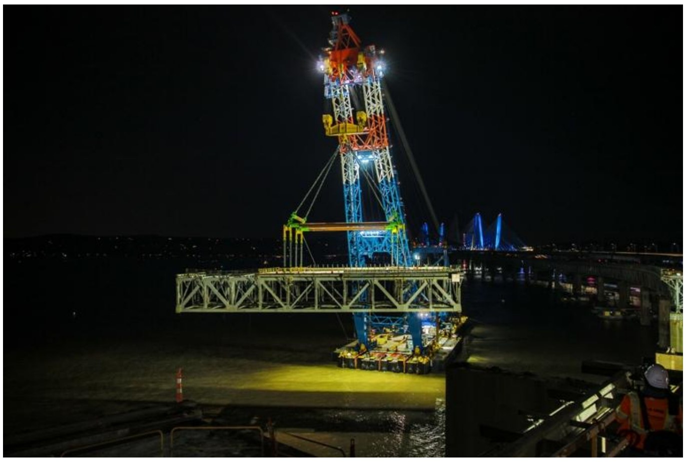


Figure 14: I Lift NY raises a large section of the old bridge near the Westchester

Figure 15: ´I Lift NY´ arrives in the Hudson Valley
Figures 6 – 15 Credit: NY State Thruway Authority

SPUYTEN DUYVIL BRIDGE

The Spuyten Duyvil Bridge is a railroad swing bridge that spans the Spuyten Duyvil Creek between Manhattan and the Bronx, in New York City.

The bridge is located at the northern tip of Manhattan where the Spuyten Duyvil Creek meets the Hudson River, approximately 300m to the west of the Henry Hudson Bridge.

The Spuyten Duyvil Bridge has only a single track on the eastern side of the span. It is part of the West Side Line and is used by Amtrak trains travelling along the Empire Connection.

The span is used by approximately 30 trains a day and is opened over 1,000 times per year, primarily during the summer months for Circle Line Sightseeing Cruises and recreational vessels.

The current steel bridge was designed by Robert Giles and constructed in 1900.

The piers rest on piled foundations in the riverbed. The bridge consists of three fixed sections as well as an 88.4m-long swing section, which could swivel nearly 65 degrees and leave a 30.5m of clearance on each side.

The swing span weighs 200 tons and has enough space to fit two tracks.

In June 2018, the ‘Left Coast Lifter’ was contracted by Amtrak which is the US National Railroad Passenger Corporation providing medium and long-distance intercity service in the contiguous United States and to nine Canadian cities.

Amtrak used the ‘Left Coast Lifter’ to lift the 725.75 tons of the bridge's spans and move them onto a barge.

It was necessary to make repairs to electrical and mechanical components which were damaged by Hurricane Sandy and also after years of malfunctions and corrosion.

Video: Removal of the Spuyten Duyvil Bridge from the Creek

To play the video please click on the image

The main facts of the Floating Crane 'LEFT COAST LIFTER'

Owner	American Bridge / Fluor JV
Type of Vessel	Floating Crane
Classification	American Bureau of Shipping ✠ A1, Barge
Service restriction	U.S.A. Coastwise
Propulsion	None
Hull material	Steel

Construction yard of the barge

Barge	2008 by US Barge (now named Vigor Industrial and formerly named Cascade General, US Fab) in Portland Oregon, USA
Yard number	2

Construction yard of the crane

Crane 2009 by Shanghai Zhenhua Port Machinery Co. Ltd (ZPMC), Shanghai, China

Lifting Capacity	1,700 metric tons
Total investment	approx. 50 million US Dollars

Milestone Dates

Steel Cutting Date	January 23, 2007
Keel Laying Date	September 20, 2007
Launch Date	January 30, 2008
Delivery Date	February 05, 2008

Crane fitted with the following equipment:

Boom skidding system allowing booming down to near flat position (4 degrees)

Boom and A-frame stowage for transit purposes

Collapsible A-frame with sea transport braces

Machine Room housing hoist winches

Diesel Generator Room

Electric Room

Operator's cabin

Six (6) removable barge stability floats

Four (4) barge spuds, each with a length of 27.43 m

Four (4) spud winches

Eight (8) anchor winches

Main particulars of barge

Length overall	121.615m
Breadth mld.	30.429m
Depth mld.	6.706m
Design draft	4.877m
Draft maximum	3.567m (at 3.048m freeboard)
Deadweight	6,872 ton
Gross Tonnage	7,695 GT (according to International Tonnage Certificate)
Net Tonnage	2,308 GT (according to International Tonnage Certificate)

Main particulars of Crane

Boom length	100m
Boom width	20m
A-frame height	40m
Lowest height	10m in stowed position
Main hoist	2 x 875 metric tons
Maximum lifting height	75m above deck
Auxiliary Hoist	120 metric tons
Maximum lifting height	92m above deck
Whip hoist	10 metric tons
Maximum lifting height	90m above the deck
Ballast Capacity	8,937m^3 / 9,160 ton

Acknowledgement

We would like to thank NY State Thruway Authority - especially Khurram Saeed - and Fluor for their cooperation and review of the articles.

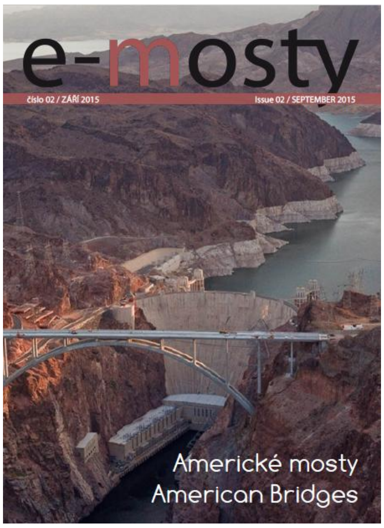
References:

https://www.newnybridge.com/photo/

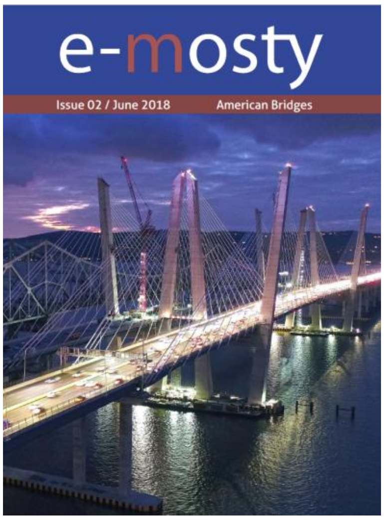
https://mariomcuomobridge.ny.gov/

www.baybridgeinfo.org

Read more about the Oakland Bay Bridge in e-mosty September 2015:



Read more about the Governor Mario M. Cuomo Bridge in e-mosty June 2018:



SKY BRIDGE INSTALLATION

Hong Kong International Airport

Edwin Blösser, Project Manager, MAMMOET

Figure 1: Transportation of the bridge using Mega Jack 5200 system
Photo Credit: Hong Kong International Airport (HKIA)

INTRODUCTION

The "Sky Bridge" is a 200m long pedestrian bridge at the Hong Kong International Airport. It runs from Terminal 1 to the North Satellite Concourse minimising travelling time between the two buildings as passengers no longer need to shuttle by buses.

Passengers can walk between the two buildings in about 5 to 10 minutes.

THE BRIDGE

The bridge sits 28m above the ground with a clear span of over 130m. This allows even the largest passenger aircraft to pass underneath.

The bridge was prefabricated and divided into three precast segments, weighing over 5,000 tonnes.

To minimise impact on HKIA's busy operations, Sky Bridge was prefabricated in Zhongshan, China.

Figure 2: Transportation of the bridge at sea. Photo Credit HKIA

The precast segments then were transported to the West Quay of HKIA and from the West Quay to the assembly yard at the midfield area of HKIA.

From September to October 2019 the three precast segments were assembled there to form the main structure of the bridge.

At midnight on 9 January 2020 it was transported over 3km on HKIA's apron from the assembly yard to the bridge's final position between Terminal 1 and North Satellite Concourse.

It took 7 hours to transport the structure. It was erected on the bridge towers on 10 January 2020.

TRANSPORT AND INSTALLATION

Mammoet transported and installed the 5,100t bridge using its Mega Jack 5200 system installed on Self Propelled Modular Transporter (SPMT) – the first time the Mega Jack 5200 had been used on SPMTs.

Figures 3 and 4: Transport of the bridge on the airport runway

The team faced the challenge of having a limited time period to transport a load weighing approximately 5,100t over 3km.

Mammoet overcame this challenge by designing a solution which provided flexibility to the client, minimized disruption to the HKIA's day-to-day schedules and provided successful delivery of work, all within a confined space.

The project first saw the team transport the bridge a distance of 3.5km across the taxiway within just five hours.

Transportation to the final erection area was performed using 264 axle lines of SPMT.

The bridge was temporarily set down on the airfield's apron, with the supports taking 10% of the weight, then jacked-up to its installation height of 14.3m.

Next, it was picked up and lifted above the final location - above the piers - before being lowered into position.

The team also closely monitored the Mega Jack's hydraulics during the welding works by the client, China State Construction Engineering.

In total, it took seven days to complete all necessary work.

Figure 5: Mega Jack 5200

Figures 3 – 6 Credit: Mammoet

Figure 6: Installation of the bridge in its final position

Figure 7: Sky Bridge in its final position

Photo Credit: HKIA

CHALLENGES

The project necessitated detailed planning, coordination with different marine authorities, departments, the airport community and relevant government departments.

The airport is very busy and could provide only limited space for construction. Impact on airport operation had to be minimised.

All delivery works were carried out during the closure of a runway for maintenance at night time.

High precision was required from component design, prefabrication, welding, delivery to erection – the allowable construction tolerance was minimal.

The works were going 24 hours throughout the 9-day critical time period. This accommodated both the client and airport authorities' requests while ensuring the timely erection of the bridge.

CONCLUSION

Construction commenced in 2018. The transport and installation operation took place in January 2020, concluding the prefabrication phase of the construction programme and marking an important project milestone.

The Sky Bridge becomes the world's longest airside bridge, allowing the largest passenger aircraft, the A380, to pass underneath.

Official Video of Hong Kong Airport: Transport of the Bridge Segments.

