e-mosty

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Mersey Gateway Bridge. Arenales Bridge. BLWT.

Front Cover: Mersey Gateway Bridge, UK. Credit: MERSEYLINK CJV

Back Cover: Arenales Bridge, Nicaragua. Credit: Bridges to Prosperity

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This issue of our magazine e-mosty („e-bridges“) has three separate sections.

The first is devoted to the Mersey Gateway Bridge. The bridge is part of the major infrastructure scheme between the towns of Widnes and Runcorn in the north west of England. The bridge is a four-span cable-stayed bridge consisting of three singular pylons carrying the 6 lane highway deck on a central cable plane arrangement.

In this section you can read about its procurement, design and construction. The article also comprises drawings, photographs and video gallery.

Secondly, as we are a medial patron of Bridges to Prosperity, they have prepared for us an article about the longest suspension bridge they have recently completed – The Arenales Bridge in Nicaragua. The bridge was constructed over six months, through a partnership that brought together representatives from seven organizations, five countries and a broad variety of backgrounds. For the community of Arenales the footbridge is extremely important because river floods make the area impassable for more than 3,000 residents for more than three months every year.

Lastly, bridge design often requires wind tunnel tests. Therefore, the final article of this issue brings information on the wind tunnel in Bratislava and possibilities for its utilization. I believe that detailed article about this tunnel will be of interest to you.

Earlier this year I noticed on LinkedIn very interesting posts by Mr Łukasz Skotny from his Enterfea company who presented his free online courses on FEA. I like his enthusiasm and the way he presents it so I offered him free medial support in our September Issue. Meanwhile Lukasz has developed his company and activities, and together we have prepared a presentation explaining what he can bring to the table.

I have also prepared an overview of all major bridge structures you can read about in our previous issues and brief information as to what is being prepared. The magazine is constantly developing so there may be some minor changes in the plan thus this is only informative. I always welcome any new ideas, information and articles on bridges which I am happy to include in our magazine.

I do my best to keep the magazine open access. If you like our magazine, you can support us directly – via a "DONATE" button. The amount of your financial contribution is solely at your discretion.

I very much thank you in advance.

Magdaléna Sobotková

Chief Editor

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THE ARTICLE ABOUT THE MERSEY GATEWAY BRIDGE:

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Thank you for reviews of the articles, valuable comments and for all your assistance all the time

MERSEY GATEWAY BRIDGE

Magdaléna Sobotková

Photo Credit: Merseylink Civil Contractors Joint Venture

Commencement of works: 2014

Opening of the bridge to traffic: 2017

Type of the bridge: Cable-Stayed with three pylons

Main spans: 318 + 294m

Total length: 2,250m (including approach viaducts)

Location: Runcorn -Widnes, North West England, UK

Client:: Halton Borough Council

Employer: Mersey Gateway Crossings Board Ltd.

Employer´s Technical Advisors:

Ramboll, CH2M, Knight Architects

Consortium : Merseylink Limited (Macquarie Capital , BBGI , FCC) employed Merseylink CCJV – Kier Infrastructure and Overseas, FCC Construccion & Samsung C&T EC UK Consortium

Contractor´s Design Team:

COWI, Fhecor, DISSING+WEITLING

the mersey gateway
A BRIDGE TO PROSPERITY

MERSEY GATEWAY BRIDGE

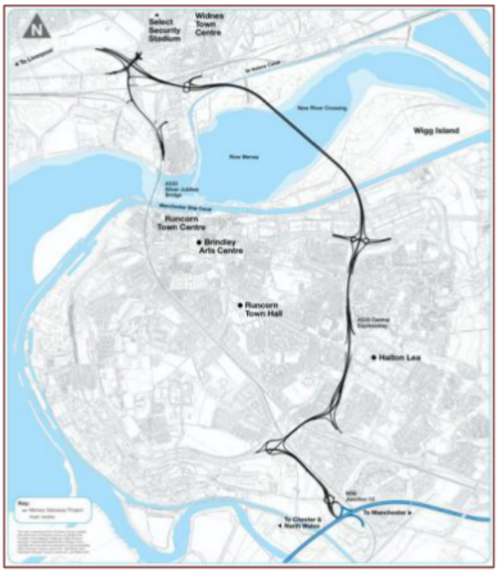
THE DESIGN AND THE CONSTRUCTION

Source: merseygateway.co.uk

1. INTRODUCTION

The Mersey Gateway is a six-lane road toll bridge across the River Mersey and the Manchester Ship Canal in north-west England. It connects the Central Expressway in Runcorn with the Eastern Bypass and Speke Road in Widnes. It is located approximately 1.5 km (0.93 mi) to the east of the existing Silver Jubilee Bridge.

A second road crossing over the Mersey was a long held aspiration of Halton Borough Council (HBC) and its neighbouring local authorities. In 2006 the Mersey Gateway Project was approved by the UK Department of Transport.



Figures 1 + 2: Location of the bridge
Source: Google Maps (1), merseygateway.co.uk (2)

Facts about the bridge

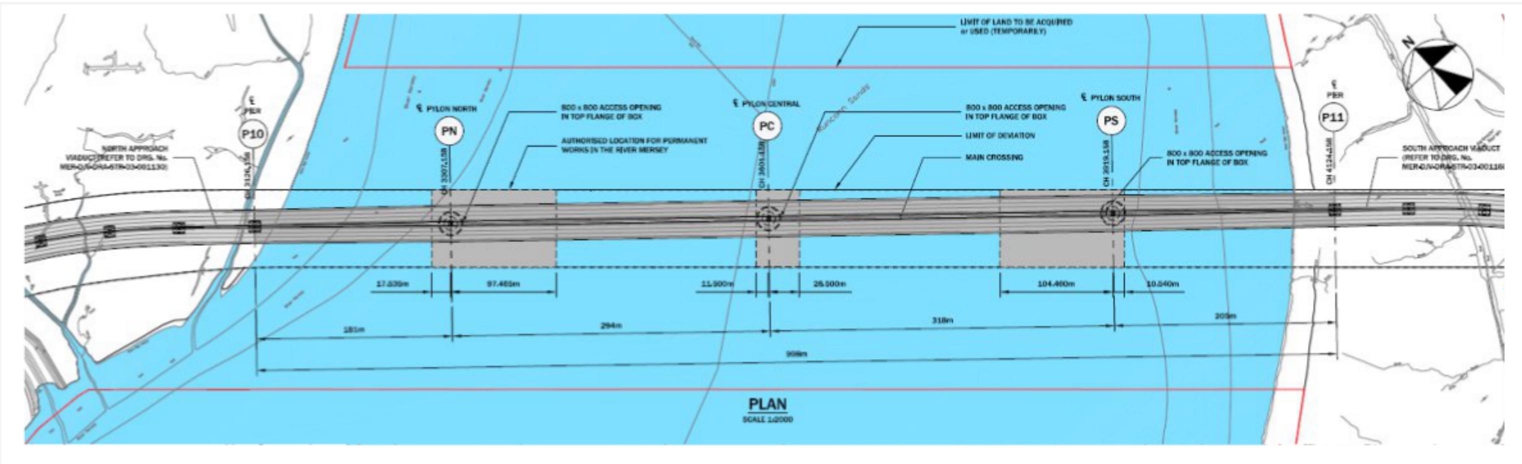
- *Contract type: 30-year design, build, finance and operate;*
- *A PPP Project financed by a mix of private and government lending;*
- *An estimated 4,640 new jobs through direct employment, regeneration activity and inward investment;*
- *An estimated £61.9 million a year in Gross Value Added by new jobs by 2030;*
- *Crosses the river around 1,500m to the east of the Silver Jubilee Bridge;*
- *60,000 vehicles to use the bridge every day are expected i.e. nearly 22 million vehicles every year;*
- *A tolled crossing with a speed limit of 60mph (95km);*
- *With three lanes across the Mersey in each direction;*
- *Forms the centrepiece of a new and improved high standard link road (9.500m long) connecting the national motorway network in north Cheshire with Merseyside.*

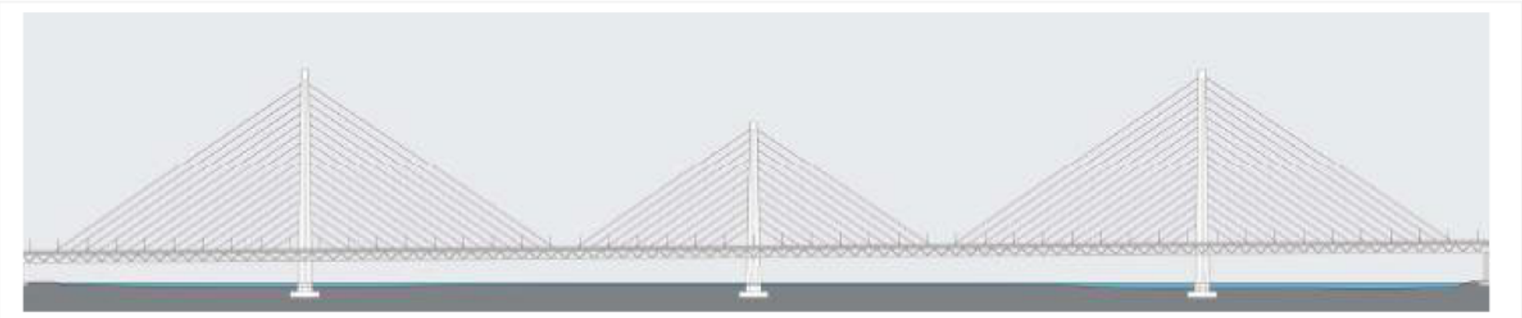
2. PROCUREMENT AND ARCHITECTURAL APPROACH

The wider project to develop the new Mersey Crossing together with improvements to the approach road network on either side was progressed by Halton Borough Council with a focus on maintaining high quality design whilst ensuring that the scheme was affordable.

The Council set out a list of strategic objectives aiming at regeneration and improvement of life quality which were subsequently defined in a set of relevant design and access policies as part of development plan. It was started in 2005 with the Planning Policy Statement 1.

For this purpose the Council employed a specialist consultant, Knight Architects, and in 2006 following the initial works started their collaboration with HBC, when extensive studies on both structural design and visual impact were analysed by Gifford/Ramboll and Knight Architects.





Figures 3 +4: Plan showing general arrangement of the bridge (above) and Early stage elevation (below)

Figure 5: Early stage design visualisation

The outcome of the 24 month study was a detailed investigation of the visual impact of the Crossing. It was manifested in the reference design which was submitted for various approvals including a successful Public Enquiry in 2009. Eventually the scheme received a formal approval by Secretary of State in late 2010.

The procurement was based on PPP process where the design and its visual quality were key driving factors whilst providing flexibility for bidders.

The Council decided to announce a Competitive Dialogue Process, in which the three pre-qualified bidders would develop a tender design over a period of 13 months subdivided by interim submissions and supported by dialogue sessions.

Tender documents included a narrative-based design guide in the form of a Design & Access Statement (DAS). It defined the principles and requirements for design quality in relation to design functionality, impact and visual quality of the project.

Alongside providing information to the Council, which would assist them in the course of the tender, the DAS was the central reference document for planners and bidders. It provided a design description with an emphasis of the design intent, clearly outlining the desired qualities of design and architecture.

Flexibility was provided so that bidders could seek innovative solutions. Throughout the Competitive Dialogue stage, the Client was backed by a core team of advisers, covering a broad range of technical expertise supporting HBC and assessing design proposals to ensure that the proposals met the design criteria set out in the DAS and other technical specifications. Financial close, and award of the contract, was achieved at the end of March 2014.

The successful tender was prepared by a team comprised of COWI, Fhecor and DISSING+WEITLING for the construction JV consisting of Kier, Samsung and FCC.

As part of the Competitive Dialogue process, this team prepared a set of preliminary design drawings and architectural images that complied with the requirements set out in the DAS. Their proposals were subsequently bound into the final contract prior to award.

In order to deliver the contract and to administer and oversee the construction and maintenance of the new crossing, HBC have established an arms-length entity named the "Mersey Gateway Crossings Board" (the Board). The Board receives support from a Technical and Contractual Adviser (TCA) consisting of an interdisciplinary team of specialists.

As with the bidding phase before, the central task of the TCA is to review, advise, monitor, and audit the construction works. One of the core competencies being to safeguard the design concept outlined in the DAS and preliminary design proposals.

3. DESIGN AND THE CONSTRUCTION

3.1 General description

The design is based on a cable-stayed structure with three pylons. The 80m high Central pylon is shorter than the two outer pylons, which are 110m (North pylon) and 125m (South pylon) high.

This design for the bridge was selected from a wide range of options and it brings maximum benefits for users and local people and has a minimal impact on the estuary and its surrounding environment.

Including the approach viaducts on each side the bridge is 2,250m long with a river span of 1,000m.

3.2 Temporary Access Bridge

Work started on the bridge in mid-2014 with two temporary access roads being built across the salt-marsh.

A 1km temporary trestle bridge with a precast concrete deck around 9m wide was built across the estuary to provide construction access. Up to 140 steel piles were driven to a depth of around 16m to support the temporary access bridge.

3.3 Cable-Stayed Bridge Construction

3.3.1 Pylon Foundations

The ground conditions comprise a relatively shallow thickness of alluvium overlying variably weathered sandstone. Piled foundation options were considered but direct (spread footing) foundations using an in-situ reinforce concrete foundation were selected as the preferred solution.

Each footing is 4.5m high and up to 22m in diameter. For their construction double skinned cofferdams were built using around 300 steel piles driven into the riverbed.

Inside each cofferdam a mass concrete base slab was cast onto which a cage consisting of 190 tonnes of steel reinforcing bars was assembled.

Vertical steel reinforcement bars were then fixed into the centre of the cage to form the base of the pylon shaft. 1,400m^3 concrete was poured to form the pylon foundations.

The weathered rock provides a high bearing capacity although careful assessment was required to validate the strength and stiffness at each foundation location.

Therefore, during construction of the spread footings and subsequent bridge pylon and superstructure construction, the settlement and rotation of the foundations and ground movement was monitored.

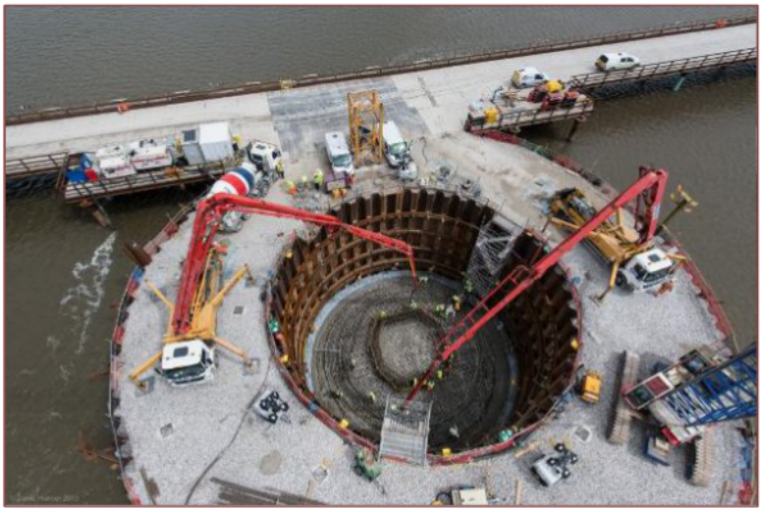


Figure 6: The concrete pour on the North cofferdam

Figure 7: The North cofferdam with its newly completed pylon base

3.3.2 Pylons

The north and south pylons feature a hammerhead which supports the deck on bearings whereas the central pylon is monolithic with the bridge deck.

The lower parts of the pylons were completed using standard forms with a plywood face and poured in four lifts. The hammerheads required shutters (formwork with the frames that served as a platform) to exact measurements, with the use of CNC (computer numerically controlled) machines to ensure accuracy for putting the formwork together.

Once the central hammerhead was complete, the formwork was removed and the platform was reused for construction of the pier tables. About 12 sections of the pier table were built offsite and transported onto site, lifted onto the hammerhead by crane and then had concrete poured into them. Together the assembly made up the pier table onto which the form travellers were installed.

A significant challenge for the designers of the pier table formwork was the requirement to transfer the high vertical loads into embedded anchors within the lower pylon. As the lower pylon geometry dictated the maximum possible number of anchors, a sequenced construction in layers was adopted to avoid the accumulation of vertical forces, ensuring that the loads can be safely supported, making the process more manageable.

The upper pylons – above road deck level – were constructed by pouring concrete into the surrounding formwork, using 5m lifts.

