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LIST OF CONTENTS

Front Cover: Suspension Bridge in Linz, Austria Photo Credit: ASFINAG

Back Cover: La Joya Bridge, Peru Photo Credit: CIMOLAI S.p.A.

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Dear Readers

In the first article of this edition, you can find information about the design and construction of a ***suspension bridge over the river Danube*** *in Linz, Austria which has already become a new landmark bridge.* ***Andreas Keil, Mathias Widmayer and Thomas Fackler of sbp*** *describe its design and construction providing a lot of interesting technical details, drawings, and photos.*

La Joya Bridge*, with its access viaducts, forms part of a larger road infrastructure project intended to create a motorway from Arequipa in the southern part of Peru to the 'Panamerica Sud' roadway, the main artery that crosses the whole of South America, from Colombia to the Land of Fire. In the article prepared by* ***Bruno Pronesti, Giovanni Sammartano and Alessandro Catanzano of CIMOLAI*** *you can read about the project, design of the bridge, steel structure engineering and modelling, workshop production, transport and erection of the structure.*

As a medial patron of ***Bridges to Prosperity****, we are always happy to share information about their activities and achievements. This time, their article was prepared with* ***Arup*** *and presents the initial outcomes of the work that B2P and Arup have done to allow B2P to understand their embodied carbon and discusses how B2P can use this data within their work.*

The last article about the ***Loko Oweto Bridges*** *in Nigeria was prepared by* ***Micha B. Petri of Kedmor Engineers*** *and brings information about the various stages of a segmental bridge constructed with the cast-in-situ balanced cantilever method above the river and the challenges involved in the design derived from the length of the bridge.*

I would like to thank ***David Collings and Richard Cooke*** *for the review and assistance with the content, and all the authors, people, and companies that have been helping me put the content together.*

We also thank our partners for their continuous support.

The next e-mosty magazine special edition "American Bridges" will be released on 20th March 2024. The next e-BrIM will be released on 20th February 2024.

We wish you a Happy and Prosperous New Year.

Magdaléna Sobotková

Chief Editor

INTERNATIONAL ONLINE PEER-REVIEWED MAGAZINE
ABOUT BRIDGES

e-mosty

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

It is published at www.e-mosty.cz and can be read
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The magazines stay **available online**
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The magazine **brings original articles about bridges and bridge engineers** from around the world.
Its electronic form enables the publishing
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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.

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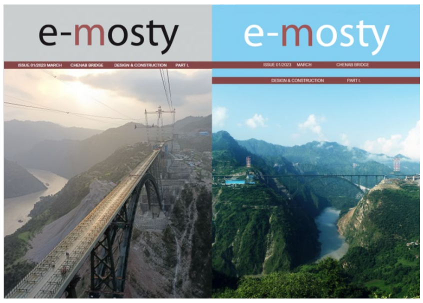

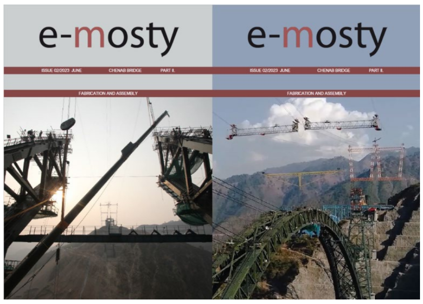

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The magazines stay **available online** on our website as pdf.

The magazine brings **original articles** about **bridge digital technology** from early planning till operation and maintenance**, theoretical and practical innovations,** **Case Studies** and much more from around the world.

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A NEW LANDMARK BRIDGE FOR LINZ, AUSTRIA

Andreas Keil, Mathias Widmayer,Thomas Fackler
sbp Stuttgart, Germany

Figure 1: Bridge View / ASFINAG

INTRODUCTION

The so-called “A26 Linz Highway” is an important infrastructure project to improve the traffic situation in the city of Linz and the surrounding area of the Austria´s state capital. Residents of the city will benefit from less traffic, while commuters from the western part of the region will profit from shorter routes.

The major infrastructure project A26 is divided into three phases. The first Phase of this major infra-structure development includes the construction of the New Danube Bridge Linz.

With a span of over 300 m, the slender suspension bridge over the river will be an elegant and functional landmark for the city of Linz. To date, the structure is the only suspension bridge over the Danube in Austria.

Construction of the 4th Danube Bridge Linz started in January 2019. Four years later, the suspension bridge is almost entirely assembled. Suspension cables weighing 65 tons were pulled across the Danube and the seven sections of the steel deck girder weighing up to 280 tons were installed.