Click on the image to play the video

DRAWINGS – Click on the image to open it in full

Drawing 1: Transport of the bridge

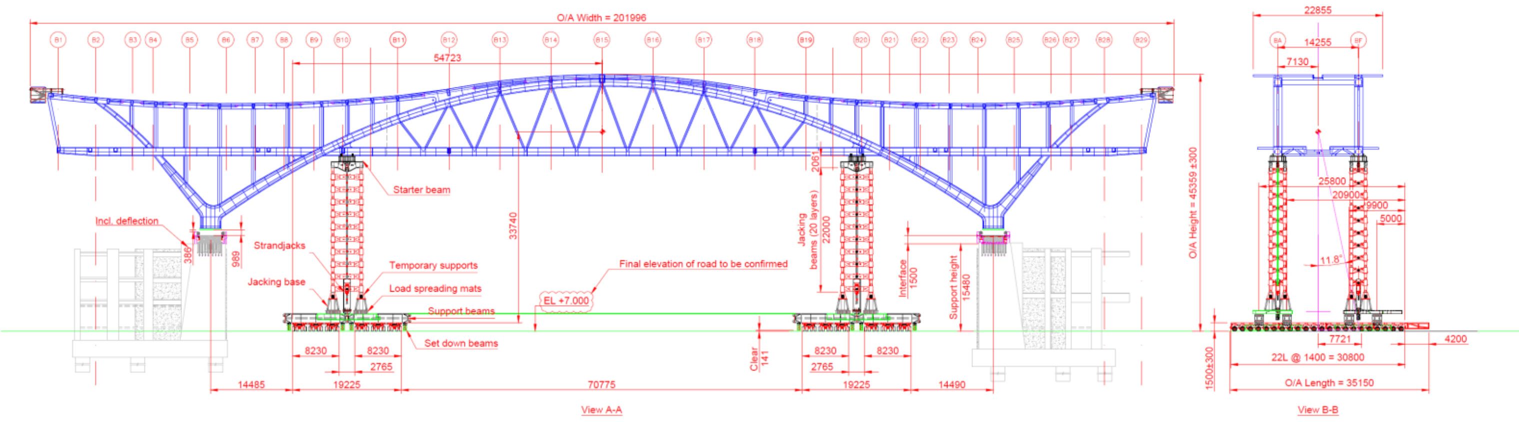
SPECIFICATION OF THE PROJECT

Weight	=	5,100t
Length	=	200m
Width	=	23m
Installation height	=	Approx. 35m

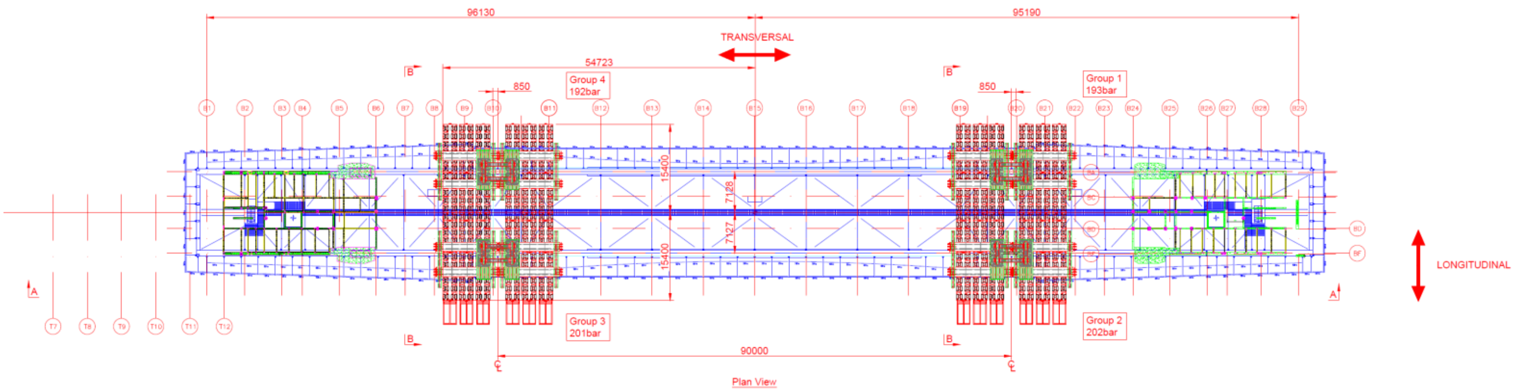
EQUIPMENT USED

- 4 x 5,200t jacking capacity
- 264 Axle lines of SPMT's
- Strand jacks to pretension the jacking towers
- Steel construction to increase stability during the jacking operations

← *Drawing 2: Transport of the bridge – final position*



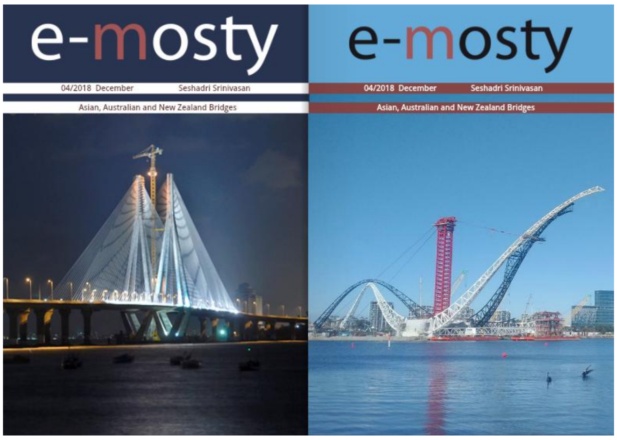
Drawing 3: Bridge Installation - Elevation



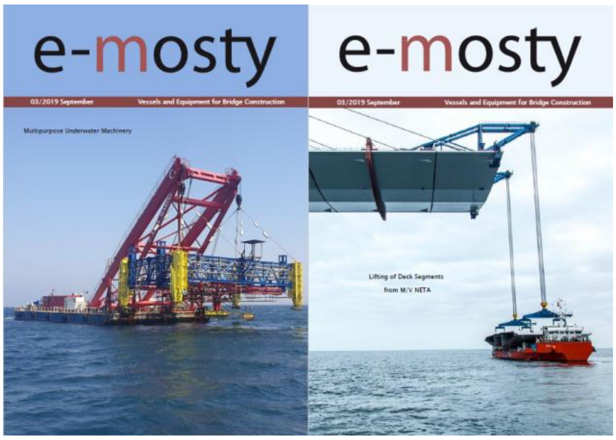
Drawing 4: Bridge Installation - Plan

Read about other Mammoet and ALE (ALE was acquired by Mammoet in 2020) Heavylift projects in previous issues of e-mosty.

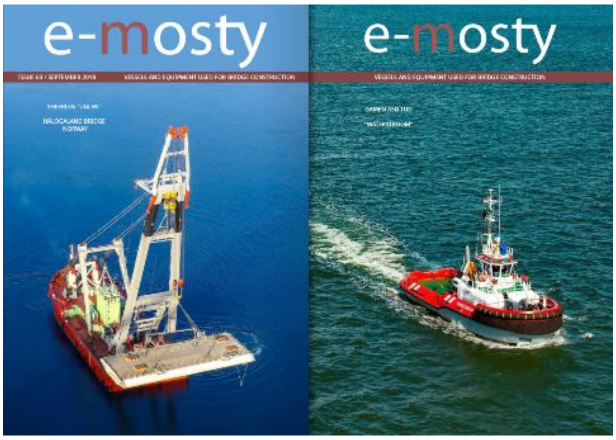
(click on the image to read the magazine in pdf)



Matagarup Bridge Installation



Bridge Removal over the Danube River in Serbia



The Constitution of 1812 Bridge: Transportation and Lifting

SŐDERSTROM RAILWAY BRIDGE REPLACEMENT

Sofia Hanner, Business Development Manager, Sarens Sweden

Figure 1: Installation of the new bridge section

INTRODUCTION

The Railway Bridge between Stockholm Central Railway Station and Stockholm Sődra is a vital part of the rail network in Stockholm. As it narrows in this section, the traffic is very heavy.

A large part of the railway through central Stockholm was built in the 1950s. Now it needs to be renovated to ensure the long-term reliability, quality and capacity of one of Sweden´s most trafficked and utilised stretches.

Every summer from 2018 to 2020 the link is closed down for eight weeks for renovation and modernisation.

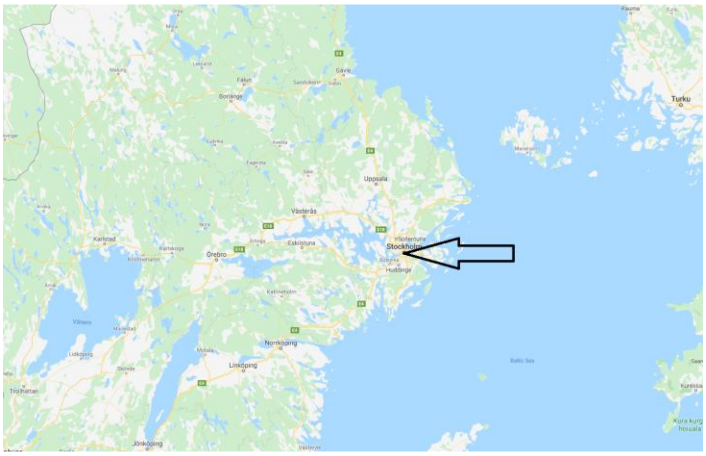
In the summer of 2019 the superstructure of the railway bridges – over Sőderstrom and Sőder Mälarstrand was replaced, and in the summer 2020 the next bridge between Riddarholmen and Tegelbacken was replaced.

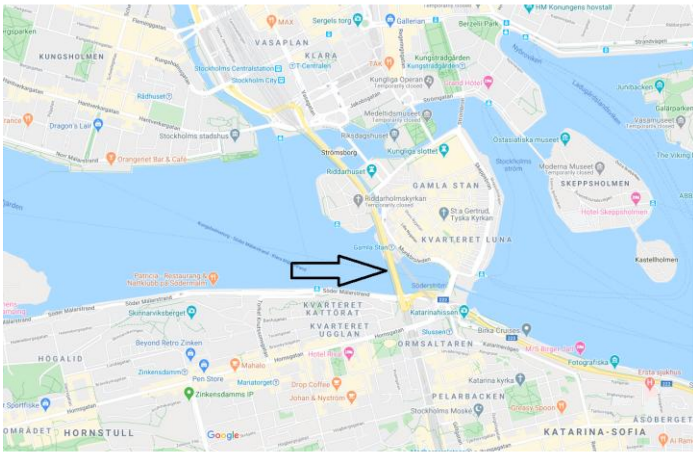
SCOPE OF WORKS - SUMMARY

Sarens scope of works included:

- Sea transport of bridge sections from Tallin, Estonia and their shipment to Stockholm, Sweden;
- Loading of old bridge parts on barges and shipping them from Stockholm to Vasteras, Sweden;
- And finally installation of the new sections at the project site in central Stockholm.

To achieve the programme, Sarens needed to undertake complex and detailed planning.