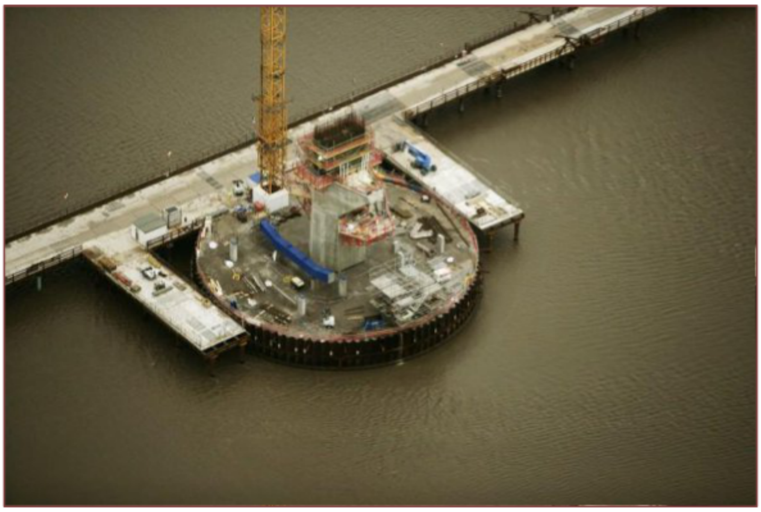
All four formwork platforms were raised those 5m by way of two hydraulic rams sitting at about the second level within the formwork. When the concrete had cured sufficiently – at least 25N/mm² - the vertical guide rails were first moved upwards 5m and then secured by huge doorknob-like anchors screwed into pylon.

The formwork was unbolted from the side of the pylon and hydraulic rams, one pushing and one pulling, slide the formwork up 5m on the vertical guide rails. It was again bolted onto the pylon for security.

One of the challenges common to all bridge construction projects is high wind speeds. The advantage of the hydraulic system for the Mersey Gateway was that it could withstand higher wind speeds than standard cranes, meaning windy conditions caused fewer disruptions.

Additionally, as crane use was restricted on-site, using this system meant that other areas of the construction project could fully make use of crane-time.

To complete an upper pylon, it took around 21 lifts. Once the pylon was completely poured, only then was a crane erected to take the formwork off its anchors and lower the sections back to ground level where it could be fully dismantled either on site or taken off-site.



Figures 8 + 9: South pylon

3.3.3 Main bridge deck

The main bridge deck is made from reinforced and post-tensioned concrete. It comprises 154 segments, each segment is around 33m wide and 6m long. Each segment was made in the same way – reinforcing steel bars are placed into the mould and about 130m^3 of concrete was then poured inside.

The deck was generally cast in-situ in 6m long segments using a form traveller. For segments around the pylons, the form traveller was suspended from the pylon. The "C" shaped form traveller provided improved access to the top of the segment during construction in comparison to a conventional form traveller.

Figure 10: Form Traveller casting standard segments

The deck was built in three separate sections using a balanced cantilever method outwards from each of the three pylons at a rate of around one six metre section per week. This allowed the bridge deck to "grow" from either side of the pylons until it met the connecting bridge deck and the structure was complete.

The largest number of deck segments - 33 - was cast from the south pylon leading to the south elevated approach viaduct and 31 were cast from the South pylon in the other direction towards the Central pylon. The North pylon had 29 deck segments cast on one side and 27 on the other, while 17 were cast from either side of the Central pylon.

Three pairs of form travellers operated to build the main bridge deck with each pair operating as a unit. The 270 tonne machines acted as movable concrete moulds. The works started with two travellers working in tandem. They were assembled at the South pylon before being lifted to their starting position around 25m above the riverbed. Construction teams then cast a pier table – a rectangular shaped platform – around the bridge pylon before preparing to start work on the main bridge deck.

Another pair of machines was launched from the North pylon and then the third pair started from the Central pylon.

From the third segment onwards, the connection anchor boxes called 'delta frames' were installed for the steel stay cables, which in turn were then attached to the upper pylon. The form travellers powered by a hydraulic system moved forward on a set of rails to the next position and the process was repeated. When the main bridge deck was complete, the form travellers were dismantled and recycled.

Internal longitudinal post tensioning was provided in the top flange for the initial cantilever construction before the stressing of the first cable stays. These tendons were anchored on the end face and did not encroach on the internal formwork. Thereafter, longitudinal post tensioning typically consisted of 27 strand tendons anchored at the junction between either the top or bottom flange and the web and then deviated in plan. The tendons were installed and stressed after completion of the key segments between cantilevers.

At the North and South pylons the deck is supported on pot bearings in the permanent condition. During construction a temporary longitudinal restraint and moment connection was provided between the deck and pylon via a system of concrete pads and additional temporary prestressing that clamps the deck to the pylon hammerheads. At the Central pylon, a monolithic connection was provided for both permanent and temporary condition.

To support the deck during construction and to ensure stability of the balanced cantilever, two temporary piers were built under each of the main span cantilevers, approx. 72m from the pylon.

Figure 11: Form traveller machines positioned on each side of the hammerhead

3.3.4 Cables

The bridge deck, with a combined load-bearing weight of more than 53,000 tonnes, is supported by 146 stay cables. There are 62 stay cables attached to the South pylon (31 on each side), 54 attached to the North pylon (27 on each side) and 30 attached to the Central pylon (15 on each side).

The cable sheaths are helix-shaped to prevent vibrations from wind and rain and were tested in wind tunnels. They vary in length; with the shortest measuring approximately 41m and the longest measuring 226m.

Once the deck concrete reached the required strength, the stay cables were installed. The first two strands were threaded through the stay pipe, the pylon crane lifted the pipe up to the anchor point in the upper pylon where the top ends of the strands were fixed into place.

Each stay cable consists of between 41 and 91 individual steel strands that sit inside a stay pipe – the outer casing that provides protection from weather-related corrosion. Each strand contains seven wires, which are galvanised, waxed and coated.

Then a winch system within the stay pipe was used to winch the remaining strands up one by one. Once all of the strands were installed they sit in parallel inside the stay pipe to form the stay cable.

The bottom ends of the strands were then attached to the anchor point in the bridge deck and stressed using a hydraulic system. This enabled to get the correct level of tension needed to support that segment of bridge deck.

More than 1300 km (810 miles) of the strands were used for the project. The strands were delivered to site in compact coils. Every single strand was installed individually, combined to achieve a rate of 6 stays per week.

Figure 12: The first stay cable being lifted into position by a pylon crane at the South pylon

Figure 13: Steel strands can be seen inside the light green stay pipe, which form the stay cable

Figure 14: First stay

3.4 Approach Viaducts

3.4.1 General Description

The two elevated approach viaducts stretch across the salt-marsh on either side of the River Mersey connecting the new bridge to the main road networks in Runcorn and Widnes. 1.3km of the approach roads are carried by 20 reinforced concrete supporting piers.

The approach viaduct decks (706m North and 544m South) were constructed in three phases, with two MSS (movable scaffold system) and two wing traveller machines. Merseylink decided to deploy two MSS machines, called Trinity and Webster, both built in China. Utilisation of two MSS instead of one saved valuable time that otherwise would have been taken to dismantle, transport and reassemble one MSS.

Once the central spans were constructed by the MSS, a deck slab was built on top of the box section, and finally the outer deck or 'wings' were built by a wing traveller machine to provide the full six-lane width of the approach road.

3.4.2 Foundations and substructures

The piers consist of hollow reinforced concrete shafts supported on (typically) 6No. 1.5m diameter bored cast in situ piles extending to the underlying sandstone. The pier and span geometry is proportioned to ensure no uplift on the bearings. Provision is made for future bearing replacement.

The design of the piles is in accordance with Eurocode 7 and the UK National Annex. Compressive resistance of a pile is assessed from empirical calculation methods applying partial factors on shaft and base resistance which is in weak sandstone and largely provided from rock sockets.

Two preliminary pile tests on bored piles equivalent to the pile design were carried out and loaded to at least the equivalent calculated unfactored ultimate pile resistance.

3.4.3 Viaduct deck

Approach viaducts were cast-in situ using the MSS with a cycle time of typically a few weeks per span in three stages.

The MSS was suspended from the cantilever end of the previous section of deck and supported from the pier and pile cap at the leading end.

Stage I: The central box was cast, concrete was poured starting from pier, progressing firstly towards the cantilever and then within the span itself. It took approximately 24 hours to pour a single span of around 1,300m^3.

Stage II: The top slab between the webs was cast using conventional formwork propped off the bottom slab of the box.

Stage III. Cantilever wings were cast using a separate form traveller.

To avoid restricting the internal void for formwork assembly and removal internal longitudinal post tensioning was adopted. Around 50% of the longitudinal cables are terminated at the transverse construction joint, with the remaining 50% coupled to cables that continue into the next span.

Transverse post tensioning is provided at the location of transverse ribs with the top deck slap generally designed as a reinforced concrete element. The cables include buried anchor at the dead end and are stressed after Stage III.

Deck reinforcement cages were preassembled in 6m lengths together with post-tensioning ducts already installed. The post tensioning was done when concrete gained its full 28 day characteristic strength (Class C50/60), which typically occurs around three days after casting.

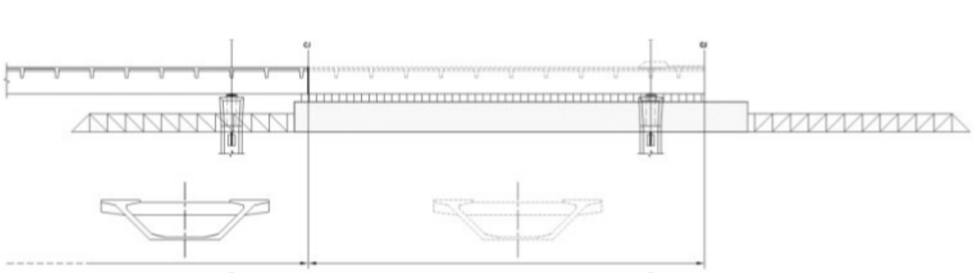


Figure 15: MSS Layout and casting of the first stage

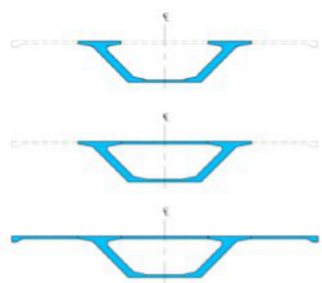


Figure 16: Casting Sequence of the Approach Viaduct

3.4.4 MSS TRINITY

Trinity, the 1,700-tonne, 157-metre long, movable scaffold system (MSS), built the central part of the carriageway. The machine – essentially a giant concrete mould – constructed 11 road deck spans, creating one seamless structure. Approximately 14,200m^3 of concrete was used during construction of the central road deck section, measuring a total length of around 715m.

The MSS was specially made for the Mersey Gateway Bridge project. While most machines of this kind typically only build bridge spans of up to 60m, Trinity was specifically designed to be able to cast spans of up to 70 metres.

With its work done, and with sustainability as a key objective of the whole project, Trinity was dismantled, reused and recycled. It took construction teams around two months to take the machine apart as they comprised approximately 1,200 components, 3,000 actual parts, and over 60,000 bolts.

The main element of the MSS Trinity, the steel structure, is to be transported to Slovakia, where it is planned for re-use in the construction of a bridge in Bratislava. The casting cell will be recycled separately as this particular section was a bespoke piece specifically designed for the Mersey Gateway Bridge.

Figure 17: Trinity starts work

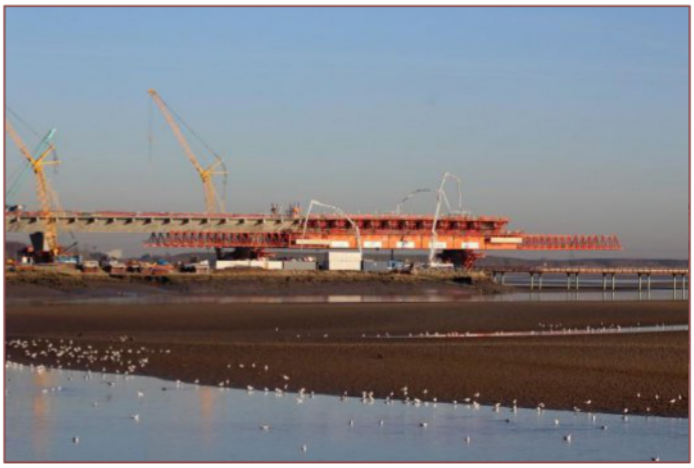


Figure 18: Final concrete pour

3.4.5 MSS WEBSTER

MSS Webster was specially designed and built to construct the curved viaducts leading to the main bridge. The machine was named by Halton schoolchildren after local engineer John James Webster who built the Widnes Transporter Bridge.

Webster is 157m long and 8m high. It is 22m across at its widest point and weighs 1,700 tonnes. In total it constructed eight spans of the South approach viaduct to create its central box section using 9,205m^3 of concrete.

Webster was assembled piece by piece approximately 12.5m above the ground around the first pier of the South approach viaduct, involving the project's biggest ever crane lift - it was lifted into place with two giant cranes, one crane weighing 700 tonnes and the other 750 tonnes, working in tandem to hoist into place the 77m-long, 240 tonne main girder section.

Operation of the MSS Webster above the Manchester Ship Canal required extra planning and a change in logistics. Additional pumps were used on top to give access to the concrete. After completion of the works MSS Webster will be dismantled and also transported to Bratislava to join its fellow MSS Trinity, which is being used to build a new bridge over the River Danube.

Figure 19: Webster above the Manchester ship canal during the concrete pour

3.4.6 Wing traveller machines

Two wing traveller machines were used on the project – one for each of the approach viaducts.

One wing traveller machine was used to build the outer road lanes on either side of the North approach viaduct in Widnes. It followed the project's movable scaffold system (MSS), which constructed the central part of the carriageway. The second was used for the South viaduct.

The wing traveller - sometimes called the Construction Cantilever Traveller - weighed 280 tonnes and was around 48m wide and 20m tall. It worked in a similar way to the MSS and the form traveller machines, acting as a movable concrete mould to complete the full deck width, which, at just over 43.5m at its widest point, carries six lanes of traffic.

The machine was fixed onto two railway tracks that sit on top of the deck section that had already been cast by the main section MSS. To maintain balance concrete was poured into both sides of the machine at the same time, enabling workers to cast 12 metre sections of the outer deck on each side of the viaduct. Once the concrete had set, hydraulic jacks pushed the machine forward to the next position and the cycle was repeated.

Figure 20: The wing traveller machine in its starting position at the North approach viaduct in Widnes

Sixty-two concrete pours were needed to create the outer deck of the North approach viaduct, while 47 pours took place for the outer deck of the South approach viaduct. Each pour consisted of around 80m^3 of concrete (40m^3 each side).

Completion of the bridge and viaduct decks involved water-proofing the deck, installing fascias along its sides, and laying the road surface.

3.4.7 Ancillary items - Windshields

To confirm aerodynamic stability and wind speeds on the bridge wind tunnel testing was used. Windshields are provided to reduce overturning moments on high sided vehicles. On the West side of the deck the windshields are significantly higher than those on the East side reflecting the prevailing wind direction.

Testing was undertaken on a representative high sided vehicle, see Figure 21.