BRIDGE DESIGN

The 4th Danube Bridge in Linz is a simple suspension bridge and consists of:

- The superstructure as a steel composite structure, with a central hollow steel box girder and tapered steel cross girders matching the spacing of the hangers.
- The cable support structure with 145 mm thick suspension cable bundles that consist of twelve parallel, fully locked cables. The hangers are also planned as fully locked cables and have a diameter of 95 mm.
- The anchoring structures, four cable anchorages (north and south) and two abutment structures at the tunnel portals.

DATA BLOCK

Owner/Client: ASFINAG Bau Management GmbH, Vienna, Austria

Conceptual & Structural Design:

schlaich bergermann partner, Stuttgart, Germany

Baumann + Obholzer, Innsbruck, Austria

gmp von Gerkan, Marg and Partners Architects, Aachen, Germany

Traffic Planning:

arealConsult Ziviltechniker GmbH, 1140 Vienna, Austria

Checking Engineer:

Dipl.-Ing. Hinko Jusufagic, Vienna, Austria

Dipl.-Ing. Alexander Oplustil, Vienna, Austria

Construction:

ARGE A26 Danube Bridge ICM - MAEG - f-pile

← Figure 2: Bridge Deck / ASFINAG

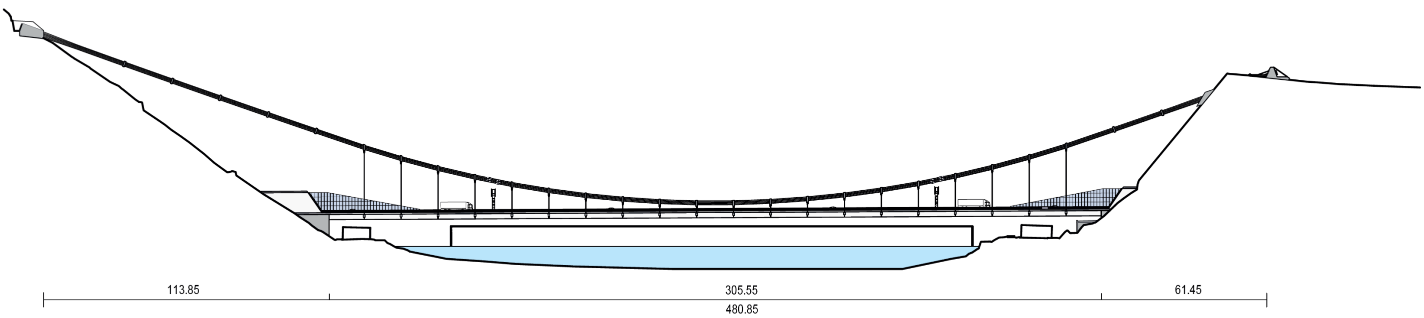

Figure 3: Bridge View / schlaich bergermann partner

DECK

The superstructure of the bridge is suspended from the main cables with vertical suspension cables. The main girder is a hollow steel box girder with a composite concrete deck slab. It ensures the bending and torsional rigidity required for suspension bridges.

In addition, the high dead weight of the steel structure, concrete slab and deck including edge beams also ensures that the deformations and fatigue loads from traffic remain within a permissible range. The central position of the box girder blends visually into the void of the cantilevered deck, creating a slender and elegant appearance of the bridge.

The choice of a combined steel and concrete supporting structure simplifies assembly by lifting the lightweight steel construction segments from the Danube and, with the concrete slab subsequently concreted on, provides the necessary robustness and durability for a road bridge with heavy traffic.

The 2.05 m high, 7 m wide at the top and 5 m wide at the bottom, accessible steel main girder in combination with the edge girder and a 28 cm thick, lightly reinforced concrete slab form the bending and torsion-resistant longitudinal girder of the bridge.

Longitudinal and transverse stiffeners (T-profile frames) in the main girder prevent the web and chord plates from buckling under compression and shear loads.

Steel cross girders (80 cm wide / 0.9 m to 2.05 m high), which are also connected to the concrete slab, transfer the forces from the main girder to the anchorage points of the suspension cables.

The cross girders as well as the longitudinal girders arranged at the edge (65 cm wide / 90 cm high) are designed as tightly welded hollow sections. The transverse and longitudinal beams also support the concrete slab.

The concrete deck slab spans mainly in the transverse direction with supports on the beams of the main girder and the edge girders. At the edges, the concrete slab cantilevers approx. 1.2 m, thus relieving the span between the edge girder and the main girder.

The slab is also supported at the cross girders, resulting in a biaxially tensioned slab in these areas.

To ease the construction, the composite slab was constructed with semi-prefabricated parts (8 cm filigree slabs tensioned in the transverse direction with an intermediate yoke support and an additional 20 cm of concrete).