Figures 2 and 3: Location of the Bridge on map. Source: maps google

The bridge is a part of the busiest railway line in Sweden.

The shutdown for the Sőderstromsbridge was limited to 8 weeks during the summer vacations.

The company Implenia was awarded the "Getingmidjan project" which includes replacement of two railway bridges.

THE METHOD

At a very early stage Implenia understood that the replacement of the new bridge was needed to be done from water level.

Several methods for the installation were discussed during a long lead-in time and the final method was not finalized until a few months before execution.

The method combining the use of self-propelled motorised transporters (SPMT) with several barges to float in the 190m long, 1,400t bridge section was very unusual in Sweden. Nothing similar had been done before.

Therefore a quick mobilization of staff and equipment from Sarens for the execution needed to be done.

TRANSPORT OF THE NEW BRIDGE FROM TALLIN TO VASTERAS

Sea transport from Tallin to Sodertalje was planned and organized by Sarens.

Sarens collected the bridge sections in Tallin, Estonia, with its largest barge Caroline and SPMTs. Load-out was done with SPMTs, and the bridge sections were positioned onto Sarens standard sea grillages.

Due to the maximum 19.5m width of the Sodertalje Lock to get into the inner lake of Malaren, a 'load-over' to smaller barges needed to be executed.

Sarens executed a load-over by use of SPMTs from the sea-going barge 'Caroline' onto an inland barge called 'Jozef-Roza'.

This inland barge had two additional barge fillings of approx. 2m height; these were necessary to get enough freeboard, to perform a trailer load-in in Vasteras with SPMTs.

Sarens planned and organized the inland water transfer from Sodertalje to Vasteras in good cooperation with local authorities and pilots.

Figure 4: Passing through the narrow lock

At the harbour of Vasteras, Sarens executed a load-in of the bridge parts and positioned them on "Temporary Modular Sarens Stooling" that was designed and delivered as part of the contract.

REMOVAL OF THE OLD BRIDGE PARTS

To remove the old bridge sections, Sarens collected and positioned two inland barges and two custom prepared Sarens Modular Barges (SMB) underneath the Old Bridge in Stockholm.

Both inland barges were equipped with two barge fillings of approx. 2m height, on top of this barge filling there were two sets of SPMTs were positioned.

SMB (barges) were configured in a special formation and equipped with Sarens Modular Stools, especially designed to fit in between the bridge pillars.

After positioning of all barges they slowly took over the load of the complete Old Bridge by de-ballasting all barges using a ballast system controlled by its operators.

When the Old Bridge was loaded onto the barges, it was cut into two parts. After this was executed safely, the bridge was moved off from the bridge pillars by the use of mooring winches.

After it was moved 30m towards the lake, the bridge section was turned 90 degrees.

To get it above the inland barge, the rotation was done by propulsion of one set SPMTs.

After turning the bridge section 90 degrees, it was possible to load the section onto the inland barge.

Bridge sections were transported from Stockholm to Vasteras, unloading of the sections was executed by the use of SPMTs and then they were positioned onto supports delivered by Implenia.

INSTALLATION OF THE NEW BRIDGE

Transport and installation of the new bridge was executed with a combination of two inland barges + two Sarens Modular Barges.

Load-out of the New Bridge in Vasteras was executed with four sets of SPMTs and was driven onto two inland barges at the same time.

Driving with two barges was a high level operation, ballasting two barges in one time. After load-out of the new bridge, the barges were transferred to Stockholm.

After arrival in Stockholm a jack-up barge was moored alongside one inland barge.

The complete superstructure and barge combination was brought in front of the bridge pillars by the use of two boats.

Sarens moored the combination by the use of mooring winches. After positioning of the combination, the SMB barges were installed and de-ballasted to take over some load from the inland barges and to unload one set of SPMTs.

When one set of SPMTs had been unloaded, the inland barge was turned 90 degrees.

Figure 5: Removal of the old bridge

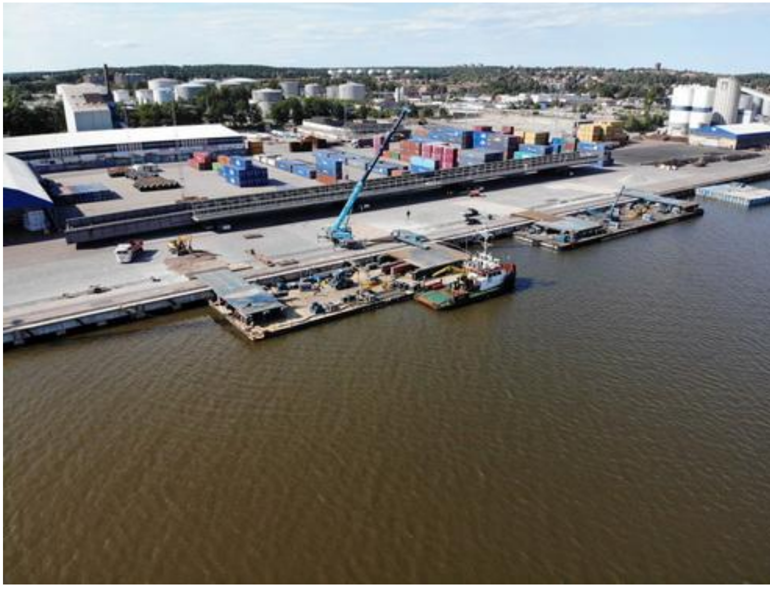


Figure 6: Load-out in Vasteras Port

Figure 7: New bridge heading toward the site

This was also executed with the other inland barge. After turning both barges the jack-up barge was fixed to the bottom.

By the use of several mooring winches the full combination was pulled into place and brought exactly above final bridge position. When it was spot-on, the barges were ballasted to lower the bridge onto its final position.

SCHEDULE AND COORDINATION

The production of the sections in Tallinn was delayed and there was a need for Sarens to take greater responsibility with additional equipment and to accelerate up the activities.

The critical timing and complexity of the project required extensive preparation and coordination at three different locations in Sweden.

Coordinating with other contractors at the installation site was also a challenge as there were other projects ongoing.

Also there were other works that needed to be executed at the bridge after installation before the eight weeks of shutdown.

EQUIPMENT

The limitations with the lock and exceptional size of the final large bridge element demanded a lot of equipment. In order to guarantee the strength of the barges to handle the heavy weight, all the barges were brought into the project from abroad.

These were mainly Sarens's own barges and modular barges that had the required capacity.

Critical requests for equipment occurred during the project that Sarens was able to handle.

Different types of equipment such as SPMTs were moved back and forth between the three different locations in Sweden which demanded detailed planning.

Approximately 5,000t of additional equipment was shipped from Belgium to Sweden to execute this project.

SAFETY

The planning of the project also included highest safety for the workers and external people.

No one could enter the barges without life jackets and the safety awareness of the staff was very high.

In the final installation days there was heavy rain, the barges were wet, so the project manager took precautions for safety reasons and decided to delay the installation until the weather was dry and the wind calm which postponed the installation.

Still there were some reserves in the schedule and the installation was done ahead of schedule.

Figure 8: Heavy rain represented complication for installation of the new bridge

BENEFIT FOR THE CLIENT

It was a benefit for Implenia to have Sarens as a contractor since we had the responsibility for all the parts connected to the replacement of the railway bridge, there was a possibility to plan everything according to our experience from other projects abroad.

With a broad network and large range of equipment within Sarens, we had the flexibility to quickly mobilize extra sets and additional support equipment when it was needed.

The expertise among the project team of Sarens was handpicked; the teams had been working for years on similar projects and knew exactly what they were doing.

Their working agility allowed thorough planned thinking of every detail in the different operations to make sure it was on time, safe and with good quality.

This has resulted in Sarens being awarded the exact same contract for the next bridge in the Getingmidjan project in 2020.

BRIEF PROJECT OVERVIEW

THE CLIENT: Trafikverket

(The Swedish Transport Administration)

THE CONTRACTOR:

Implenia Sverige AB

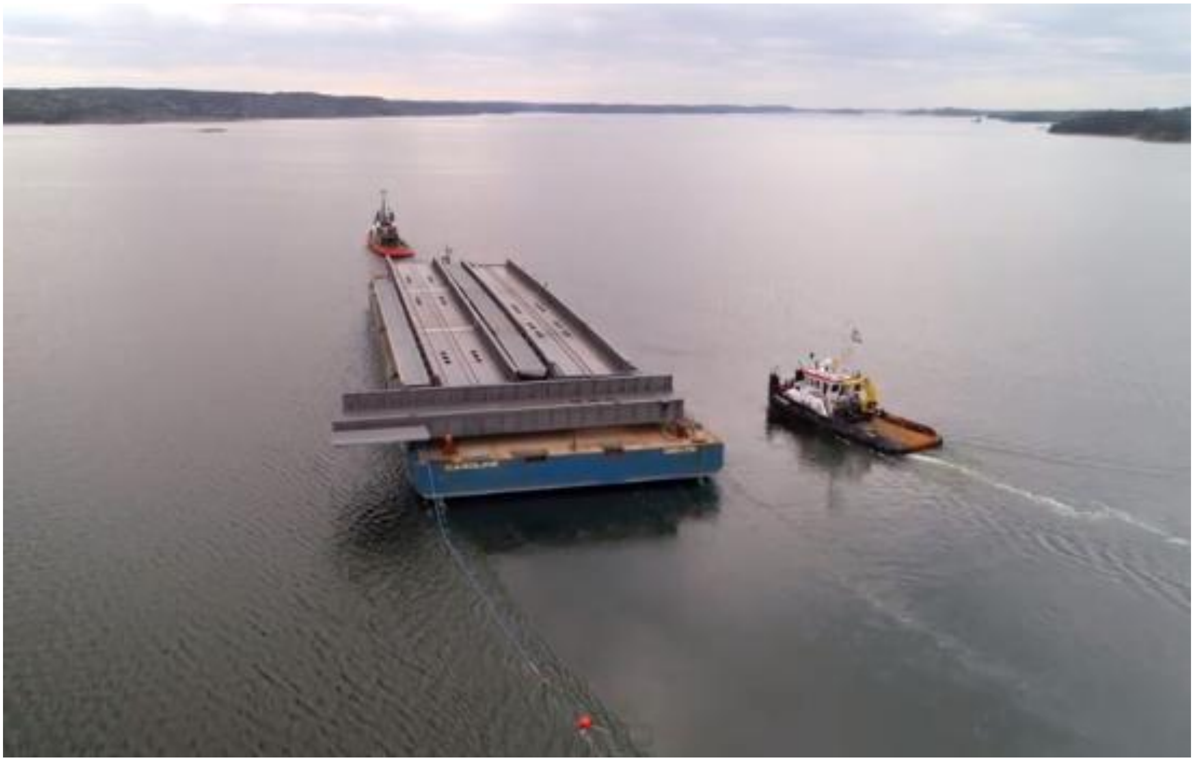
Transport and Installation of the Bridges:

Sarens

Figure 9: SPMT on a barge during installation of the new bridge

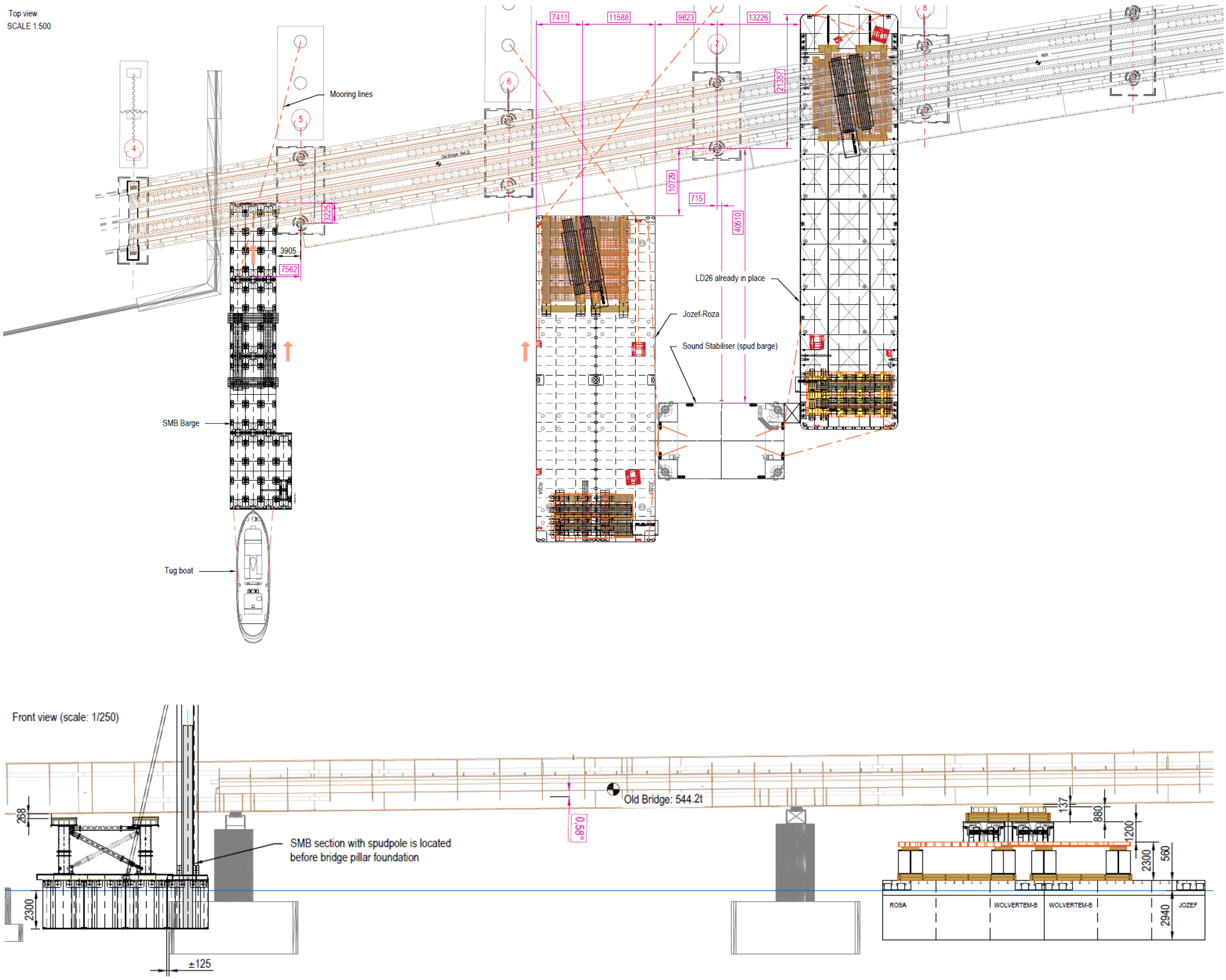
Figure 10: Installation of the new bridge – final moments

Video 1: Visualisation of the replacement of the bridge



Video 2: Transport and installation of the bridge

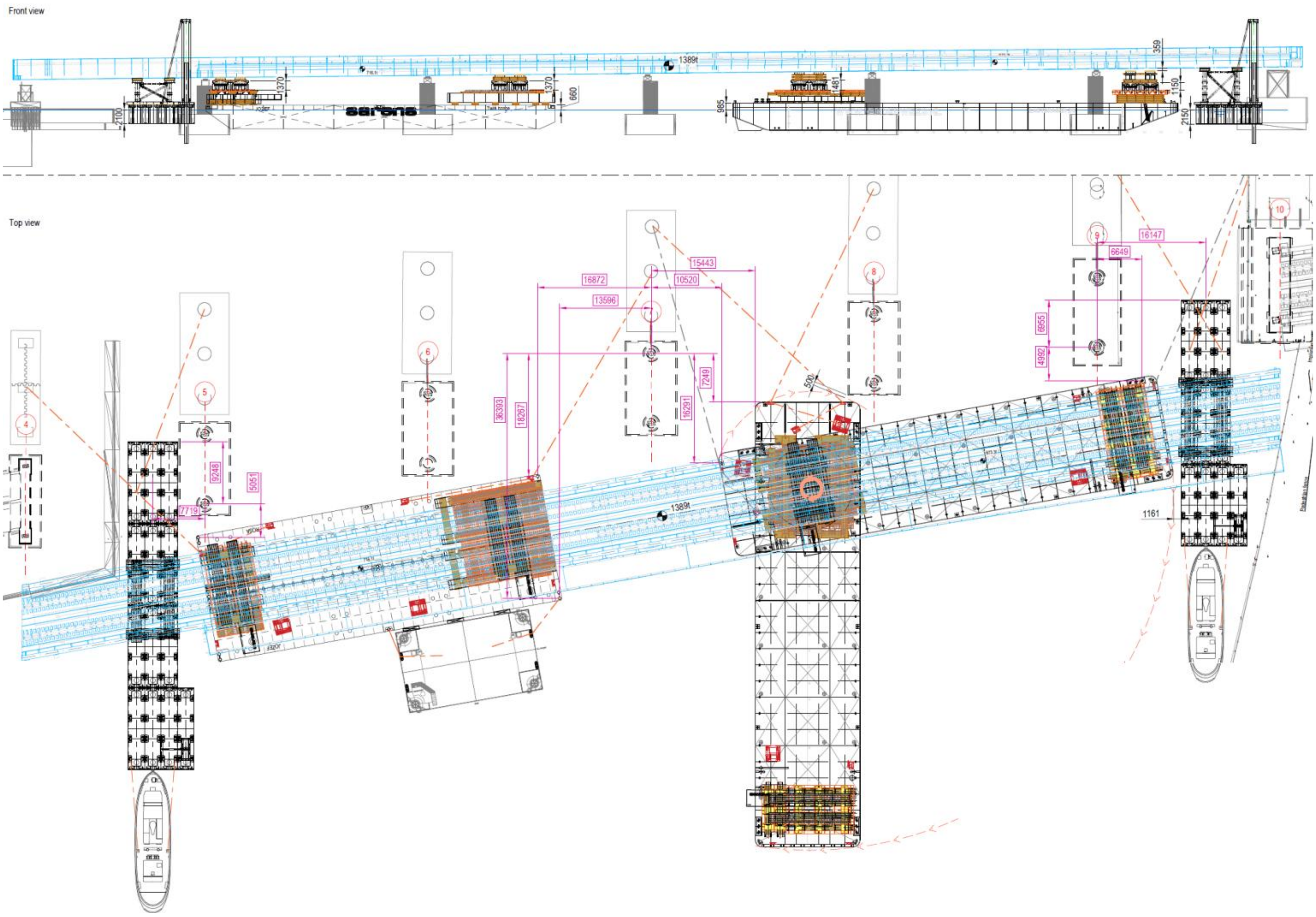
Click on the image to play the youtube video