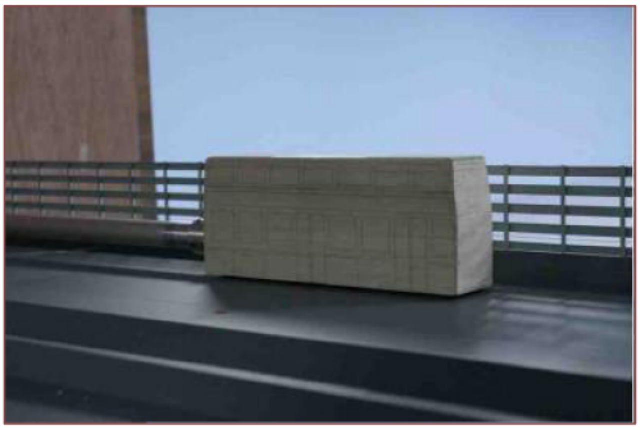


Figure 21: Windshield testing on high sided vehicle

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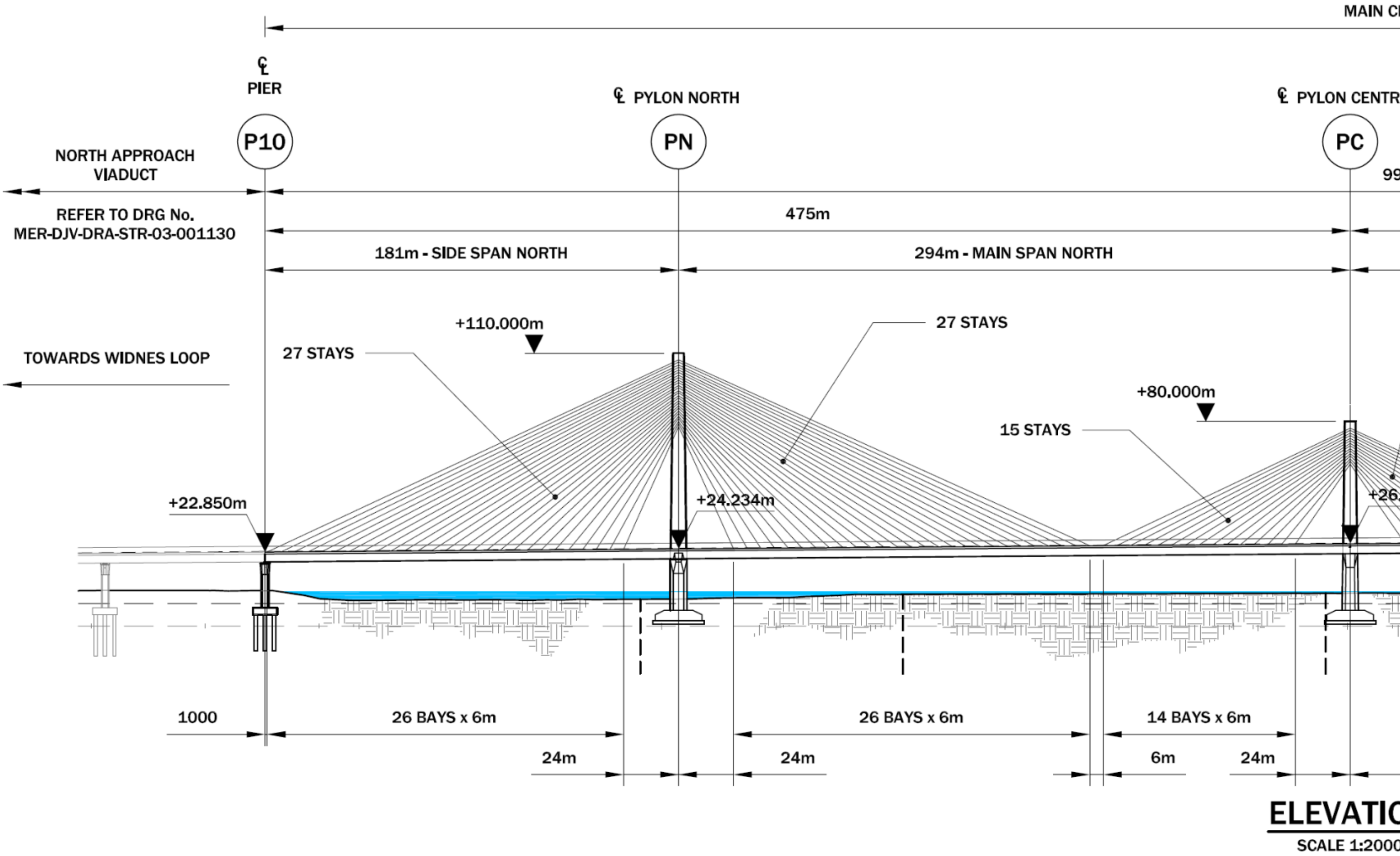
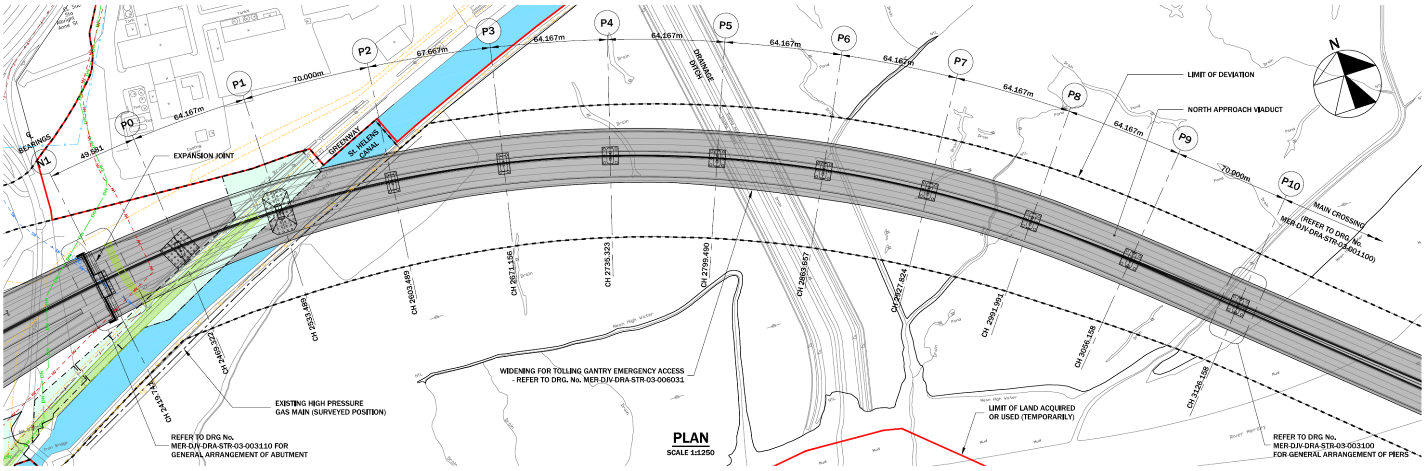
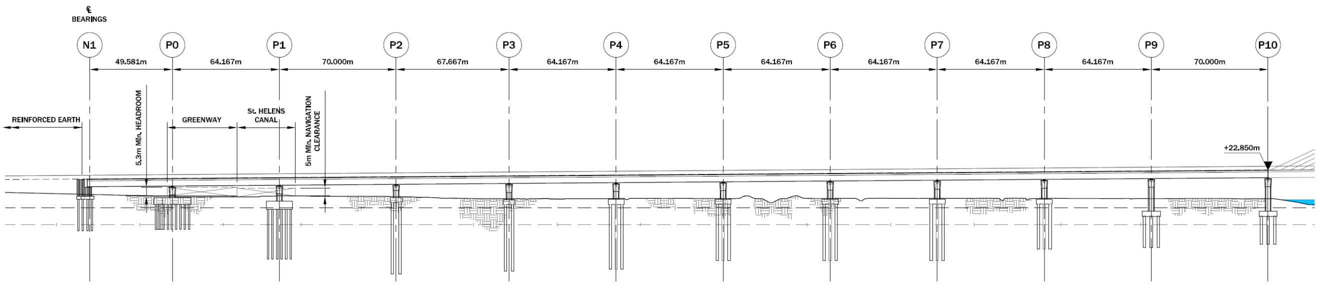
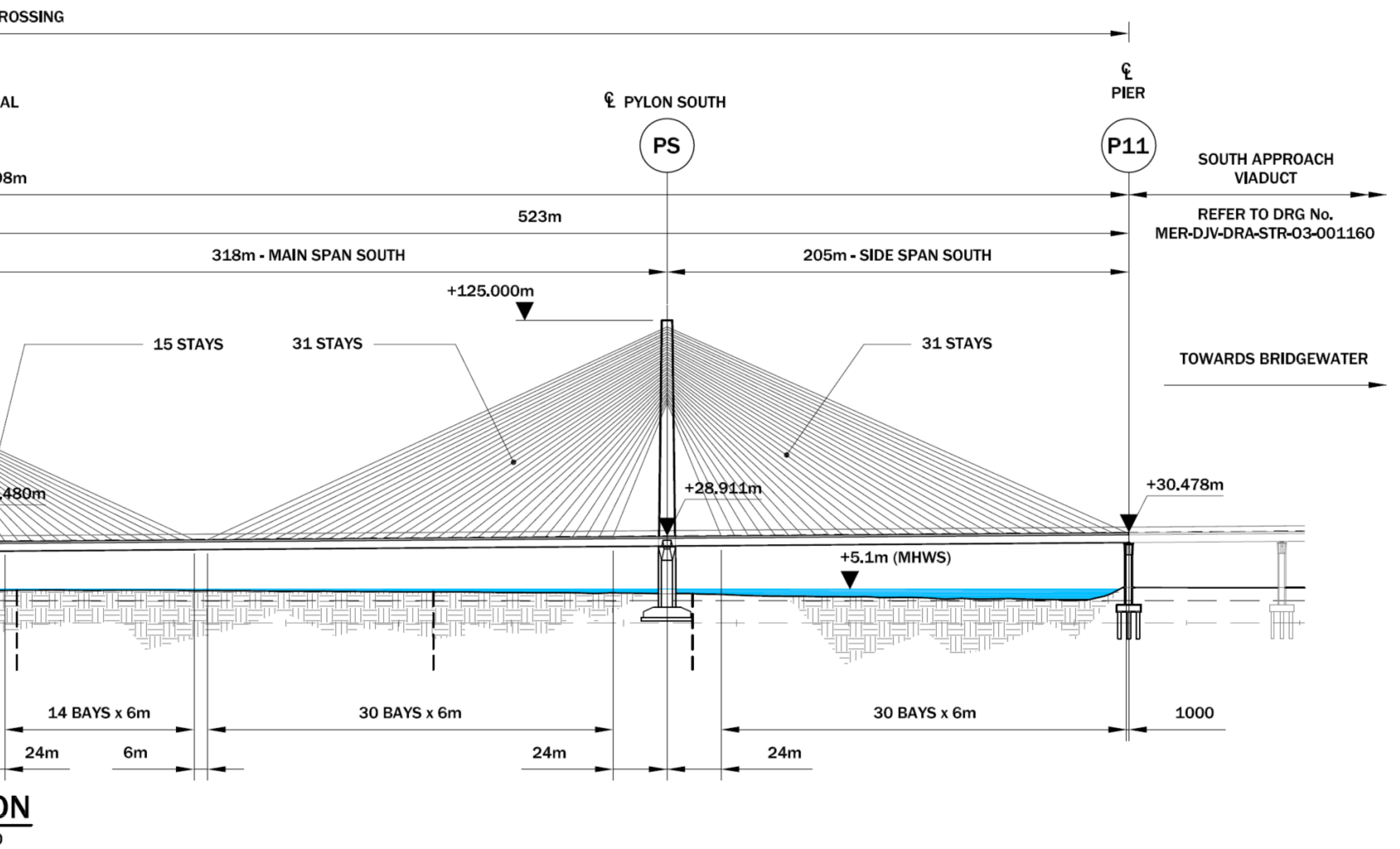
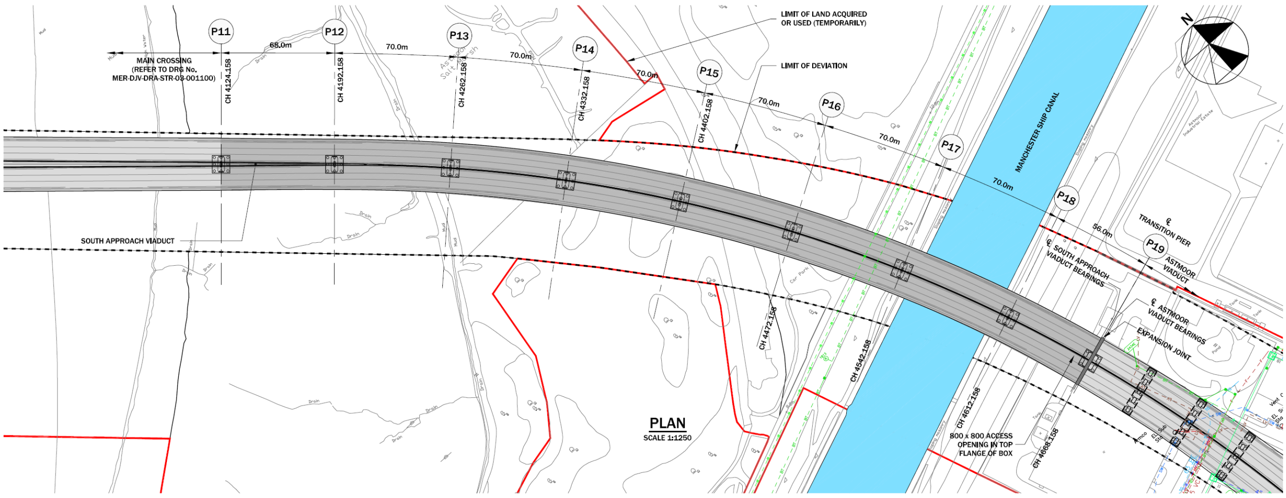