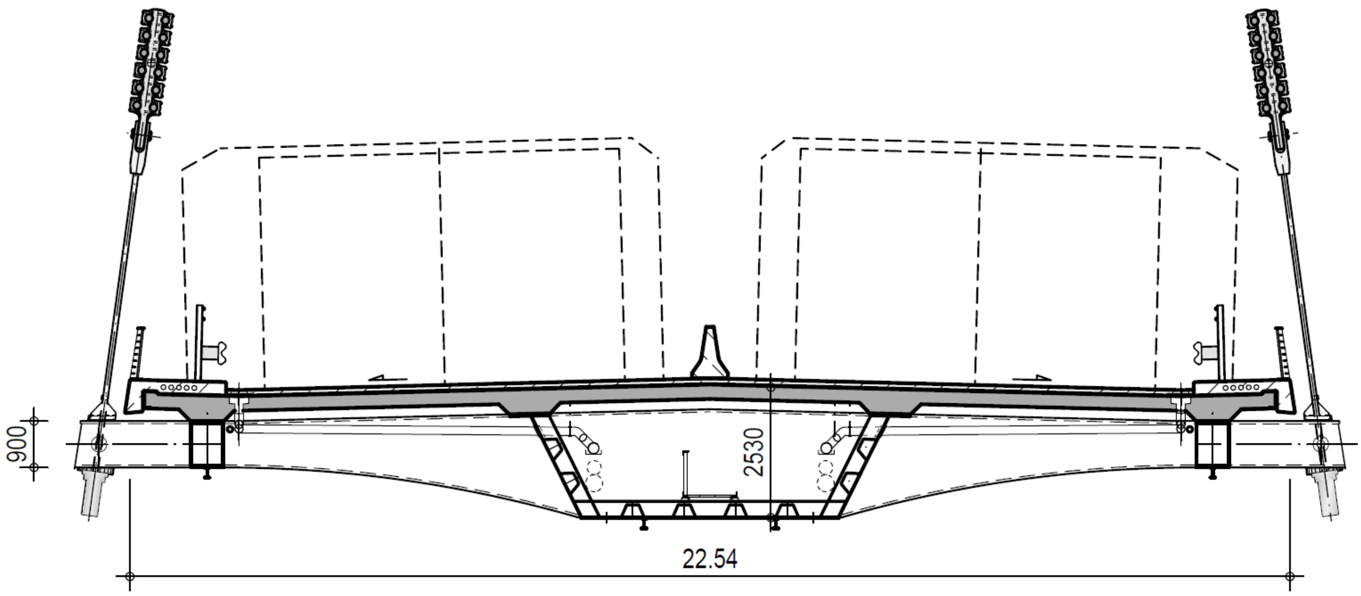

Figure 4: Bridge cross-section / schlaich bergermann partner

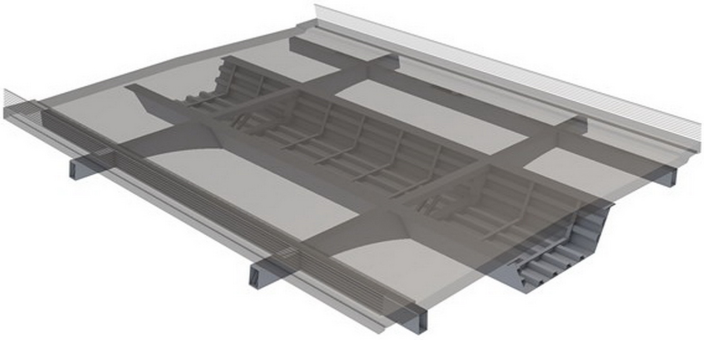

Figure 5: Section of the bridge deck and roadway slab
schlaich bergermann partner

Figure 6: Installation of semi-prefabricated composite slabs
schlaich bergermann partner

CABLES

The main suspension cables across the Danube, which carry a weight of 13,000 tons, are around 500 m long. They are arranged in two bundles, each consisting of twelve individual fully locked cables with a diameter of 145 mm.

The vertical suspension cables, which connect the main cables to the bridge deck, have a diameter of 95 millimeters and are spaced 14.55 m apart from each other.

The two sets of cables reunite at the steep banks of the Danube and are secured in two steel anchor blocks in the massive, guyed structures, each with 100 anchors in the rock of the Freinberg and the Urfahr walls.

This layout not only allows the cables to be installed easily but also ensures that individual cables can be replaced at any time; a requirement for a long service life of the structure.

By choosing two levels per cable, it is possible to anchor them simply and efficiently to a strong, upright plate (anchor sword).

Shim plates are included to adjust the length of the suspension cables.