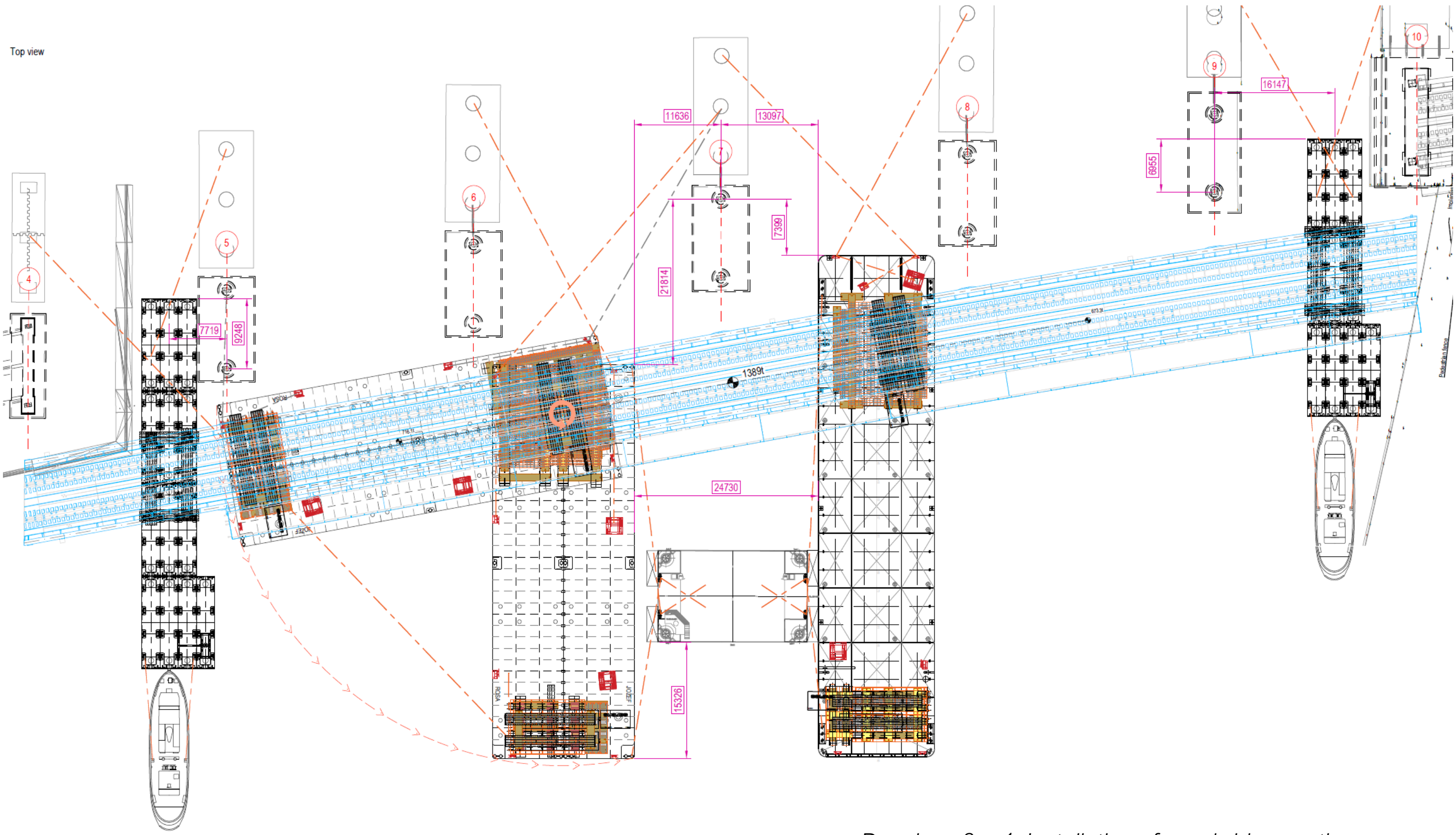


Drawings 1 + 2: Removal of old bridge sections, Step 1

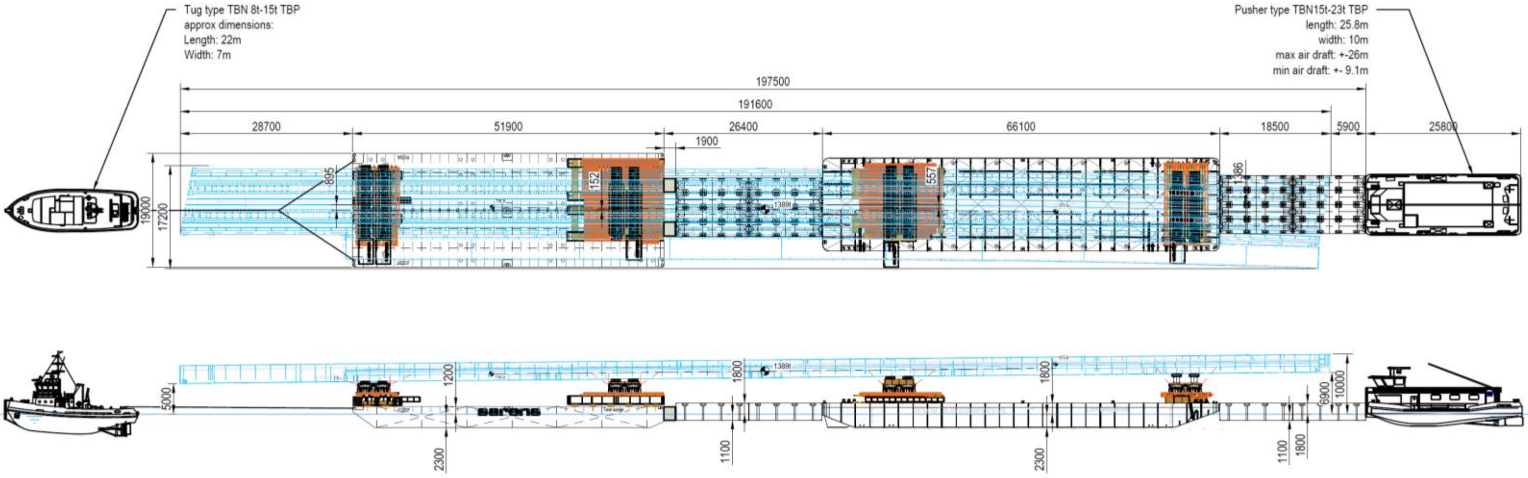
<u>Removal of old bridge sections</u>

Step 1: Pre-ballast to sail underneath old bridge
Step 2: Sailed underneath and ballasted until touching
Step 3: Bridge lifted and sailed back
Step 4: After horizontal move of 2450mm
Step 5: Turning manoeuvre, take over weight from SMBs





Drawings 3 + 4: Installation of new bridge sections



Drawing 5: Towing Arrangement - Jozef/Roza +Lastdrager 26 + SS

The equipment: Jozef/Roza + Lastdrager 26 + SMBs + push-/tugboat + SPMTs

Cargo				
Name	Length (mm)	Width (mm)	Main girder height (mm)	Weight (t)
SS1	100440	15280	3000	716,1
SS2	91490	16120	3000	673,3
SS (comb)	197500	17200	3000	1389

APOLLO BRIDGE INSTALLATION

Peter Paulik, Slovak Technical University

Figure 1: View of the Apollo Bridge in 2019
Photo Credit: e-mosty

INTRODUCTION

The Apollo Bridge in Bratislava, Slovakia, built 15 years ago in 2005, has become world-famous with its distinctive construction method.

The main bridge structure weighing 5,200 tons was built on the riverbank and turned into its final position around a special spherical 'calotte' bearing.

In recognition of this construction method, the bridge was nominated for the OPAL AWARDS 2006 in the USA, where it withstood the competition of much larger structures and was among the top 5 awarded structures.

This article describes the design and construction method focussing on the process of its complex installation from the Danube riverbank.

KEY FACTS

Main span	231m
Total length of the bridge steel structure	517.5m
Rise of the arch	36m
No. of lanes	2x2
Weight of the steel structure	5,240t
General designer:	Dopravoprojekt a.s
Main constructor:	Doprastav a.s.

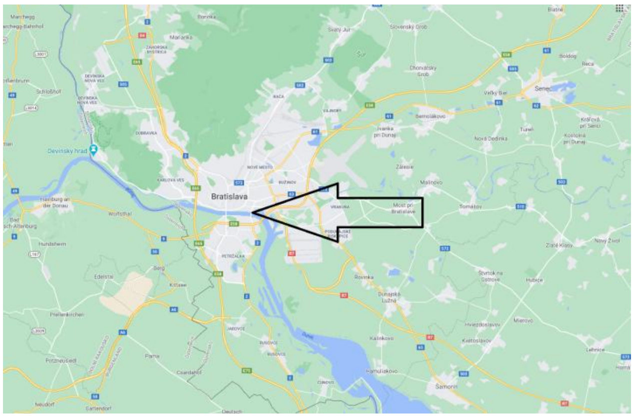


Figure 2: Position of the Apollo Bridge in Bratislava
Source: google maps

DESIGN

Bratislava is a fast-growing capital city located on the Danube River with increasing demand for traffic solutions. These resulted in the need to provide new Danube crossing every 10 years.

One of them was a road bridge built in 2005, which connects the city center with a residential urban area.

When choosing the shape of the bridge, the main restrictions were the required navigational clearance and the existing intersections on both sides of the Danube.

Final design solution had to ensure the required minimum height of the structure above the water level of the Danube (approx. 10m) and, on the other hand, to ensure that the roads leading to the bridge would not exceed maximum design gradients. The navigable width also required a span of the main bridge to be more than 200m.

Figure 3: Location of the bridge and its connections to existing infrastructure

Suspended as well as cable-stayed systems were excluded in respect of the urban perspective, which required no building to have a significantly dominant element that would disrupt the free view of the waterfront.

Another reason, why suspended and cable stayed structures were discounted, was the need to build high pylons and to perform complex structural design which would result from a non-linear alignment consisting of curved and straight sections.

After these considerations and investigations, a bowstring-arch structure was chosen for the main span.

The final geometry was further complicated because the main span of the bridge is skewed to the river, and the arches are inclined.

By this means the arches are formed by asymmetric ellipses, mainly for architectural reasons.

This specific geometry arose from the necessity to keep the harmonic shape of all main parts of the bridge, even though its main arches are skewed.

Little imagination is needed to realize how awkward would it look like with inclined segmental arches with bases that are not orthogonal to each other.

Mathematically defining the shape of such surfaces and their intersection with other surfaces requires a considerable dose of imagination as well as the ability of spatial vision.

Such geometry brought several technical difficulties during the design and construction, but, in the end, it is not visible at all.

The last design decision, to bridge only two thirds of the Danube, resulted from the traffic requirement for smooth curves and the economic criteria.

Also, from the architectural point of view, if the bridge were to span the entire width of the Danube, it would have to have an arch about 10m higher, making it too dominant in the city environment.

Furthermore, the planned widening of the Danube riverbed, as part of the flood protection of Bratislava, would lead again to the situation that the bridge would not span the entire width of the river.