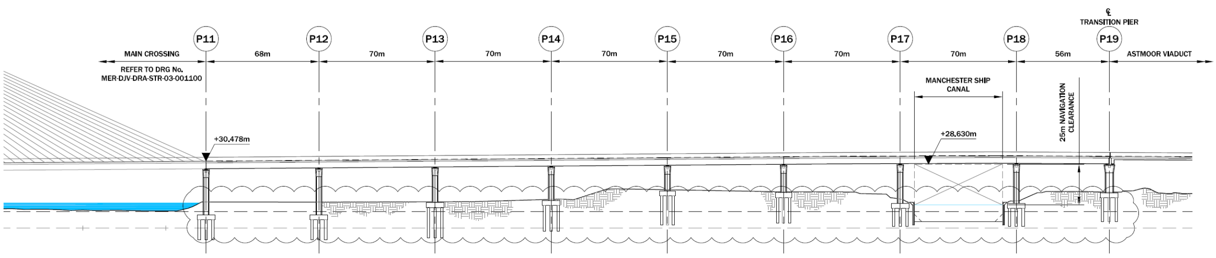




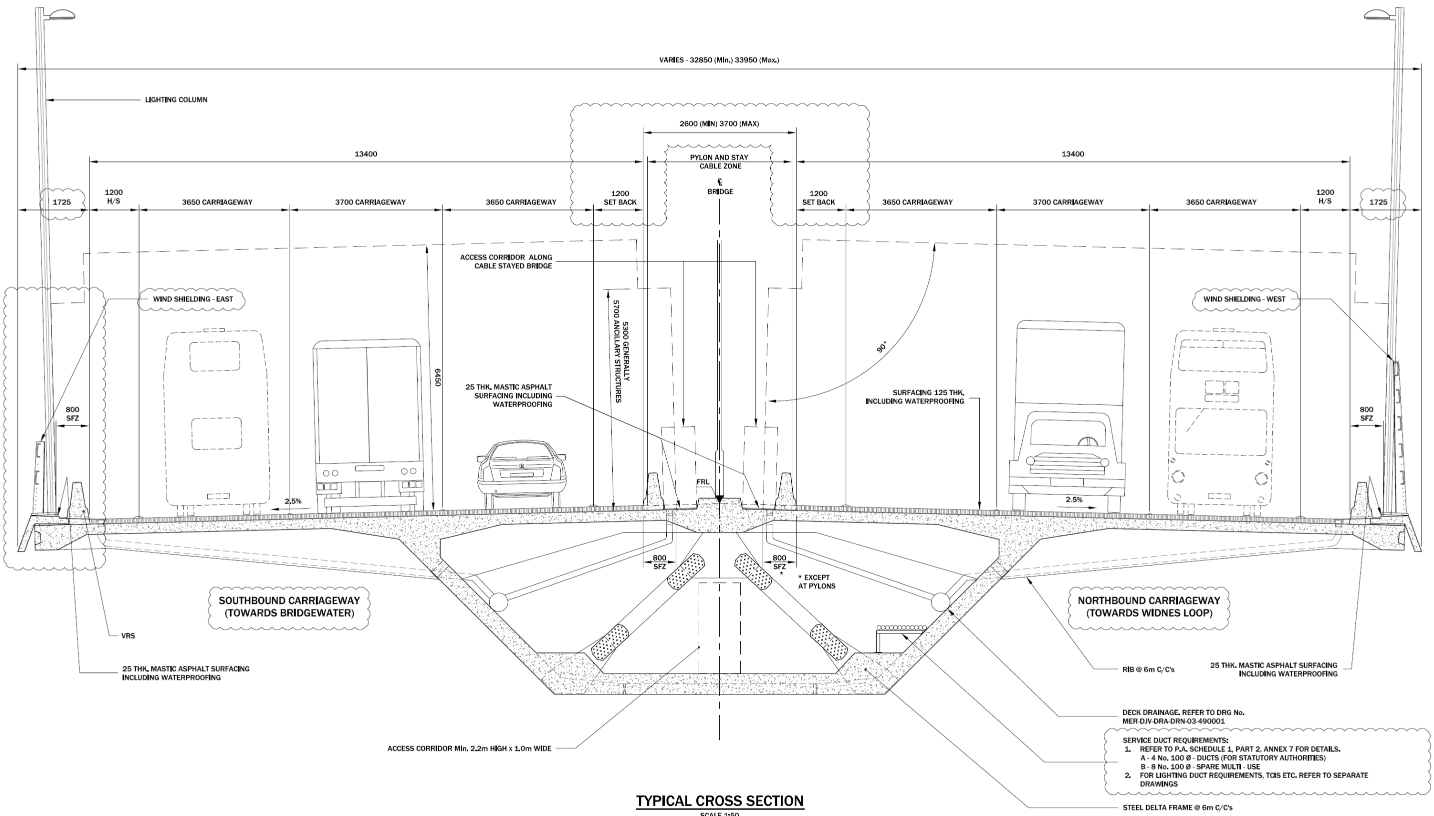
Elevation - North Approach Viaduct



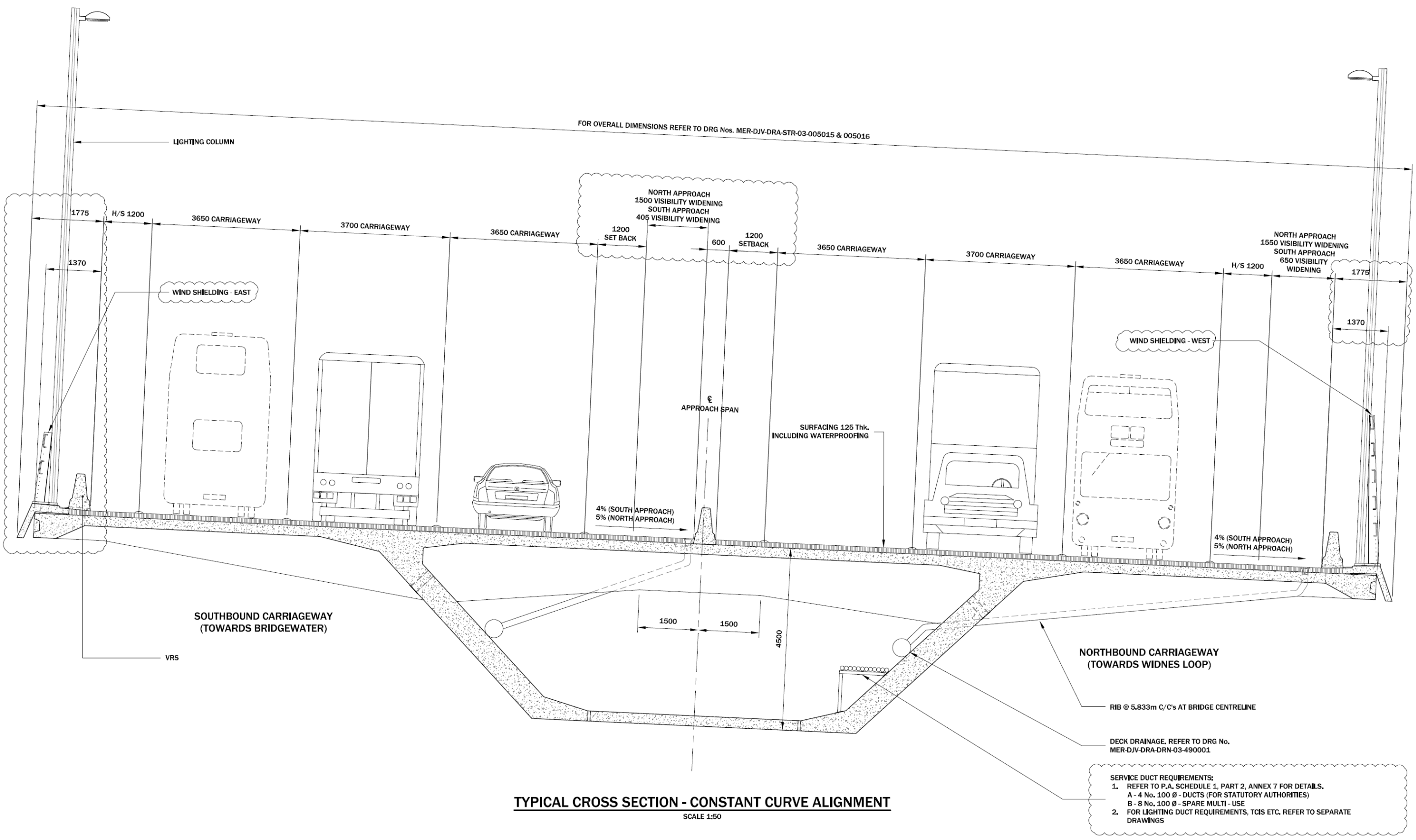




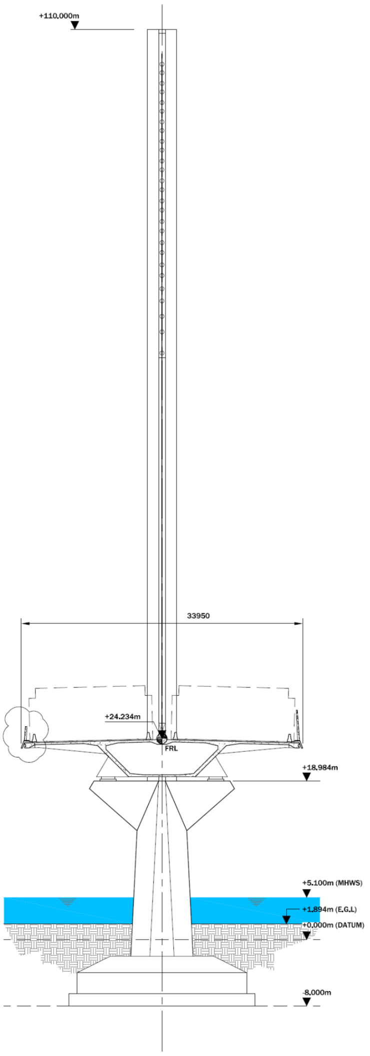
Elevation - South Approach Viaduct



TYPICAL CROSS SECTION
SCALE 1:50



TYPICAL CROSS SECTION - CONSTANT CURVE ALIGNMENT
SCALE 1:50



PYLON NORTH
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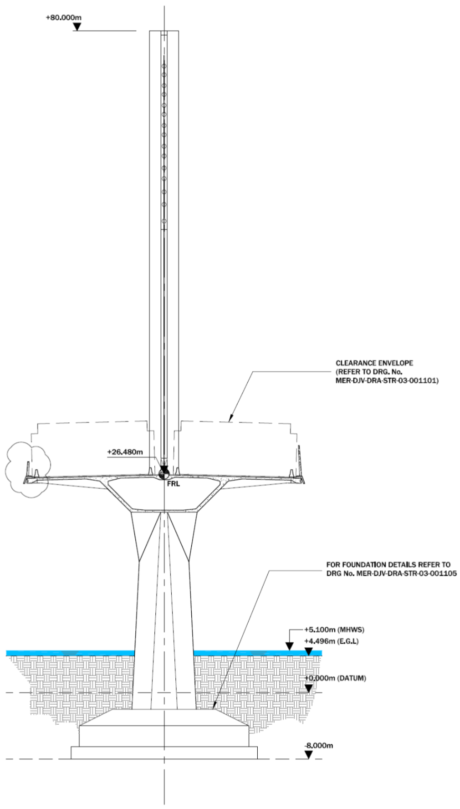

PYLON CENTRAL
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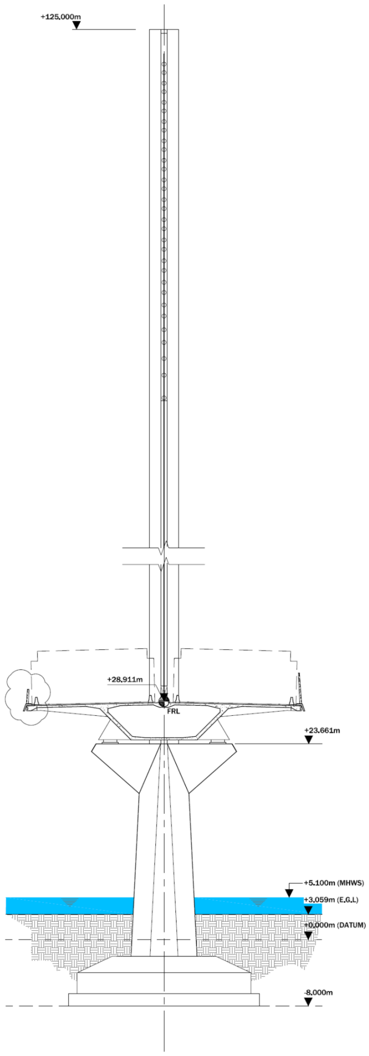
SCALE 1:250



PYLON SOUTH
(REFER TO DRG No. MER-DJV-DRA-STR-03-003020)
SCALE 1:250

Drawings provided by COWI UK

Client: HALTON BOROUGH COUNCIL

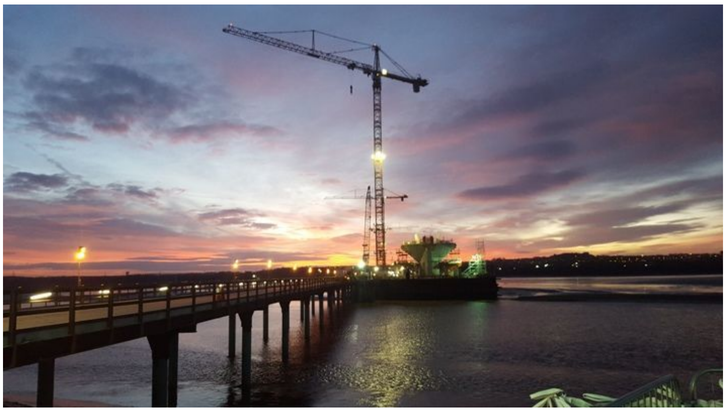
SPV: MERSEYLINK

Contractors: SAMSUNG C&T, KIER, FCC

Designers: flint neill (a COWI company), URS, FHECOR Ingenieros Consultores, eptisa

Concrete pour for the first vertical section of the south pylon

Central pylon base concrete pour



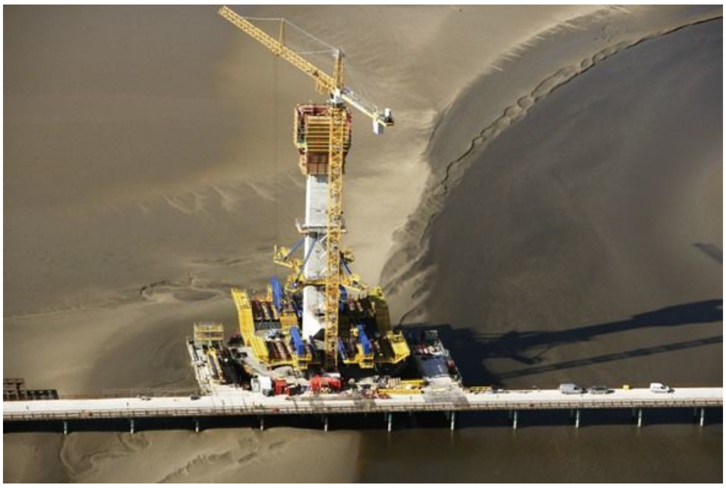
Sunrise over the Mersey Gateway

Concrete pour at the central pylon

South pylon concrete pour

View from the Widnes Tower crane at dawn

South pylon foundation



North pylon foundation

Central pylon

First cable anchor boxes being delivered to the south pylon

First pier table pour at the south pylon

Cable anchor box

Central pylon

Central pylon

All three pylons

The bridge at sunrise

MSS Webster over the Manchester Ship Canal

MSS Trinity and the Bridge

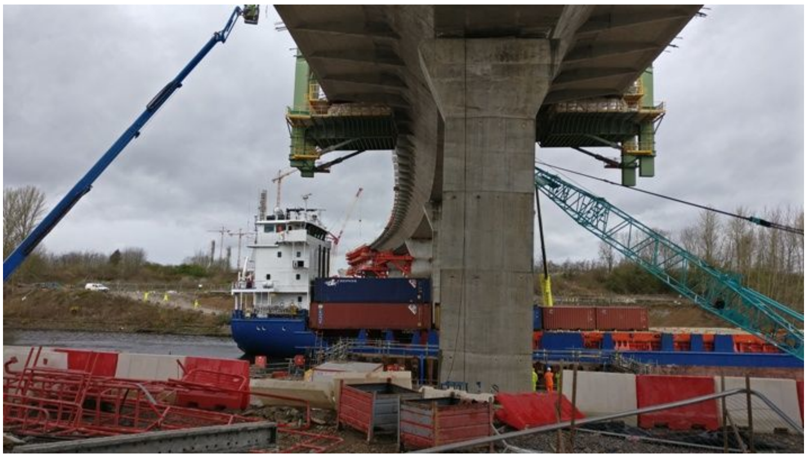
Pouring of the final key segment

MSS Webster being launched to its new position

MSS Webster in its casting position

Lateral view of MSS Webster, with Wing Traveller at the back

Bottom view of the MSS Webster between pier 14 and 13



A ship passing under the Wing Traveller 2, the Manchester Ship Canal

Wing Traveller 2 over the Manchester Ship Canal, using a 52m pump on the ground and a 36m over the deck

General view from the top of the North Pylon

View from the top of the south pylon, with form traveller, pier 11 under construction, MSS Webster and Wing Traveller

Posttensioning team stressing one of the strands of the cables at the north pylon

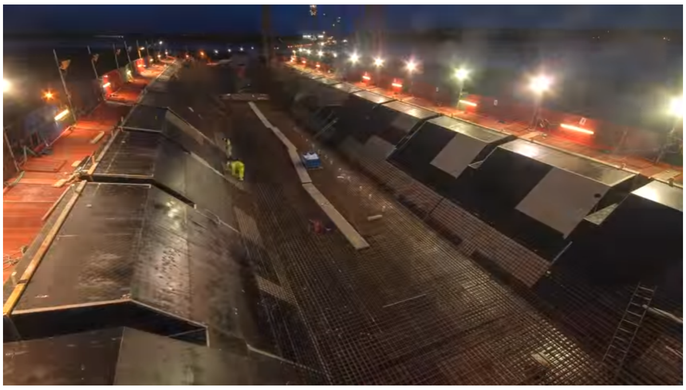
Prefabricated reinforcement for the piershaft of pier 11 being lifted into position, the form traveller of the south pylon at the back

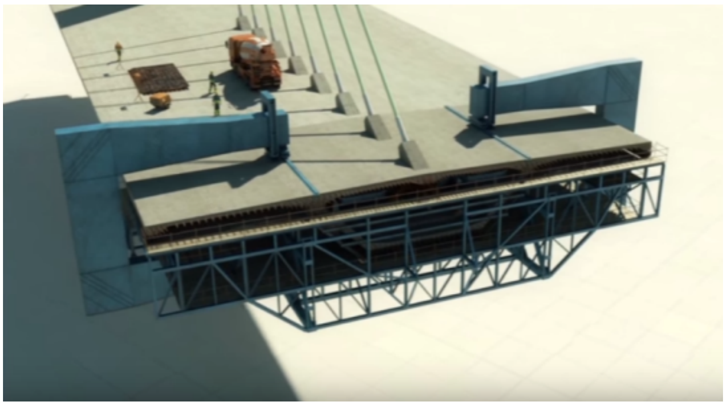
Last duct of the last cable of the main bridge being placed into position

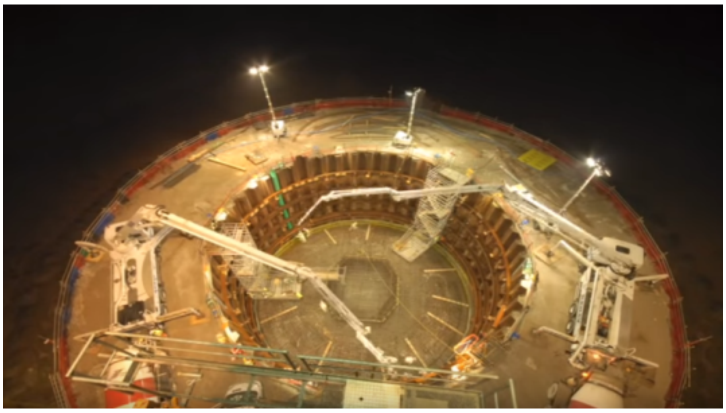
Front view of the form traveller of the south pylon

Photos on pages 20 - 22: MERSEYLINK CCJV, merseygateway.co.uk
Photos on pages 23 - 24: Antonio Martinez Diez, FCC Construcción

VIDEOS - click on the picture







The Arenales Suspension Bridge, Nicaragua

A study in design for the rural environment

Alan Kreisa
Director of Engineering

Brandon Johnson
Director of Programs

Alissa Smith
Director of Engagement

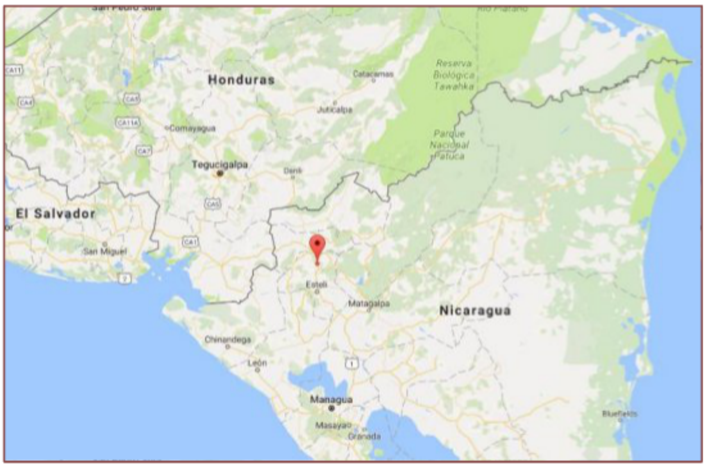
1. INTRODUCTION

More than one billion rural residents across the globe lack access to a road that is passable during all seasons. In the developing world, where walking is the primary mode of transportation, this lack of infrastructure limits possibility: individuals and families are cut off from essential healthcare, education, and economic opportunity, particularly during the rainy season. When rivers swell and become impassable, walks to school, work, or the doctor become life-threatening without a bridge to cross.

For the community of Arenales in northwest Nicaragua, the need for a footbridge was especially stark. The Estelí River floods for more than three months of every year, standing between the 3,300 residents of Arenales and primary and secondary schools, the local market, jobs on tobacco farms, and the health clinic.

The local municipality had built a suspension bridge over the river in the early 2000s, but design errors had led to the structure's dramatic collapse in 2011. The community salvaged what they could from the river and attempted to resurrect the bridge themselves, knowing that this was a temporary solution (see Figure 3).

When the international non-profit organization Bridges to Prosperity teamed with the local government of Condega, Rotary clubs from Nicaragua and New Mexico, international construction and engineering firms Kiewit and KPFF, and members of the community to construct a replacement structure in 2017, the existing walkway was missing decking planks, making the crossing extremely dangerous.



Figures1 + 2: The location of the Arenales Suspension Bridge. Source: Google Maps

The 130-meter Arenales Suspension Bridge was constructed over six months, through a partnership that brought together representatives from seven different organizations, five different countries, and a broad variety of backgrounds.

The superstructure was completed in just two weeks, all while maintaining a constant eye on safety and an insistence on superior quality.

Inaugurated on February 4th, 2017, the bridge now provides safe, reliable access to critical resources for the community of Arenales.

2. THE PREVIOUSLY-BUILT CROSSING

The original bridge constructed by the municipality in the early 2000s had failed in part because it was built with a mid-span tower constructed in the river. In rural Nicaragua, local municipalities don't have the specialized and expensive machinery needed to excavate to reach bedrock.

The insufficient anchorage of this center tower contributed the scouring of the tower's foundation, and eventually to the bridge's collapse in 2011.

Bridges to Prosperity's suspension bridge design has been refined by a group of volunteer bridge engineers (the organization's Technical Advisory Board) over the course of the last five years to efficiently span significant distances without the need for a mid-span tower, and utilizing a unique tower design that uses less fabricated steel.

All of this is done for nearly a fifth of the average cost of a typical Nicaraguan suspension footbridge. In this way, the Arenales Suspension Bridge stands as a model for innovative design, elevating local standards and providing a replicable solution.

Figure 3: The prior crossing at Arenales over the Esteli River

3. DESIGN

Quick facts, also refer to Figure 4:

- *The walkway is supported by six 32mm diameter wire rope cables that each have a total length of 195m from anchor to anchor.*
- *The clearance between the walkway and the highest known water level is a minimum of 3m above the full width of the river.*
- *The bridge walkway is 1m wide and made of steel crossbeams and a timber deck.*
- *The steel towers are 9.5m tall, supported on 3m tall concrete pedestals.*
- *The total concrete volume for all foundations and anchors is 127m^3.*

3.1 Bridge Design Criteria

The tropical regions of western Nicaragua are not only subject to substantial seasonal rainfall, but also tropical storms and hurricanes moving west across the Caribbean. The high water levels of the Esteli River and high winds accompanying these storms are the primary design criteria for the bridge layout and lateral capacity, respectively. The vertical loads on the footbridge are derived from the AASHTO Guide Specifications for the Design of Pedestrian Bridges. The design pieces together several resources that encompass the Bridges to Prosperity design philosophy as agreed upon by the Technical Advisory Board. In addition to the AASHTO code mentioned, the organization use the latest editions of AISC Steel Design Specification, ACI 318, ASCE 7, and NDS National Design Specification for Wood Construction. The bridge is expected to support an average of 250 pedestrian, animal, and moto crossings per day.

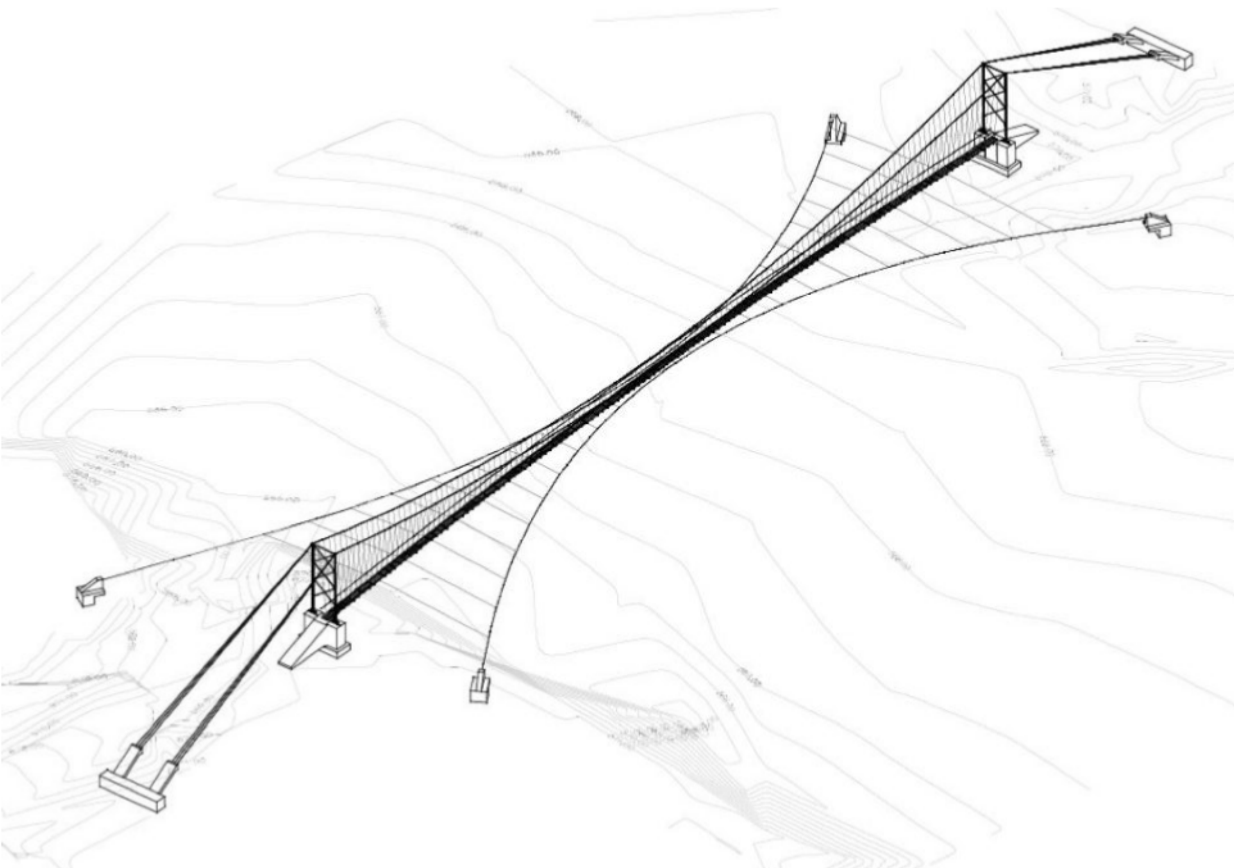


Figure 4: Arenales Suspension Bridge Rendering

3.2 Towers

The identical 9.5m towers are composed of two vertical 219mm diameter steel pipes spaced 3.5m apart with a lattice of double angle cross-bracing. The towers are designed to be hinged at the bottom connection to the concrete pedestals by means of a "T section" welded from steel pipe (see Figure 5). The main cables are supported at the top of the tower over curved steel saddle plates and clamped to prevent slipping.

The tower design was governed in part due to limitations of construction. With no heavy machinery available, the pipes must be transported and assembled by hand. Taller towers are more slender and require a larger and heavier section of pipe. At 64 kg/m, the 219mm pipe with a 12.7mm wall thickness was the most practical section available. The maximum height possible to maintain sufficient capacity was 9.5m. The design allowable bearing pressure is 144 kPa. The total weight of the tower assembly is 1780kg.

The width of the tower is established from two primary criteria. From a structural standpoint, the width is determined such that no uplift occurs in a tower leg with the design lateral wind load applied. From a serviceability standpoint, the width is found from the transversely inclined plane of the main cables. With the walkway width set at 1m and the minimum distance between the main span cables at midspan set to 1.4m to allow for passage of a laden burro, the suspenders connecting the cables to the walkway become inclined. This angle of inclination is relatively constant across the entire bridge and sets the width at which the cables must be supported at the towers.

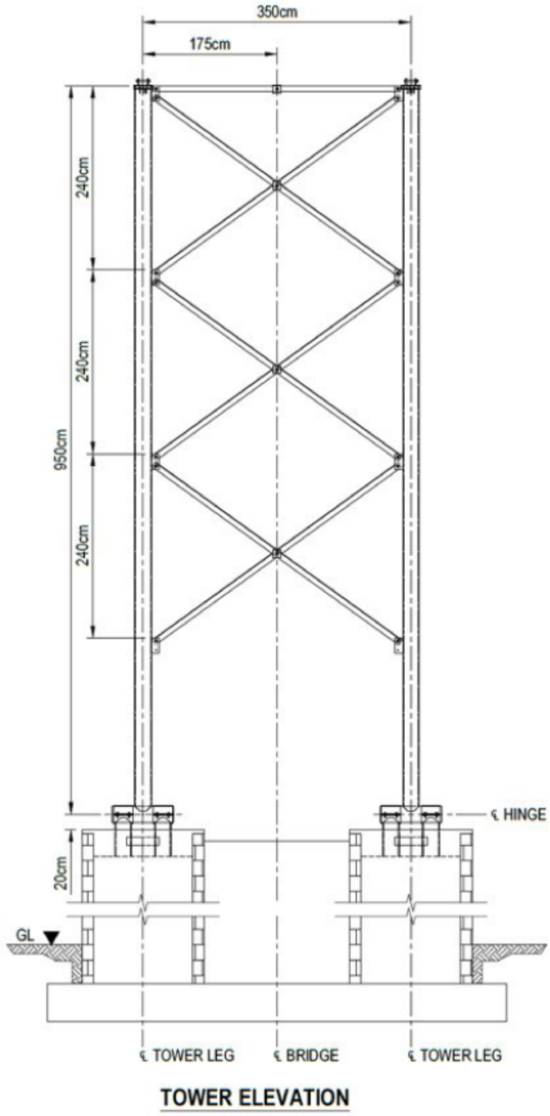


Figure 5: Tower Elevation

3.3 Main Cables

The main cable support system is comprised of three 32mm diameter wire ropes bundled together on each side. The vertical profile of the cable is set such that under fully-loaded conditions, the walkway profile maintains a positive camber. For this bridge, the cable sag at maximum load is 8.3m; a ratio of 15.6:1 span length to sag (refer to Figure 6). This ratio is much higher than a traditional suspension bridge, which falls closer to 10:1, but the limitations in tower height require this less efficient arrangement.

The cable back-stay angles were determined by matching the main span cable angle within a few degrees. By keeping these cable angles similar, the forces acting on the tower are almost entirely vertical, which is important with a hinged tower that is free to rotate.

The transverse geometry of the main cables is due to the inclined suspenders as mentioned in the tower design. The suspenders are approximately 6° from vertical and the main cables match accordingly (see Figure 7).

The trajectory of the cables is carried beyond the towers all the way to the anchor to limit the compression in the tower top brace member. The resulting anchor points are 5.6m apart.

The cables are anchored by looping them around a steel pipe and clamping them to themselves with drop-forged wire rope clips. The anchor beam is designed as a deadman anchor beam with overburden soil vertical resistance and passive earth pressure horizontal resistance.

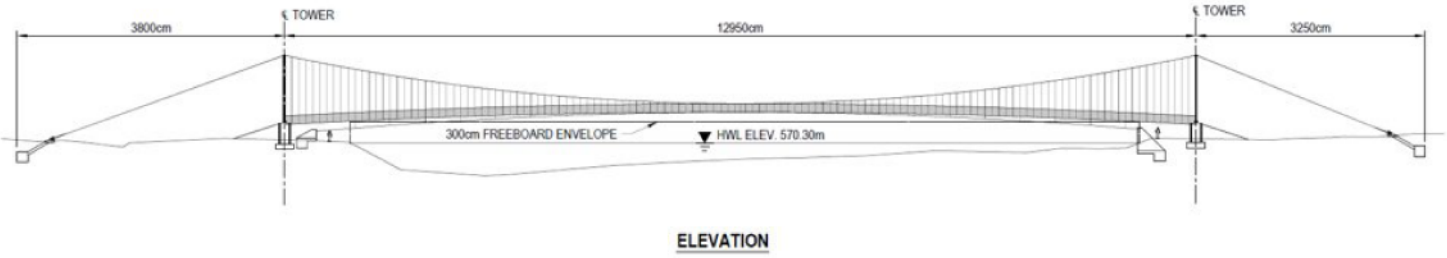


Figure 6: Elevation

3.4 Walkway

The walkway is carried by double angle steel crossbeams spaced every 1m. The crossbeams are supported by steel reinforcing bar suspenders, which transmit the load to the main cables. The deck surface is made of planks of a local tropical hardwood with superb durability.

A safety mesh fencing is attached between suspenders and anchored to the side of the deck planks on the bottom and a hand rail cable on the top.

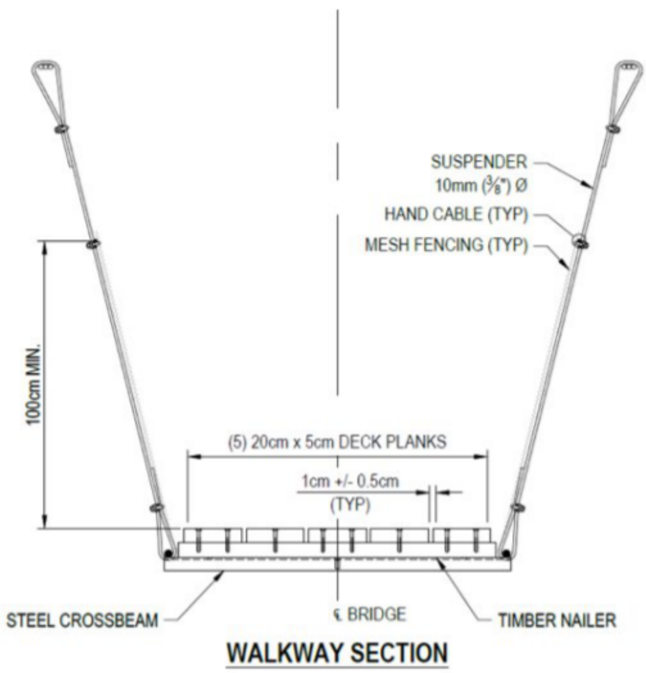


Figure 7: Walkway section

3.5 Lateral Stabilization

Cable suspended footbridges tend to be very light structures with susceptibility to large vibrations and sway. The self-weight of the walkway surface is only 20% of the total design load. Furthermore, the long span and high design wind speeds contribute to a large lateral load on the bridge. To improve serviceability with reduced sway and alleviate lateral loads on the towers, a cable wind guy system was designed (see Figure 8 below).

The geometry of the wind guy cable for the Arenales Bridge was challenging due to the local topography. An efficient layout was made possible using custom anchorages and spanning over a river tributary on the southwest corner of the site.

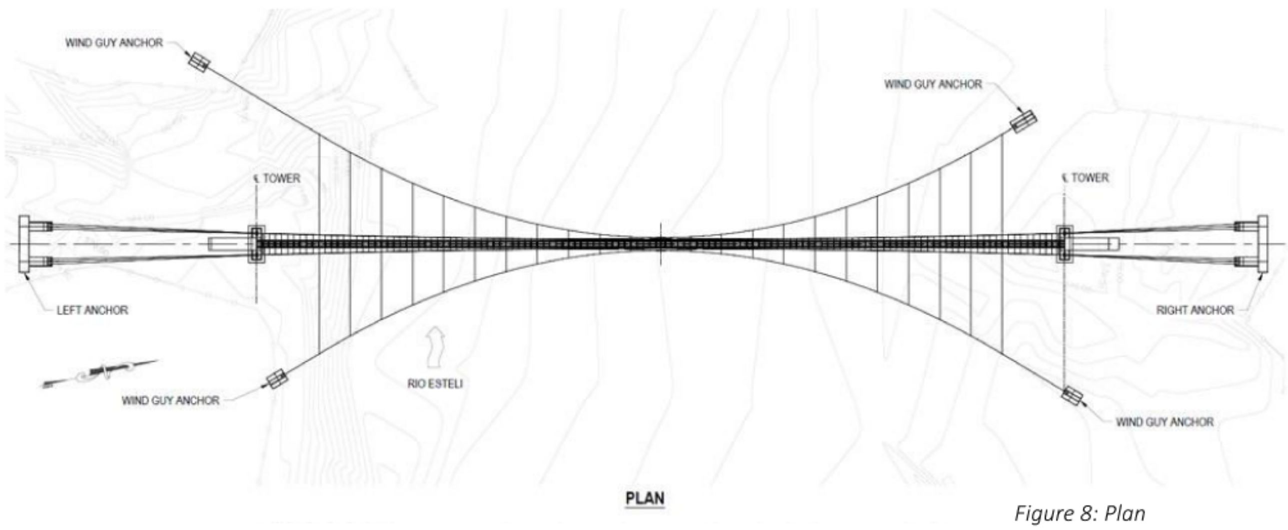


Figure 8: Plan

4. CONSTRUCTION

The team worked with the locally-sourced materials they were provided by the municipality and community, enlisting quality control aids in managing materials that are often of low strength and durability and completing the bridge's superstructure in just two weeks. The final bridge product, however, showed redundancy and resiliency despite these challenging materials, a testament to the team's focus and dedication to create a structure that would stand for years to come.