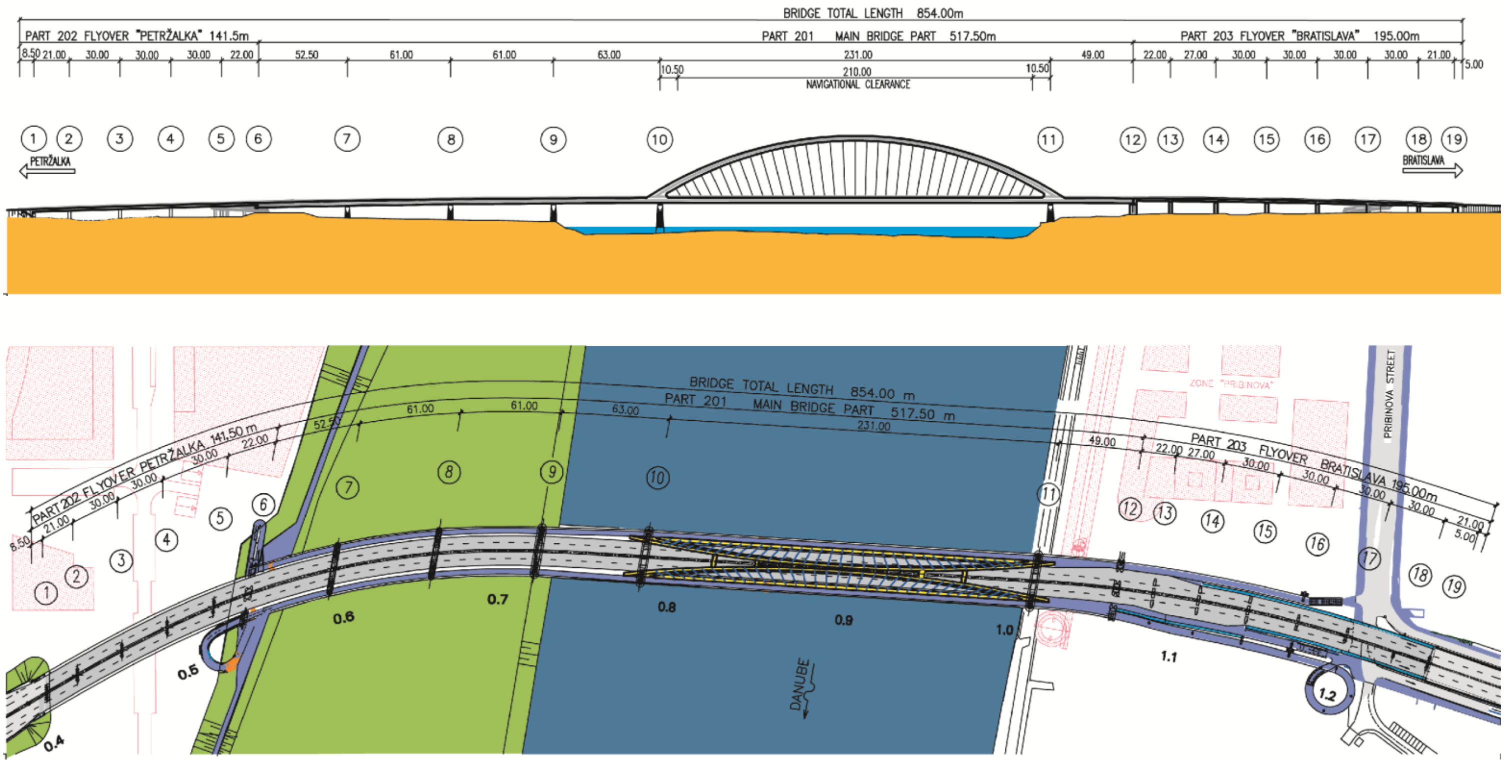


Figure 4: Elevation and Plan View of the Bridge

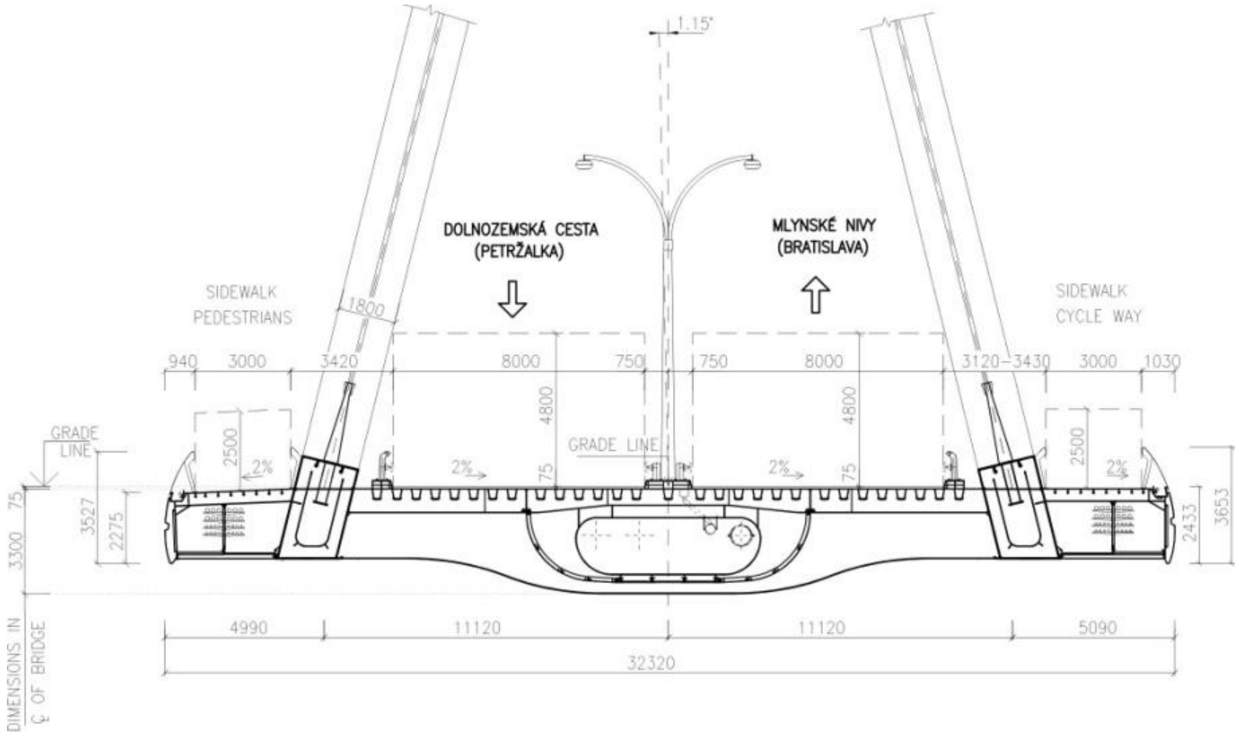


Figure 5: Cross-section of the main span

Thus, the final design is a multi-span girder bridge, with a bowstring arch in the main span.

The decision on the orthotropic deck was closely connected with the design of the main girders, crossbeams and longitudinal beams.

Two main beams are designed as continuous box-girders with 6 spans. In the main span, which has a length of 231m, they are suspended from the arches.

They also vary in height. In the main span they are 0.9m taller than in the other spans, where they have a height of 2.20m.

Thus, a part of the beam is projecting above the bridge deck in form of a parapet. This shape of the main beam is very efficient in several respects. It is statically very effective, provides a smooth alignment during construction (assisting hanger tensioning) and during operation of the bridge.

This parapet also creates a psychological and a robust safety element between the roadway and the pathways.

And finally, extension of the beams above the deck optically reduces their height (the parapet is hidden behind a railing from a side view), which enhances the slim line of the bridge.

From the underside view of the bridge the dominant elements are the unusually shaped crossbeams.

Their shape is both interesting visually, and it is also statically efficient. These crossbeams are also a structural part of the longitudinal tube, in which service pipelines are laid.

On the outer side of the main girders pathways for pedestrians and cyclists are situated, under which passable corridors for cable lines are also placed.

Concrete flyovers

All concrete substructures are shaped using the same "technique". The basic design consists of an elliptical cross-section walls, which are modified by different "cut-offs" in a statically or a functionally practical shape.

The superstructure of these flyovers on both sides of the river is also creatively shaped, especially the flyover on the Bratislava side, which has several functions.

Directly on the flyover bus stops are positioned so that they are coordinated with the adjacent walkways, stairways and elevators.

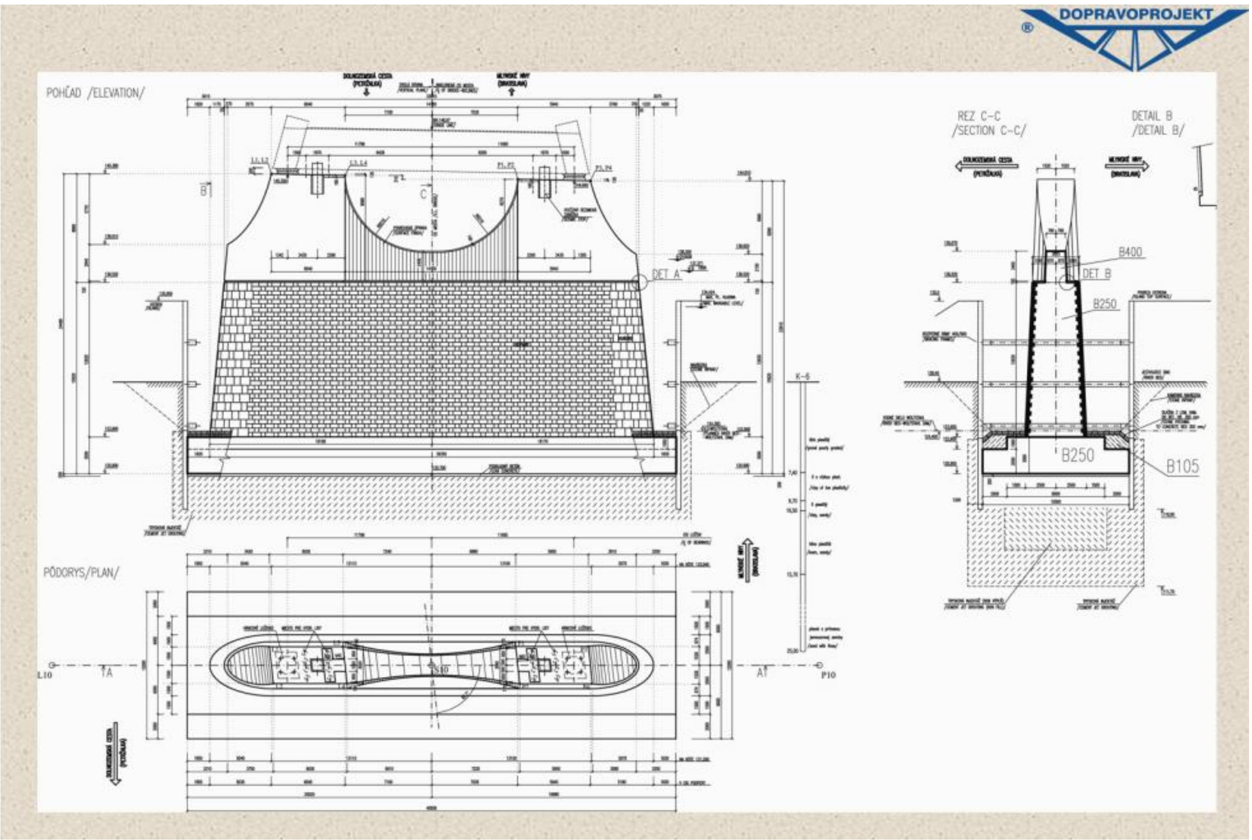


Figure 6: Plan and Section of the piers

There is also a bicycle bridge just along the main flyover.

All this creates a complex of structures with boldly overhanging crossbeam consoles. Cross-sections of the structures of the flyovers and walkways are repeating in different variations the shape theme of the main girders of the main bridge structure.

Special attention was given to the shape of the flyovers, which soon became a part of an attractive urban area on both sides of the Danube.

Figure 7: View of finished concrete flyovers
Photo Credit: M. Maťaščík

Figure 8: View of complete piers
Photo Credit: M. Maťaščík

CONSTRUCTION METHOD

The free area nearby the construction site at the left riverbank and the possibility of regulating the water level in the river, by means of the Gabčíkovo dam, led the designers to an unconventional construction technique.