Excavations were dug by hand, the largest of which were for the anchors, with dimensions of 9m x 1m x 2.5m. For the foundation works, all rebar was cut and bent by hand and 127 cubic meters of concrete was mixed using only drum mixers (see Figure 9 below).

Figure 9: Bridges to Prosperity staff and community laborers pour cement for the anchors

The steel towers were prefabricated at a fabrication yard in Nicaragua and assembled on-site in a horizontal position with the "T section" of the tower resting in hinges embedded in the substructure. Because cranes are not readily available in rural Nicaragua, scaffolding was erected with a series of ropes and pulleys to allow a 'tirfor' winch to raise the towers from the horizontal position to their designed canted vertical position.

Using the scaffolding as a working platform, the main cables were then lifted over the tower saddles and one end was secured at the anchor. The cables were tensioned one-by-one until they reached their design hoisting sag.

Rebar suspenders were cut to length and bent by hand. In order to achieve a cambered profile, each suspender was of a unique length.

Wooden nailer boards were attached to the steel crossbeams to allow for a lag screw to be used to attach the wooden decking boards to the crossbeams. The rebar suspenders were attached to the crossbeam and wooden nailers to form swings that were launched from the top of the scaffolding (Figures 10 and 11).

Figure 10: Volunteers from Kiewit and KPFF launch suspenders and cross beams from the scaffolding

Because the suspenders are not positively attached to the main cables, an additional smaller cable, called a restraint cable, was used to restrain movement of the swings along the bridge. The restraint cable follows the profile of the main cables and is attached to the suspenders with cable clamps. The swings were installed and launched in sequence from each tower.

Figure 11: The bridge begins to take shape as suspenders and crossbeams are launched from one side

Once all of the swings were installed, the scaffolding was disassembled and the decking planks were installed to the wooden nailers (see Figure 12 below.

Figure 12: Volunteers from Kiewit and KPFF, along with Bridges to Prosperity staff and community members, install walkway decking boards

Tie cables to connect the walkway to the wind guy cables were cut to length and attached to the wind guy cables at predetermined locations. As the walkway was being completed, a second work team followed on the completed section of the deck, attaching the tie cables to the appropriate crossbeams. Once the decking was finished, the wind guy cables were tensioned. Finally, handrail cables and fencing were installed to complete the bridge structure (see Figure 13).

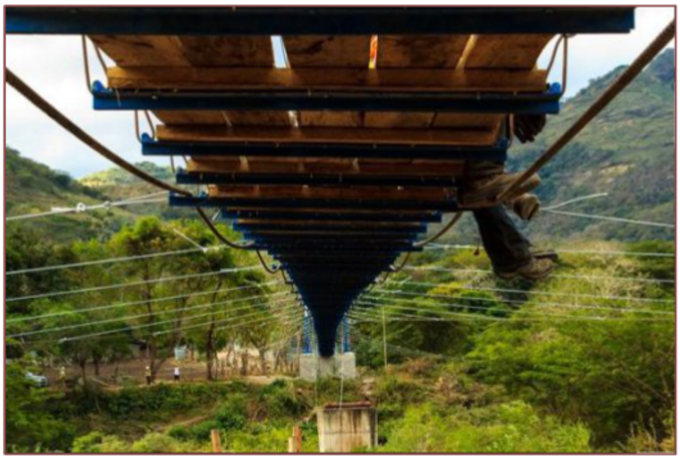


Figure 13: Walkway and guy wire installation is complete, and fencing is installed

5. SAFETY

Local safety standards are extremely unsophisticated in remote, isolated communities like Arenales. Instilling a culture of safety with unskilled volunteer labor in this environment can at times seem a nearly unsurmountable task. The Arenales Suspension Bridge team tackled the challenge with resolve. With an average of 6 community volunteer workers on site each day, the project closed with 1008 days of local labor, 880 days of skilled labor, and not a single safety incident beyond minor cuts and bruises. The B2P, Kiewit, and KPFF teams modeled safe practice for local community members, supplying them with necessary PPE such as hard hats, gloves and glasses, leading safety discussions each morning, and training community members on the appropriate use of fall protection when working at heights.

Figure 14: Volunteers from Kiewit and KPFF lead an all-hands meeting at the start of the day to review tasks and assess safety risks

The size of the Arenales Bridge presented unique safety challenges. The anchor reinforcement cages weighed nearly a ton, and had to be moved using a customized cable and pulley system to avoid manually dropping them into place. Excavations for foundations were dug nearly 2 meters deep, so they were benched for safety, a practice not common locally.

The dynamics of the site layered on another unique set of challenges. The new bridge was being constructed over where the existing crossing still stood, which acted as a main thoroughfare for the Arenales community to get to essential services. To maintain the community's access throughout construction, the team rerouted that thoroughfare multiple times. All community labor was directed to a single intake point, where they could ensure they were appropriately trained and outfitted before entering the site. Similarly, the team worked with local volunteers to complete a Hazard Analysis for every operation identifying hazards and how to mitigate them.

6. MAINTENANCE

The technical design life of the main structure is 40 years based on the tower pipe capacity and an allotment for steel corrosion rates in tropical regions. It is assumed the decking, fencing, and suspenders will be replaced as needed, with the Municipality of Condega financially responsible for repairs. As members of the community trained and worked alongside Bridges to Prosperity staff and Kiewit and KPFF volunteers in every phase of bridge construction, they are equipped to now make minor repairs, such as suspender or decking replacement.

7. LESSONS LEARNED

Over the course of Bridges to Prosperity's 16-year history, they've continued to refine their design and construction process to better fit the constraints of the rural environment and the available materials. These refinements have included moving from one pulley to two in the tower erection assembly to better distribute load during erection, and a similar transition from one bay of scaffolding to two to allow for easier installation of suspenders. On the Arenales bridge in particular, for the first time, B2P installed the wind guys as decking was assembled. Typically, this is done after decking installation is complete.

8. TRANSFORMATIVE IMPACT

The benefits of the Arenales Bridge project are far-reaching. The individuals who participated in the bridge's construction are trained in global safety standards and general construction and maintenance techniques, empowering them with skills for the future. The bridge stands as a sign of their accomplishment, but it also stands as a symbol of opportunity. The more than 3,000 residents of Arenales now have safe, year-round access to schools, markets, employment, and healthcare, and that sort of connection is transformative for a population that lives on less than $2 a day, and is cut off from these essential services for at least three months of every year.

A study recently completed in partnership with the University of Notre Dame showed that for communities receiving a B2P footbridge in Nicaragua:

- Corn crop yields increase 56%
- Average household income increases 32%

And studies of B2P's work worldwide show that in communities served:

- School enrollment increases 12%
- Healthcare treatment increases 24%

A reliable footbridge allows communities like Arenales to plan, grow, and thrive in ways they couldn't before. The story of Leonel best illustrates the power the bridge has to create lasting and transformative impact. Leonel,as pictured in Figure 15, is a community leader for Arenales, and was a strong advocate for Bridges to Prosperity to work with the local municipality to replace the failing bridge.

He showed up to site, ready to work, nearly every day of construction. He was there, helping to lift the towers into place, at the top of the scaffolding, installing decking and fencing. And as the new bridge was completed, Leonel was the one to dismantle the old, unsafe crossing. As a member of the construction team, he will now lead fellow community members in routine maintenance of the bridge in the years to come. His commitment to his community, his dedication to learning, and his excitement to inaugurate the new bridge are testament to the compelling impact the structure will have on the Arenales community far into the future.

Figure 15: Leonel joyfully dismantles the old, unsafe crossing over the Esteli River at Arenales

Figure 16: The completed Arenales Suspension Bridge on inauguration day

Contributing Kiewit and KPFF Volunteers

Ellis	Beckwith	Associate	KPFF
Bill	Binnig	Project Manager	Kiewit
Keith	Boulton	Logistics Superintendent	Kiewit
Evan	Callahan	Field Engineer	Kiewit
John	Chapman	Civil Engineer	KPFF
Shukre	Despradel	Structural Engineer	Kiewit
Dustin	Donahoo	Deputy Operations Manager	Kiewit
Kaitlyn	Fleming	Geotechnical Engineer	Kiewit
Jennifer	Grob	Project Coordinator	KPFF
Amber	Harley	Structural Engineer	Kiewit
Zack	Hill	Structural Engineer	Kiewit
Jim	Hingtgen	Structural Engineer	KPFF
Trevor	Lighty	Associate	KPFF
Steven	Millett	Civil Engineer	KPFF
Don	Oates	Principal	KPFF
Michael	Rakowski	Structural Engineer	Kiewit
Meghan	Stotts	Project Engineer	Kiewit
Sean	Weeks	Track Engineer	Kiewit

Cable and clamp detail

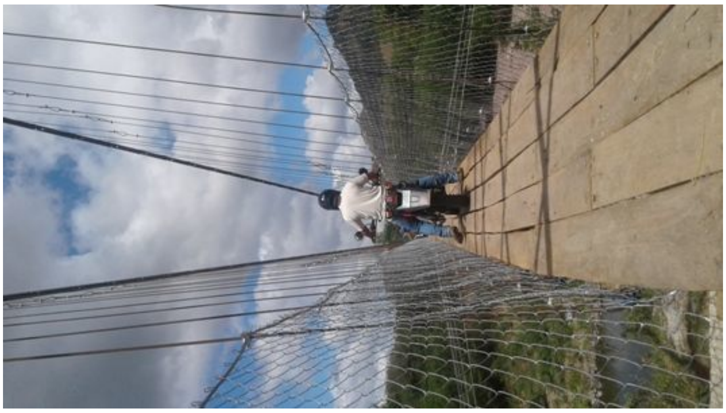
Tower hinge detail

Top tower detail

Walkway detail

New bridge in use - near tower view

New bridge in use - walkway view



A moto crosses the new bridge

The new bridge in use

Traditional dancers at the inauguration celebration

Kiewit, KPFF volunteer team with B2P staff and community

Bridges to Prosperity envisions a world where poverty caused by rural isolation no longer exists.

We work alongside communities and in partnership with governments to construct footbridges over impassable rivers, connecting people with schools, markets, and hospitals - the critical resources they need to thrive.

12%	24%	18%	32%
MORE children enroll in SCHOOL	INCREASE in healthcare TREATMENT	INCREASE in women EMPLOYED	INCREASE in household INCOME

Join us to create safe access for isolated communities around the world!

Learn more at:

www.bridgestoprosperity.org | bridgestoprosperity | bridgestoprosperity | b2p

WIND TUNNEL IN BRATISLAVA AND POSSIBILITIES FOR ITS UTILIZATION

Doc. Ing. Olga Hubova, PhD.

Department of Structural Mechanics, Slovak Technical University

1. ABSTRACT

The new Boundary Layer Wind Tunnel (BLWT) at the Slovak University of Technology (STU) in Bratislava allows in its two measuring areas to simulate steady and turbulent wind flow. Atmospheric Boundary Layers (ABLs) developing above suburban and urban terrains were reproduced using different barriers and roughness elements.

The series of flow characteristics were investigated with boundary layer for the urban terrain. Experimental results presented as mean velocity, turbulence intensity, integral length scale of turbulence and power spectral density were compared with EN 1991-1-4 [2] and ESDU data. Verification of the use BLWT tunnel was made on Silsoe cube. The obtained results were compared with literature and measurements done in-situ and it documents the applicability of BLWT STU wind tunnel in a broad spectrum of engineering, environmental and micrometeorological studies.

2. BRIEF DESCRIPTION OF WIND TUNNEL

Equipment for experimental measurements is located in the Laboratories of STU in Bratislava, Trnávka and was built during 2011-2013. This device enables primarily the experimental assessment of static and dynamic effects of wind on reduced models of buildings and structures or their parts, which are positioned in steady or turbulent flow, simulating the natural wind in various terrain categories.

The BLWT wind tunnel in Bratislava is constructed as a vacuum tunnel. This means that the pressure in the out-of-operation tunnel is equal to the outside barometric pressure. During operation, the static pressure in tunnel decreases counter to the dynamic pressure.

The wind tunnel with overall length 26.3 m and the operation sector of cross-section 2.6 x 1.6 m and length of boundary layer 14.6 m can be divided into front and rear operation sector (see Fig. 1).

The air flow is supplied by two axial fans Ø1600 powered by asynchronous motors 2 x 75 kW with frequency changers feed they supply the flow air capacity above 100 m^3/s by max 1000 rpm. It is also possible to use very low velocities that investigate the flow and diffusion of toxic or radioactive agents in the scales 1:1000 to 1:1500 under the condition of validity of Froude number.

The tunnel is equipped with two reference sensors – Prandtl sensors (Pitot static tubes) for assessment of dynamic air pressure and measuring the overall and static pressure. Differential pressure sensors are also available for monitoring of wind pressure distributions on models.

Pressure sensors transfer pressures to electric quantities which are compiled and saved in a computer; next they are processed using the LabView software. Saved data can be used in the next investigations or they can be shared with tunnel control systems for governing the air flow velocity settings in tunnel.

Devices:

- *Digital ALMEMO device with probe type FVAD 35 TH5K2*
- *Three 16-channels pressure scanner type Scanivalve DSA3217/16 (measuring range up to 2.5 kPa)*
- *CTA (Constant Temperature Anemometry) - an anemometer with heated wire is a proper device, working on the principle of King's cooling law. CTA is used for measuring velocity in a point and continuously provides information on the velocity in time series. Presently the BLWT tunnel is equipped with Mini CTA Type 54T42, sufficient for simple experiments.*
- *20 Irwin probes - simple omni directional sensors for wind-tunnel studies of pedestrian level winds.*

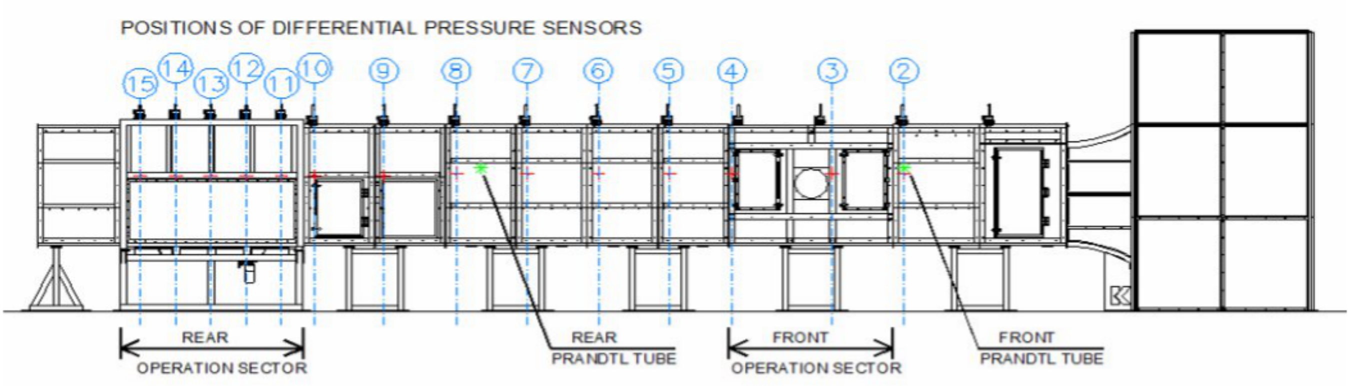


Figure 1: Positions of measuring devices

Figures 2 + 3: View on moveable arm and anemometer probe

Front operation sector provides steady wind flow up to a velocity of 32 m/s (115 km/h). The sector will be used for testing of sectional models of thin structures and their parts see Fig. 6 - 10 (bridges, masts, chimneys, towers, hinges and bridge cables, etc.) where the wind effects are dominant. The results provide data about mean and dynamic loads and response of structures to the wind effects.

The front section was tested for the flow uniformity. Using digital probe ALMEMO detailed measurements of the horizontal profiles of wind speed were made in the front section.

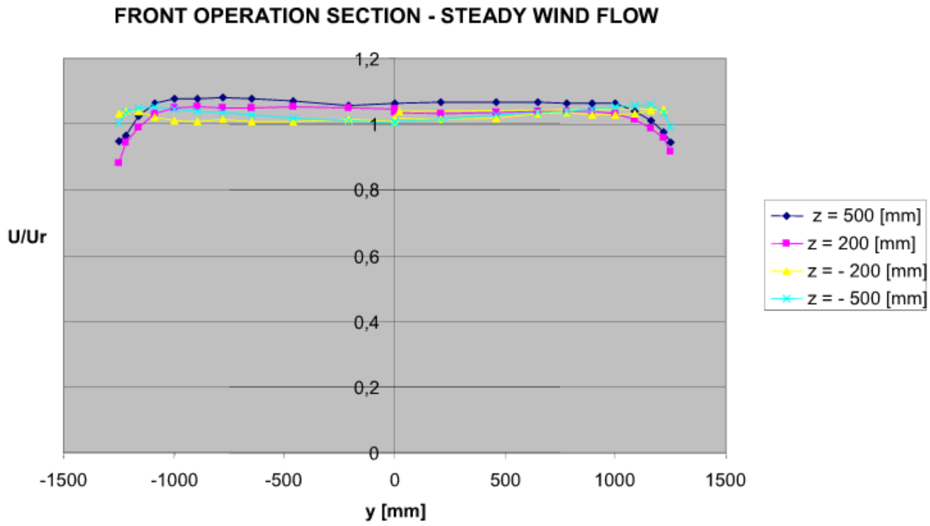
Barometric pressure: p_b = 98 770 [Pa], temperature: T = 18.3 – 18.6 [°C], air density: ρ = 1.17548 – 1.1742 [kg/m^3],

U - mean wind speed, *Ur* - reference wind speed on Prandtl sensor.

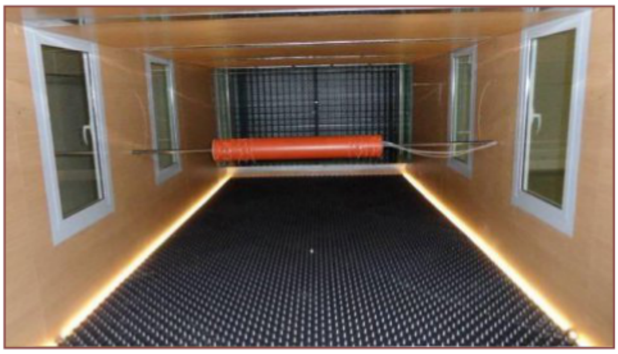
Measurements were made from the base height of 800 mm ± z above the floor.

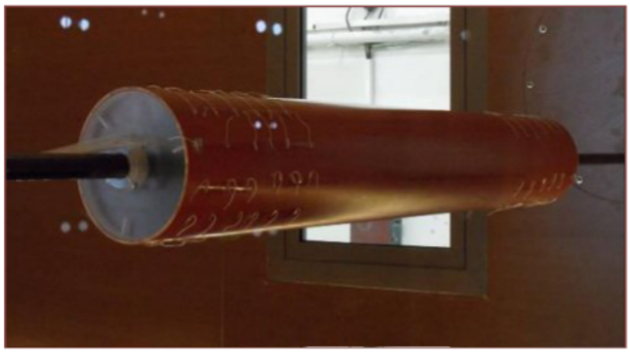
Preliminary tests reported that measured mean wind velocity at this section differed less than 1% and vertical tunnel walls affect uniformly distributed wind flow to a distance 400 - 450 mm from the walls (see Fig. 5).

← *Figure 4: Front operation sector*

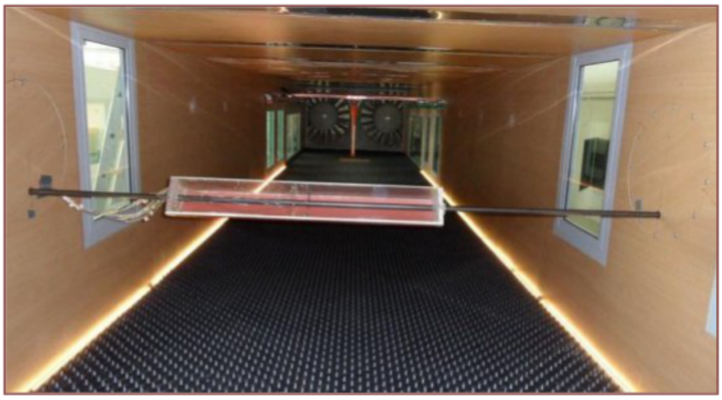


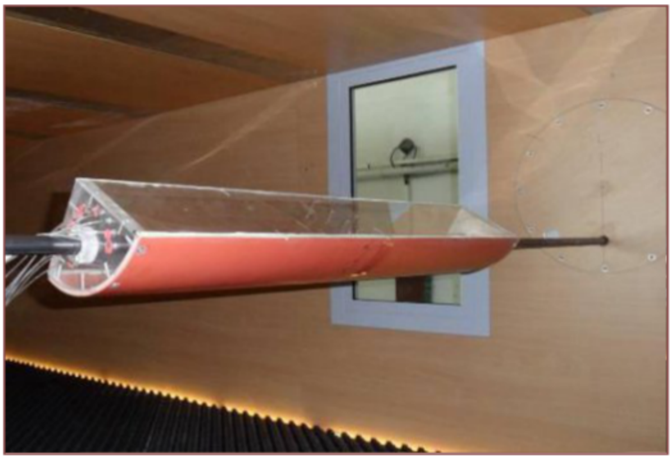
← *Figure 5: Steady wind flow at different heights in the front cross section*





Figures 6 + 7: View on sectional model in front sector in steady wind flow - cylinder





Figures 8 + 9: Quarter circle tested in front sector

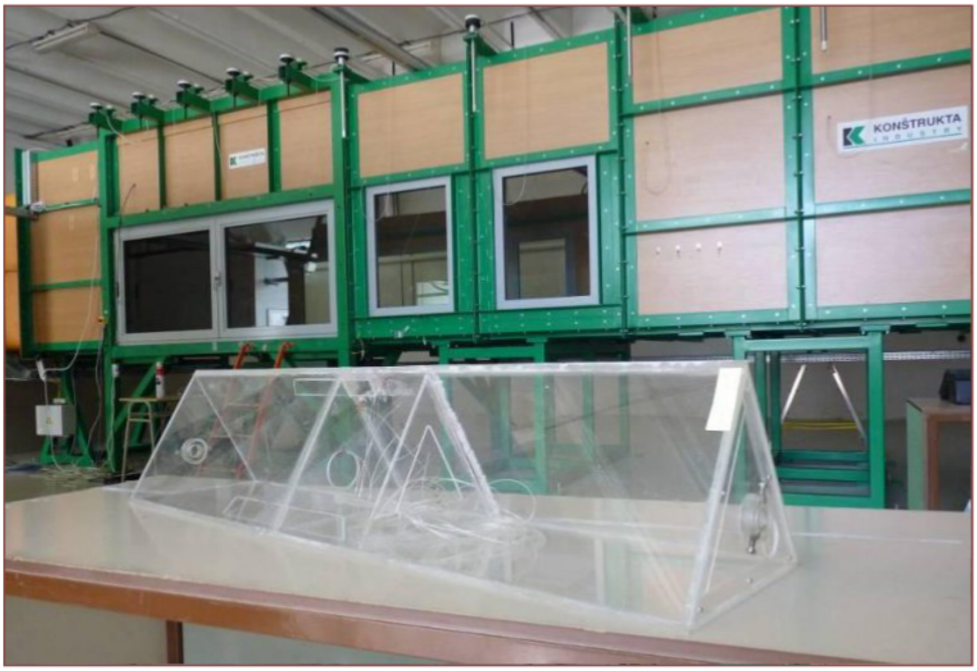


Figure 10: View on the model tested in front sector

Rear operating sector (ROS) is suitable for detection of effects caused by turbulent wind flow with velocities from 0, 3 to 15 m/s. Measurements of local pressure on the small-scale models, surface and overall wind load under various wind directions and to determine mean and fluctuation wind load on structures having atypical special shapes for which the wind effects are not specified in standards.

This sector is also suitable for assessment of wind effects upon the pedestrians as well as for monitoring of wind comfort in built-up areas, air purity (diffusion of emissions, trajectories of pollution), terrain and topographic studies.

In regards to possibilities for utilization of this tunnel (two operating sectors with different kinds of wind flow, dimensions and technical parameters of tunnel), it can be a good tool for various branches (civil and mechanical engineering, chemical industry, energetic industry, ecology).

ABL simulation and comparison with EN 1991-1-4

Simulated boundary layer for urban terrain requires the similarity criteria in four basic parameters:

1. Profile of mean wind velocity,
2. Profile of turbulence intensity
3. Integral length scale,
4. Power spectral density function.

Mean wind velocity and intensity of turbulence profiles were investigated for different roughness and we obtained information on type and quality of the boundary layer. The special devices like grids or foil and 2D barriers (Fig. 11) were inserted along wind tunnels according [1].

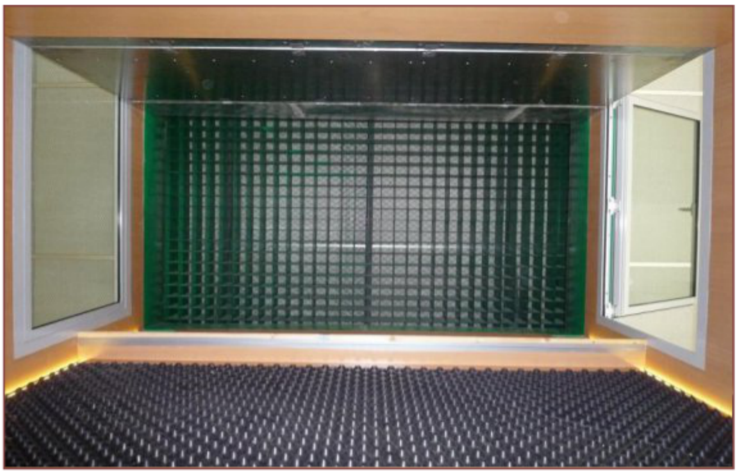


Figure 11: Arrangement of Boundary layer - plastic FASTRADE 20, barrier 100-250

The results of the experimental measurements in BLWT STU for different barriers (height *B*=150-200 mm) and comparison with EN 1991-1-4 [2] are shown in Fig. 12.

The boundary layer simulation was developed and is uniform in the area of test section used for experiments on models. The mean velocity profiles in the ABL simulations proved to be in good agreement with logarithmic law. The best results gave us barrier with height 150 -170 mm.

The detailed measurements of the wind action, especially near the ground, help us to prepare boundary layer in BLWT STU according to EN 1991-1-4.

We can classify ABL simulation and terrain roughness in STU wind tunnel between the III and IV terrain category, which corresponds to the roughness of terrain in Bratislava and cities in Slovakia. Experimental measurements in BLWT STU so far have ensured height of boundary layer about 1.05 m and scale factor - SF 366 - 390.

The roughness length for area with regular cover of buildings or vegetation - terrain category III z_0 = 0.3 m, our ABL simulation with value z_0 = 0.7 – 0.77 m is closer to the terrain category IV, where z_0 = 1 m (area with at least 15 % of the surface is covered with buildings their height exceeds 15 m).

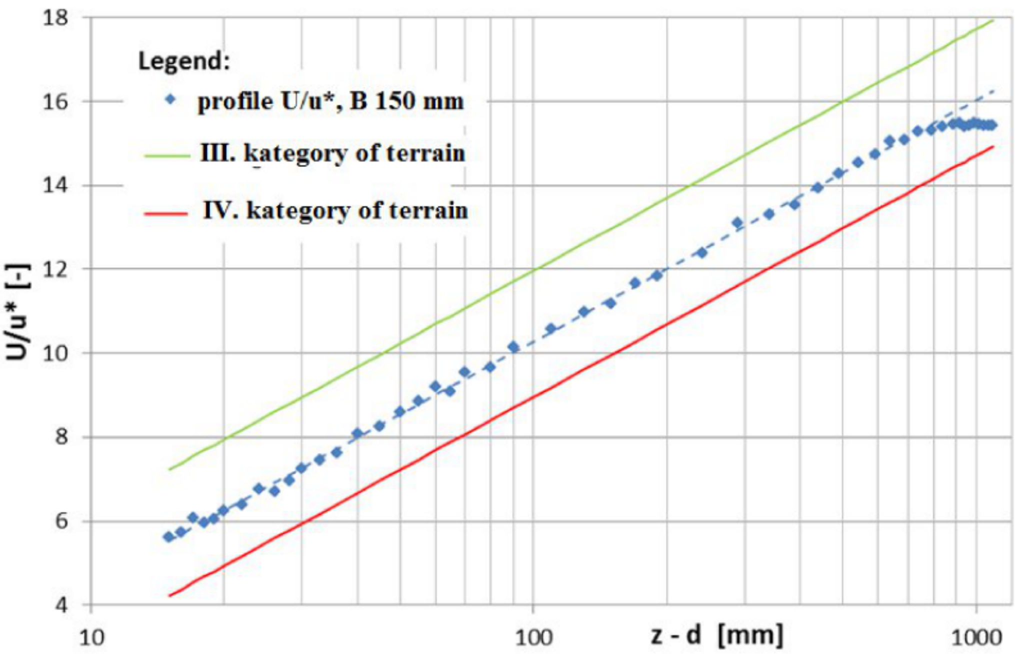


Figure 12: The profile of mean wind velocity compared with EN 1991-1-4

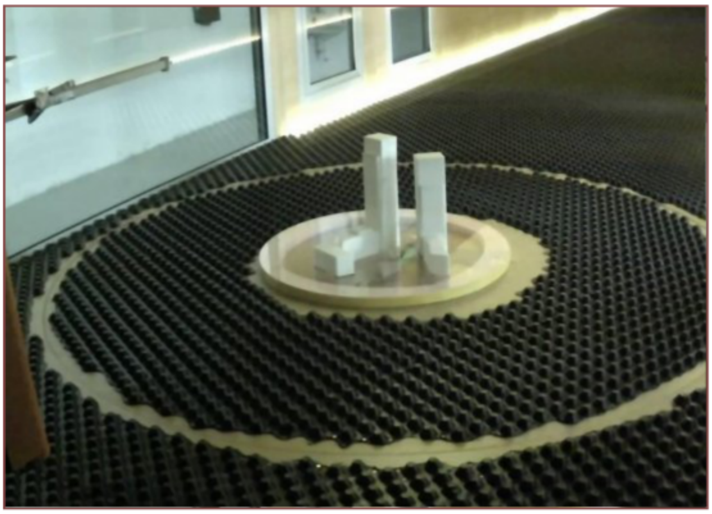
3. WIND PRESSURE DISTRIBUTION ON BUILDINGS

The values of external wind pressure coefficients on the facade are not specified in EN 1991-1-4 for atypical buildings and buildings in groups. It is necessary to determine these values by experimental measurements or numerical simulation.

The new wind tunnel in Bratislava allows in its two measuring areas to simulate steady and turbulent wind flow. In the first phase we tested the model – a quarter of a circle in the front space in steady flow by changing of wind direction (Fig. 13, 14). The models were rotated every 15º or 22,5º, thereby simulating the changing of wind direction acting on the objects.

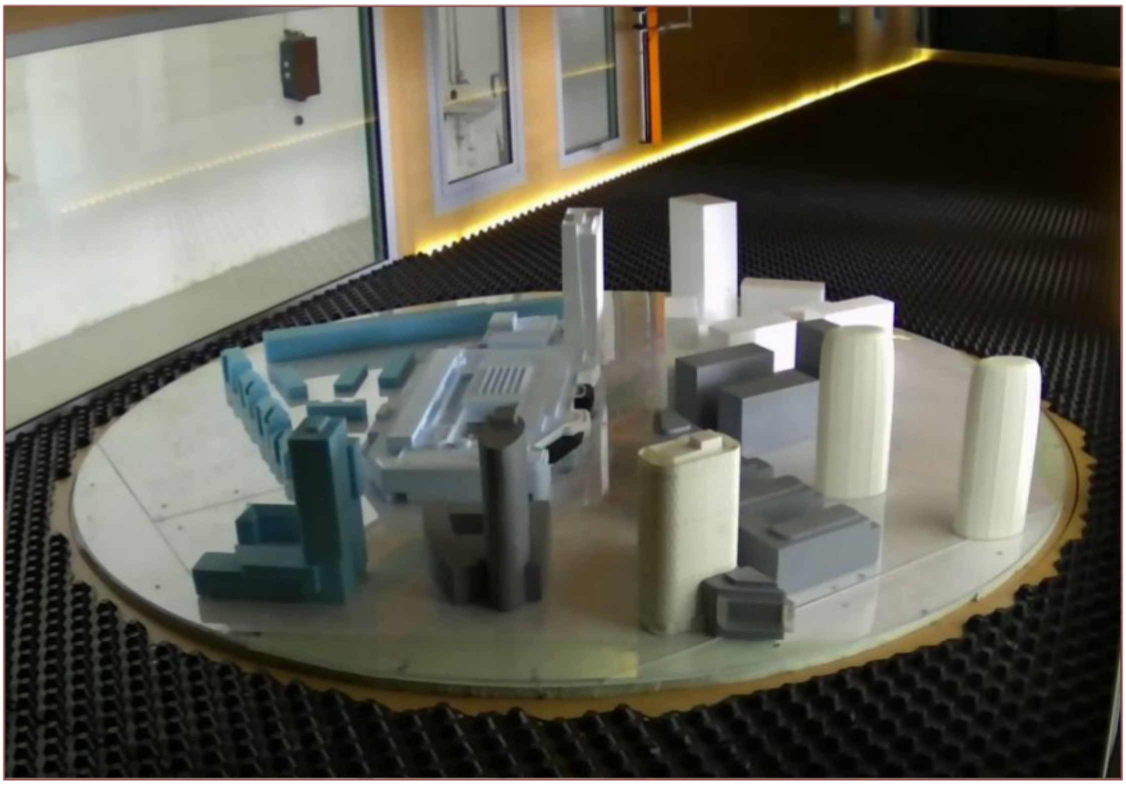
The external wind pressure coefficients obtained from repeated experimental measurements made on the model in steady and turbulent wind flow indicates the local extremes of suction in certain directions.