The adopted solution was to construct the main span on the riverbank of the Danube River and then to rotate it around a special calotte bearing to its final position by means of a floating vessel.

This solution was cheaper than constructing the whole bridge in a dry-dock, and to transport it as a whole to its final position, even though the process of rotation was more challenging.

The steel structure of the bridge was welded from sections which were produced in production facilities in the Czech Republic and Hungary and from there they were imported to Slovakia by means of heavy-duty trailers.

The size of the individual parts was limited due to the transport restrictions and the carrying capacity of the cranes.

During the assembly of the arch, the individual parts were placed on steel supports, which were removed only after their full completion, when the arch was able to function independently.

As it is common in arch structures, the most difficult parts of arch construction were the placement of the first bottom segments of the arch, which had a complicated shape and the placement of the last segment on the top of the arch due to thermal deformations (the shape of the last segment had to be slightly adjusted according to the real geometry).

After the completion of the arch, 66 hangers were installed, which were stressed to the calculated minimum value. Their full activation was achieved after removing the steel supports from beneath the deck.

At this construction stage, the main bridge span was placed on a slideway on a temporary pier at the riverbank, on a special calotte bearing on one of the final piers at the riverbank and on a quarter-circle steel track, which allowed the structure to rotate around the calotte bearing.

The special calotte bearing was designed for this purpose, which allowed the rotation of the bridge.

Figure 9: Assembly of the arch with individual parts on steel supports
Photo Credit: P. Paulík

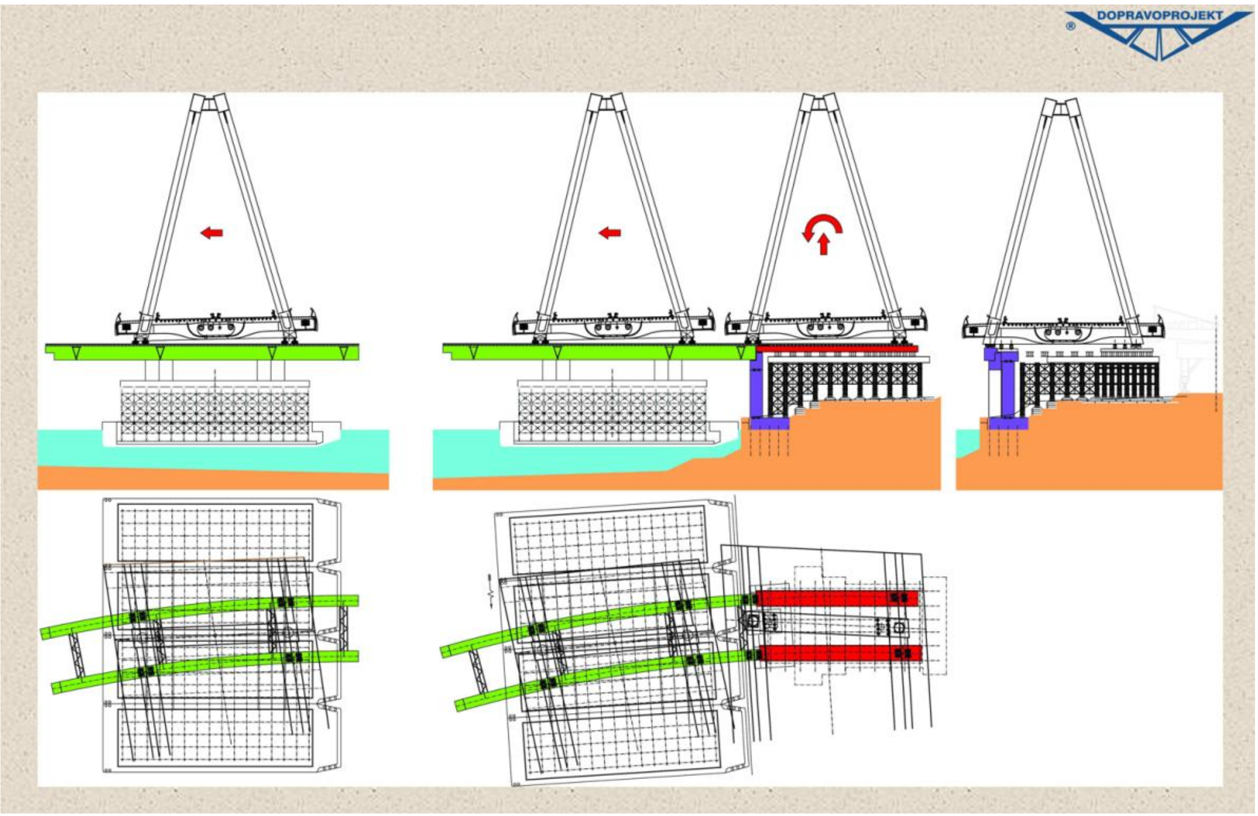


Figure 10: Principle of sliding the bridge from temporary pier onto the vessel

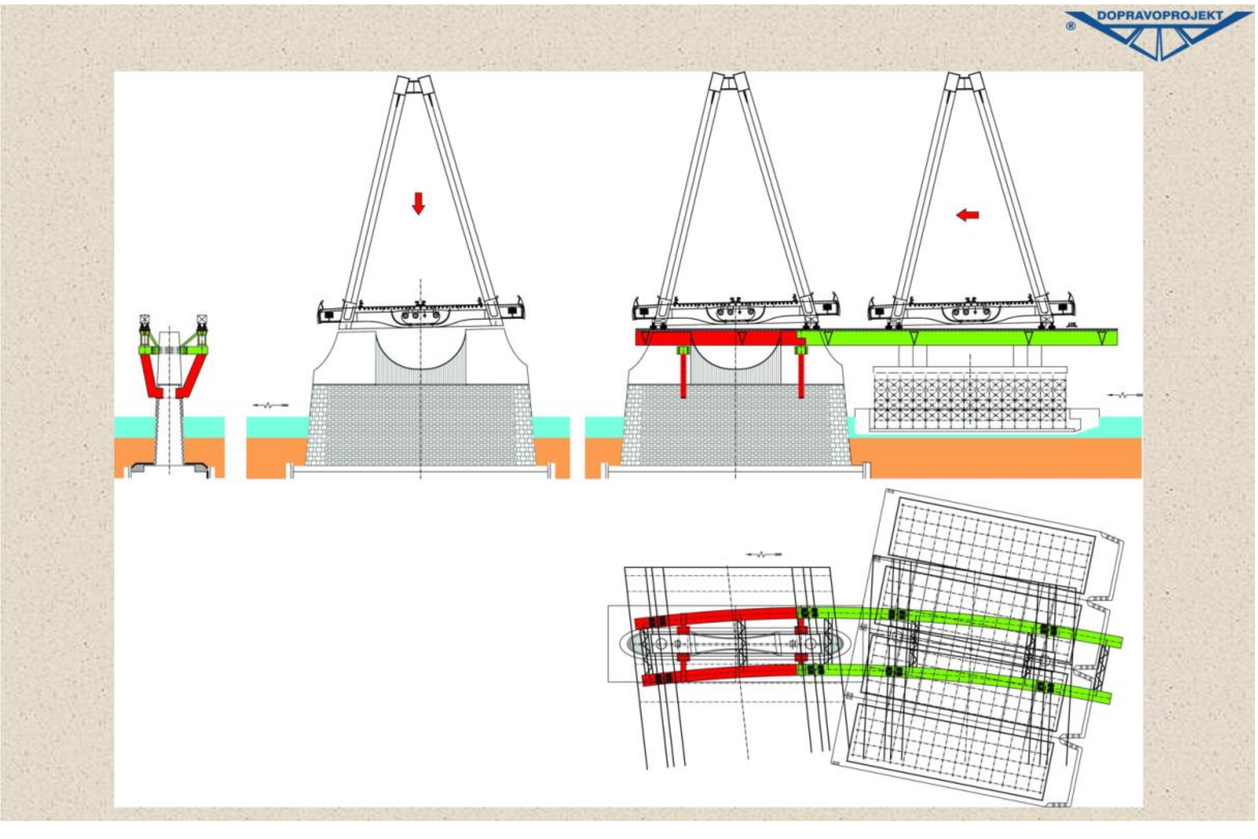


Figure 11: Principle of sliding the bridge from the vessel onto the pier in the riverbed

It had to be strong enough to transfer all horizontal forces at this construction phase and after bridge completion to allow longitudinal movements.

To fulfill all these criteria, it was designed to have two "stories" and a blocking mechanism to restrain longitudinal movements during the construction stages.

The preparation for the rotation of the bridge began with the temporary steel slideway structure being floated on the vessel beside the steel slideway structure placed on the temporary pier.

Subsequently, the height of the slideway on the vessel was aligned with the height of the slideway on the temporary pier.

This height adjustment was performed by regulating the amount of water in the chambers of the vessel (i.e., when water was pumped into the chamber, the immersion of the vessel increased and the height of the slideway decreased).

After precise adjustment, the two steel slideways were interconnected.

After this connection, the rotation of the bridge began, consisting of three main phases:

- sliding one side of the bridge onto the vessel,
- turning the bridge nearby its final position, and,
- sliding its one side from the vessel onto the pier.

Sliding the bridge from the temporary pier onto the vessel and then from the vessel onto the pier was a very demanding operation, during which every millimetre was closely monitored.

It was always necessary to stop the movement in prescribed steps and to adjust the water level in the inner chambers of the vessel.

Thanks to the chambers filled with water, it was possible to maintain the balance of the whole bridge during the sliding operations (the weight of the water in these chambers had to be in balance with the weight of the bridge, to prevent its excessive tilting).

After moving one side of the bridge onto the vessel, the two slideways were separated from each other and for the spectators the most interesting part of the turning of the bridge on the Danube began.