This can cause hazardous zones on facades or cladding of buildings. We can optimize the position of the objects - buildings in urban planning with respect to the wind direction in the site.



← *Figure 13: Models of buildings on turn table in central zone in Bratislava city (SF 1:300) in turbulent wind flow*

↓ *Figure 14: Models of different types of buildings on turn table in Bratislava city in turbulent wind flow*



4. POSSIBILITIES FOR EXPERIMENTAL MEASUREMENTS AND MODEL TESTS

Type of test

I. Investigation of local pressures on scale models (open roofs, roof lining and atypical shapes structures).

II. The total wind load.

III. Tests of sectional models - using dynamically mounted models (bridges, high-rise buildings, towers, cables and hinges).

IV. Aero-elastic studies - testing using dynamically similar models of buildings, bridges and structures (wind-induced response of building and other structures). Testing of active and passive damping devices for slender structures of large spans.

V. Wind in the level of pedestrian - (character of flow around buildings and structures, measurement of local wind speed and direction for environ-mental assessments).

VI. Air Quality - tests for evaluation of the dispersion of pollutants. Modeling and monitoring dispersal of pollutants and hazardous substances in the area of chemical and radioactive devices. Trajectory of pollution and the resulting air quality around buildings to urban spaces.

VII. Terrain and topographic studies - tests with small scale topographic model using a flow visualization and hot wire anemometer (flow over complex terrain roughness and estimate the potential for wind energy of sides, monitoring soil erosion in deforestation).

The possibilities for using the wind tunnel BLWT STU are offered not only in area of civil engineering and architecture, but also in mechanical engineering, the environment and also forest and land management. Experimental testing in the wind tunnel allows repeated measurements at varying wind speed and direction, which would not be possible in situ with respect to the stochastic nature of the air flow.

Wind engineering that works with the new software (CFD), and also new methods of experimental testing of structures in BLWT tunnel, will provide a new approach to research at the University of Technology in Bratislava. We expect closer cooperation with architects, designers and researches will help us achieve safer and more economic design of structures.

Acknowledgement

The presented results were achieved under sponsorship of the Grand Agency VEGA of the Slovak Republic (grant. reg. No. 01/0544/15 and 01/0265/16) and with the support of the TU1304 COST action “WINERCOST”.

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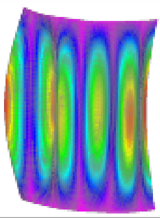
Łukasz Skotny



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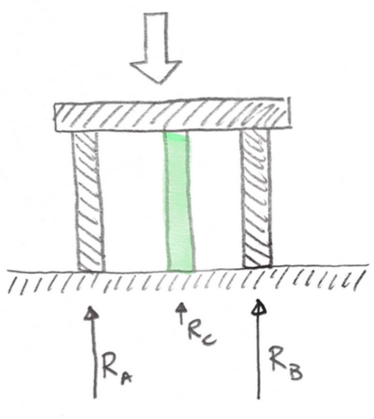

Examples are fun, but problems are serious.
Learn what structural rigidity is,
and why it is so important.
There are no equations inside
but I feel you may learn something here.

Something that might be crucial in your next design.

Trust me you would like to understand that!

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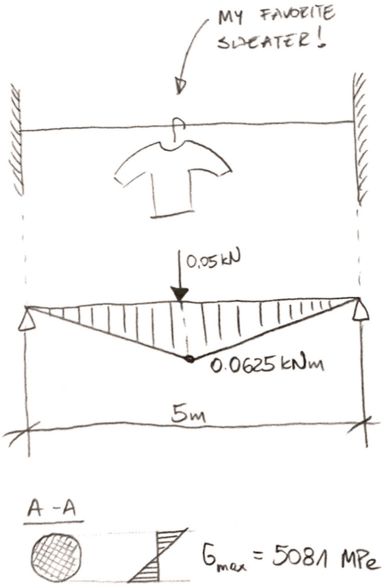
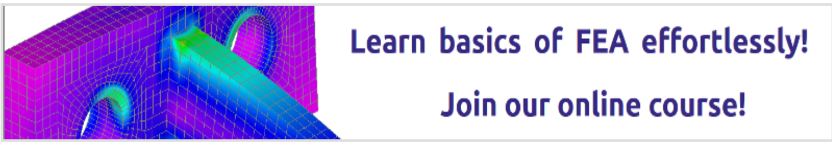


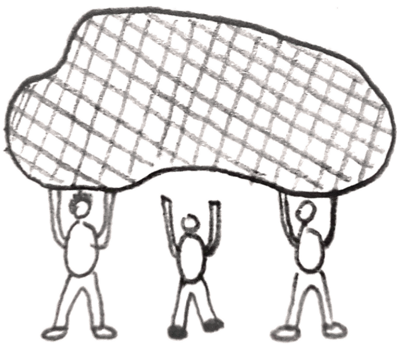
What geometric nonlinearity does
(and my favorite sweater)

Without a doubt, the nonlinear analysis is getting more and more popular.
But have you ever wondered what geometric nonlinearity does?

I'm certain you can find dozens of manuals online with all the equations for it...
but I focus here on something totally different.

I simply explain what it does.





How yielding works
(or what to do if you want the short guy to carry a stone with you!)

Plastic redistribution of loads is often used.

This can easily save you some material costs if you wish to go that way.

However, before you decide, it is worth understanding how the phenomenon works – and this is what this article is all about!

Contact

Queensferry Crossing

The Queen officially launched the crossing on 4 September 2017

- exactly 53 years after she opened the Forth Road Bridge.

The bridge fully opened to traffic on 7 September 2017.

The bridge is located in Scotland where it crosses the Firth of Forth - it is an estuary that separates the Scottish capital of Edinburgh from the Kingdom of Fife to the north. The downstream crossings of the Forth at Queensferry are a pair of historic bridges – the famous cantilever rail bridge constructed in the 1880s and the Forth Road Bridge, Britain´s first long-span suspension bridge, which was opened in 1964.

The Queensferry Crossing comprises three approximately 200 high main towers which support two 650m main spans with associated approach viaducts with a total crossing length of 2,638m.

It is the longest three tower cable-stayed bridge in the world and also by far the largest to feature cables which cross at mid-span.

Photo: Courtesy of Transport Scotland

Read about the design and construction of the Queensferry Crossing, enjoy drawings, photos and videos in our e-mosty March 2017: Three Bridges, Three Centuries.

Hålogaland Bridge, Norway

The Hålogaland Bridge is located in Norway. It is a suspension road bridge with main span 1,145m. The viaducts, towers and anchorages for main cables are concrete.

The towers are concrete A-frames. The bridge deck of the main span is 18.6 wide steel box girder.

Concrete viaducts are 15.4m wide, with 5 piers 12 to 30m tall. The viaduct from Karistranda is 244m and the viaduct from Øyjord is 152m.

The deck is constructed as a closed steel box with trapezium-shaped stiffening trusses and transverse bulkheads in 30 segments. They are transported to the site using a ship with boxes placed on top of each other, lifted directly from the ship by floating crane to their final position and attached to the suspension hangers. The middle section is installed first, further installations will be made symmetrically from the middle. After all 30 segments are lifted to correct position they will be welded together.

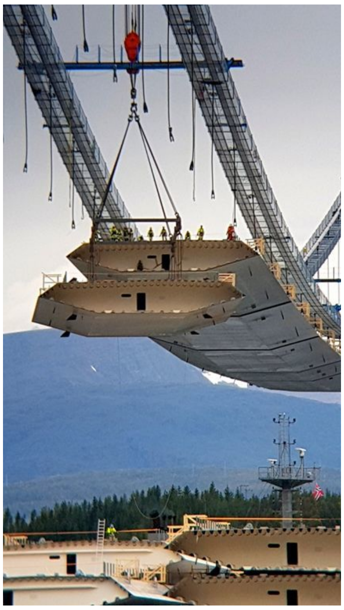


Photo Credit: Srdjan Boskovič

Read about the design and construction, enjoy drawings, photos and videos in our e-mosty June: Suspension Bridges (click on the picture below).

Osman Gazi Bridge

The bridge is located in Turkey. It is a part of Build-Operate –Transfer scheme including the build and operation of the adjacent 420km motorway stretching from the outskirts of Istanbul, the largest city of Turkey, to Izmir.

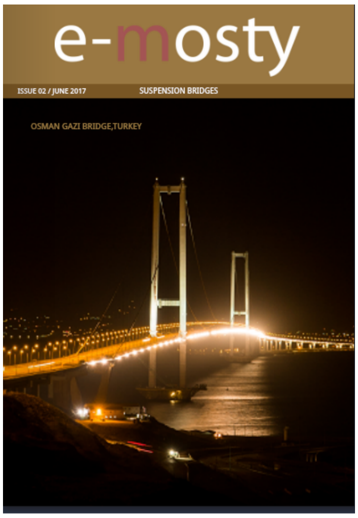
The bridge and the first phase of the motorway were opened to traffic on 30 June 2016.

The bridge consists of a three span continuous suspension bridge with a 1,550m main span. The 252m tall H-shaped towers are stiffened steel plate construction.

Closed box sections were used for both legs and cross beams. The suspended deck is a 30.1m wide and 4.75m deep single streamlined orthotropic steel box girder deck.

Read more about its design and construction, enjoy drawings and photos in our magazine e-mosty June 2016:

Read about its operation and maintenance in our magazine e-mosty June 2017:



Yavuz Sultan Selim Bridge

The bridge is located in the Odayeri – Paşaköy area of the Northern Marmara Motorway project in Turkey with the "Build, Operate and Transfer" model.

The bridge was opened to traffic on 26 August 2016.

The bridge combines two different transport solutions – rail and road – within the same corridor and the same level, supported on a 58.5m wide steel deck. The main span is 1,408m with two on-shore concrete 322m towers. The bridge is a suspension bridge combined with stay cables, i. e. hybrid solution, called HRSB (Highly Rigid Suspension Bridge).

Picture of architectural illumination (Rumeli Kavaği) - 27 august 2016.Source: 3kopru.com

Read more about its design and construction, enjoy drawings and photos in our magazine e-mosty June 2016:

Almonte Viaduct

The Almonte River Arch Viaduct over the Alcántara Reservoir in Spain is part of the Madrid-Portuguese Border High Speed Rail link. The viaduct whose length is almost 1km is within a 6.1km section of the line is all the centre-piece of this unique project.

The viaduct is formed by three distinct areas: two sequences of approaching spans from both banks, and the main span. The 384m deck-arch main span gives support, by means of spandrel columns, to the upper deck, which has continuous multi-supported prestressed box-girder scheme all along the viaduct.

The deck is a double-cantilevered prestressed concrete box girder with a constant depth of 3.10m and a depth of 14m.

Tagus Viaduct

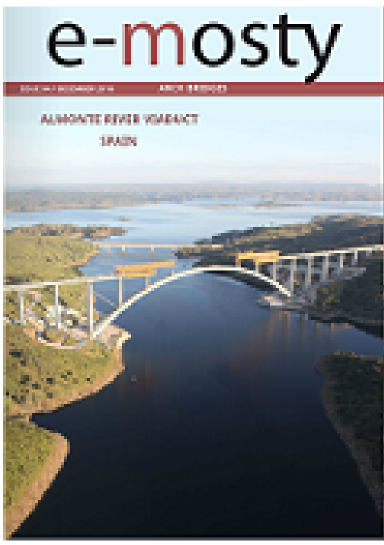
The viaduct over the Tagus River in the Alcántara Reservoir is also part of the High Speed Rail Link between Madrid and the Portuguese border.

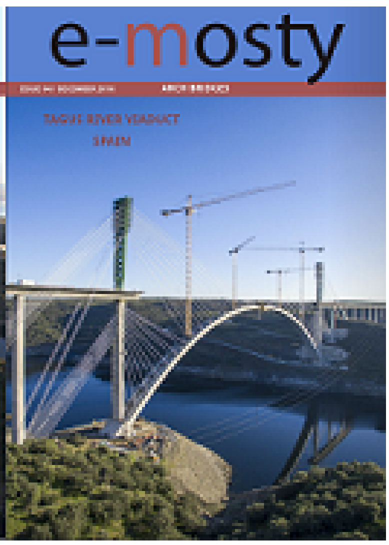
The two approach viaducts are composed of 60m long spans except the spans adjacent to the arch, which are 57m long.

The bridge has a total length of 1,488m and has a 324m long arch. The deck spans over the arch are 54m long.

The arch is formed by a box section variable both in width and height. The deck is a prestressed concrete box girder with a maximum depth of 4.00m.

Read about design and construction of both bridges, enjoy drawings, photo and video galleries in our magazine e-mosty December 2016:





River Irwell Network Arch Bridge

An 89m, twin network arch bridge was designed to span the River Irwell in the North of England. The bridge will carry a twin bidirectional track arrangement as part of the Ordsall Chord intervention.

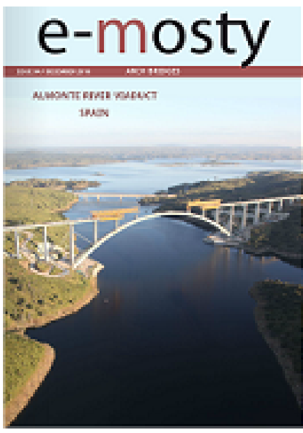
This is the first network arch railway bridge in the United Kingdom. The viaduct is approximately 300m long and connects two existing masonry arch viaducts.

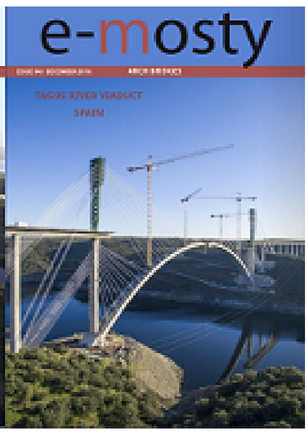
The structure comprises a system of two inclined, braced network arches supporting two tracks via a steel and concrete composite deck with transverse member supported from the longitudinal steel tie beams.

The bridge had to be designed to respect the significant heritage of the site. Following extensive public consultations, the aesthetic requirement for a slim and elegant but emblematic structural line led to the choice of the architectural signature of the Ordsall Chord, a ribbon in weathering steel, connecting and unifying visually the adjoining structures.

The complex configuration and the construction sequence adopted, which was tailored to the particular site constraints, presented a number of challenges to both the design and construction phases.

Read more about the bridge ,its design and construction, enjoy drawings, photo and video gallery in our magazine e-mosty December 2016:





Editorial Plan

e-mosty December 2017

Movable Scaffolding Systems.

e-mosty March 2018

Naeem Hussain. Bridges.

e-mosty June 2018

American Bridges.

e-mosty December 2017: Movable Scaffolding Systems

Professor Pedro Pacheco, BERD

BERD
ONE BRIDGE, ONE SOLUTION

Overhead MSS M45-S with OPS system in Highway Construction in Slovakia

MSS

OPS SYSTEM

CHALLENGES
INCREASE IN TRAVELLING WEIGHT
VERY DEMANDING FORMWORK PROJECT DUE TO THE PROXIMITY OF THE DECKS AND THE RADIUS OF CURVATURE ON PLAN (LOW AND VARIABLE)
ALLOWING THE CLIENT THE 4TH REUSE OF THEIR OWN EQUIPMENT

SOLUTIONS
CALCULATIONS CARRIED OUT IN ORDER TO INCREASE THE TRAVELLING WEIGHT AND KEEP THE MODIFICATION COSTS AS LOW AS POSSIBLE IN ACCORDINGLY TO THE CLIENT'S EXPECTATIONS
WORK DONE TOGETHER WITH THE FORMWORK SUPPLIER IN ORDER TO ENABLE LAUNCHING

RESULTS
CONSTRUCTION PERIOD: 48 WEEKS
HIGH CONSTRUCTION QUALITY AND DEFORMATION CONTROL
HIGHLY OPTIMIZED DECK CONSTRUCTION
HIGH SAFETY LEVELS DURING CONSTRUCTION

e-mosty December 2017: Movable Scaffolding Systems

Almonte River Viaduct. Source: e-mosty December 2016

Antonio Póvoas – AP Bridge Construction Systems – Portugal, Lda.

<u>The Utilisation of MSS in large spans and major projects presentation</u>

Almonte Viaduct – Tagus Viaduct – Vasco de Gama - Viaducto do Engano

Tagus River Viaduct

Vasco de Gama Bridge

e-mosty

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- Achieved an international profile with increasing numbers of readers
- Provided support to various conferences, books, educational activities etc.

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ISSUE 03 / SEPTEMBER 2017 MERSEY GATEWAY BRIDGE. ARENALES BRIDGE.

BRIDGES TO PROSPERITY