The principle of rotation can be easily explained in the following figure:

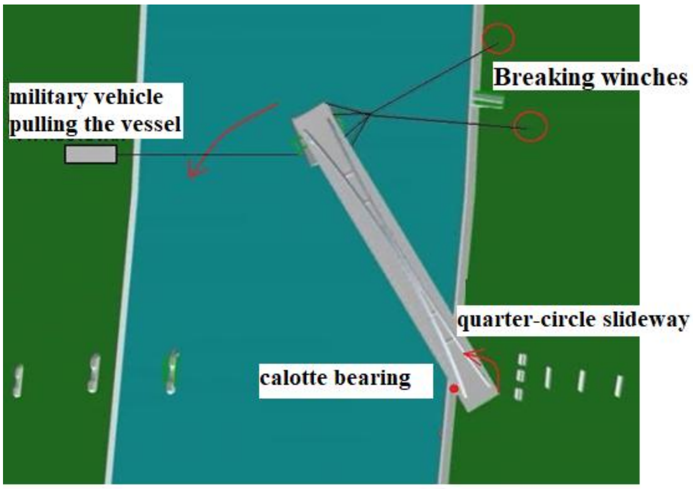


Figure 13: The principle of rotation

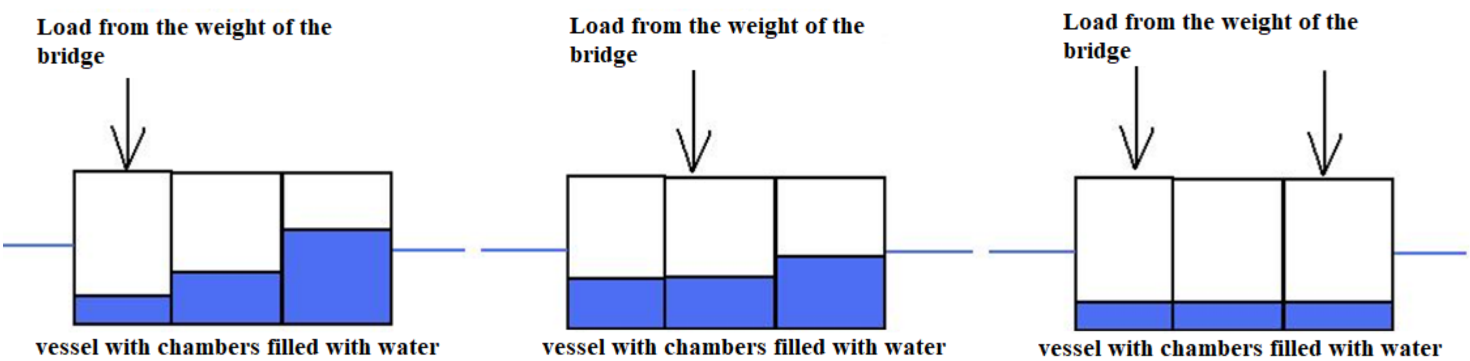


Figure 12: Maintaining the balance of the bridge during the sliding operations

Figure 14: Sliding the bridge from temporary pier onto the vessel – view from the riverbank. Photo Credit M. Pokorný

Figure 15: Sliding the bridge from temporary pier onto the vessel – aerial view. Photo Credit: M. Pokorný

To move the vessel a military vehicle was used, which pulled it from the opposite riverbank. Originally, it was planned to tow the vessel only few meters, and from there it was believed that it would be moved by the current of the Danube River itself. However, the reality was different.

Due to the stabilization of the water level by the Gabčíkovo Dam, the flow of the river slowed down so much that it was not possible to move the vessel with the bridge on it.

By this means, it had to be constantly pulled from the riverbank and the brake winches installed to control the motion were found to be redundant.

The turning procedure was divided into several steps during which the bridge was constantly monitored and the data were compared with the theoretical values.

Figure 16: Turning the bridge - a view of the quarter-circle slideway. Photo Credit P. Paulík

Before reaching the pier, the height of the slideway was adjusted again by pumping the water out of the chambers of the vessel.

In the last phase of turning, it was necessary to draw the vessel to the pier by boats, as pulling by the military vehicle from the right riverbank was no longer possible due to lack of space.

Due to the water level regulation by Gabčíkovo Dam, the surface of the Danube River was as steady as a surface of a lake.

After reaching the pier and with height adjustments of the slideway on the vessel, the bridge was connected with the slideway on the pier.

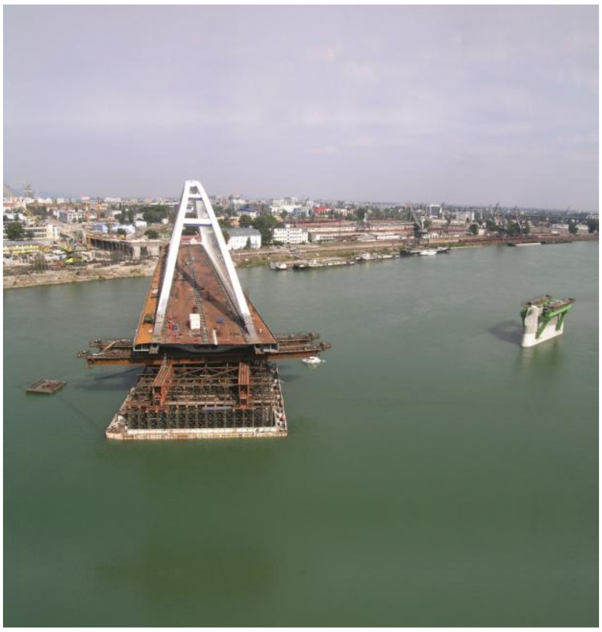


Figure 17: Turning the bridge. Photo Credit P. Paulík

Figure 18: Turning the bridge. Photo Credit P. Paulík

Figure 19: The bridge reached the pier
Photo Credit M. Pokorný

The transfer of the bridge from the vessel onto the pier was once again divided into several steps in which it was necessary to maintain the balance of the whole structure by pumping water in and out of the chambers of the vessel.

Finally, the vessel was towed away and the bridge was set into its final position.

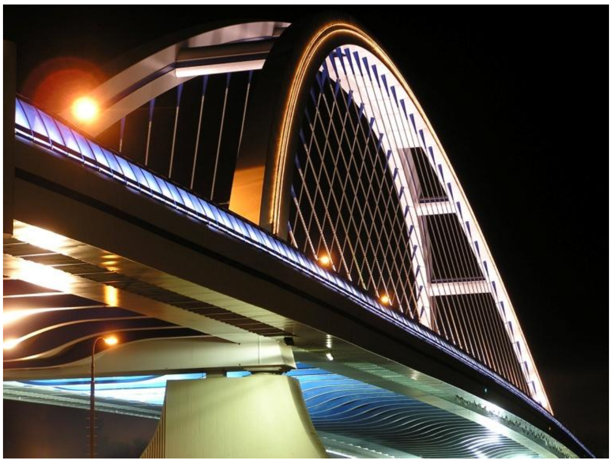
CONCLUSION

The described method of construction was very innovative, mainly due to the fact that it is seldom possible to construct the bridge that close to its final position on the river bank as well as it is not always possible to regulate the water level in the river, needed during the process of turning. method is very distinctive and shows the ingenuity of engineers to use every aspect of the available possibilities to their advantage when designing this bridge.

References:

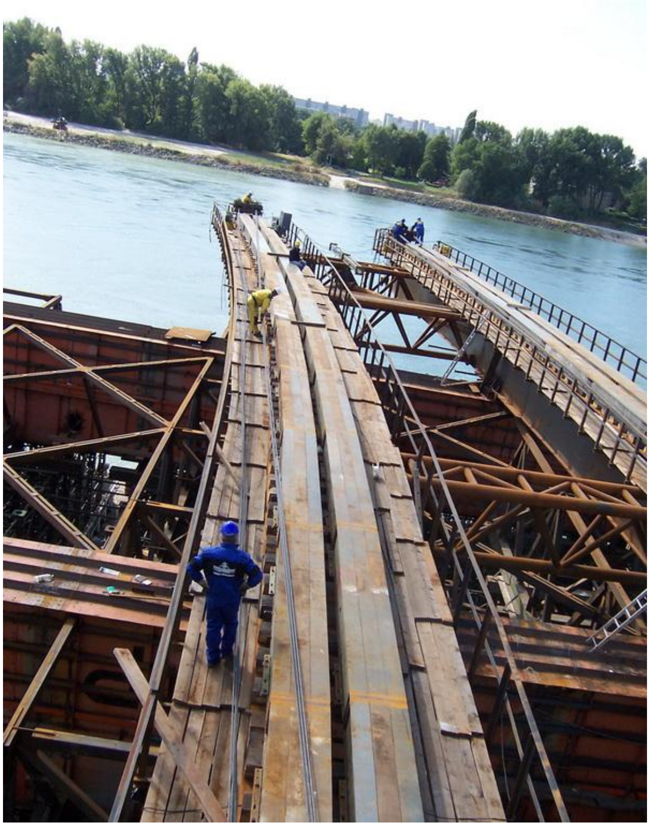
[1] Miroslav Maťaščík, Igor Masaryk: The conceptual design of the Apollo Bridge, in: Apollo Bridge – conference proceedings, Bratislava, 2006

[2] Ladislav Nagy: Construction drawings of the Apollo Bridge, in: Apollo Bridge – conference proceedings, Bratislava, 2006



Figures 20 and 21: Day and night view of the complete bridge. Photo Credit: M. Maťaščík

Photos from the construction



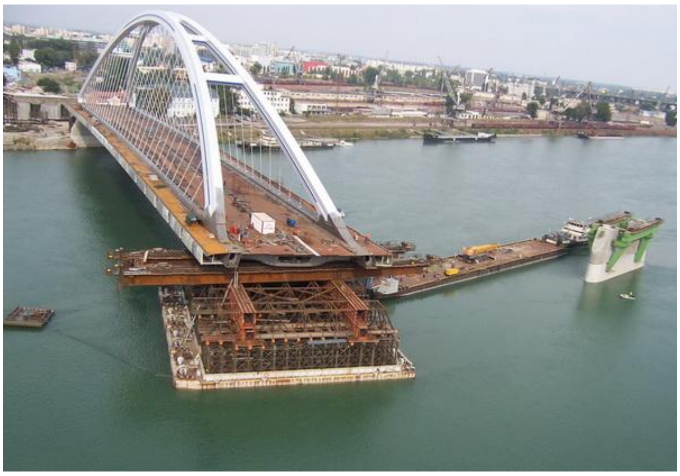


Photo Credit: AECOM

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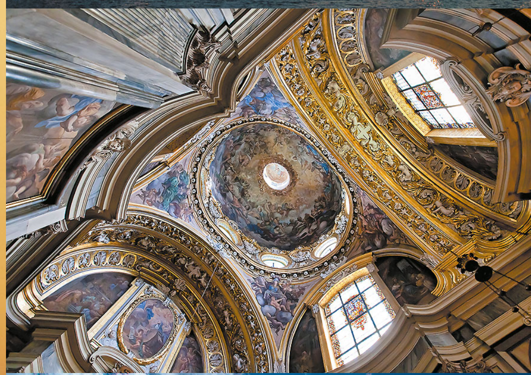

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+60%	+75%	+35.8%
Women Entering the Labor Force	Farmer Profitability	Labor Market Income

*Wyatt Brooks and Kevin Donovan - "Eliminating Uncertainty in Market Access: The Impact of New Bridges in Rural Nicaragua," 2017.

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