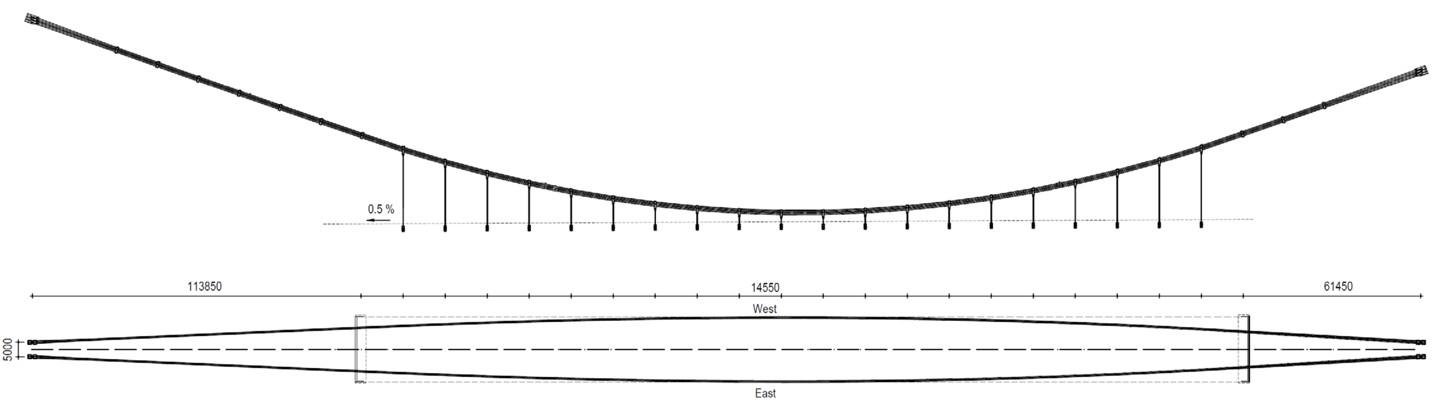

Figure 7: Cable support structure / schlaich bergermann partner

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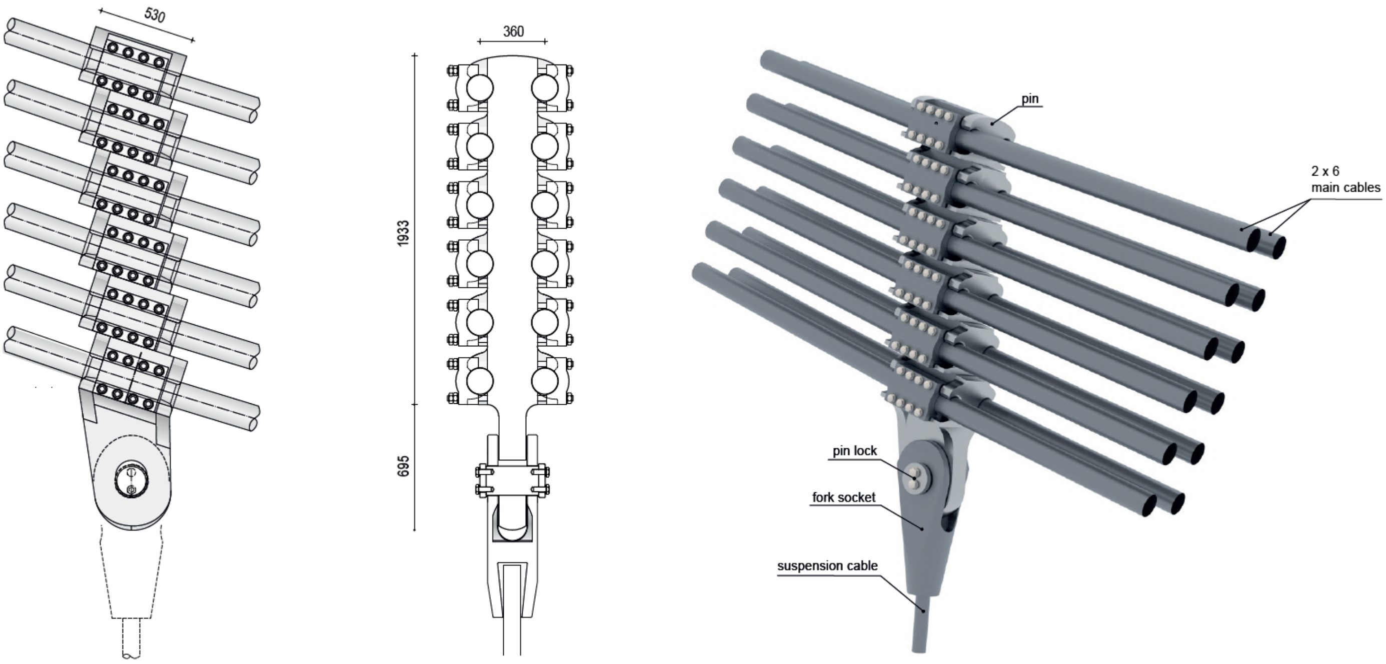


Figure 8: Suspension cable clamp with hanger connection / schlaich bergermann partner

The main cables are anchored to the cast steel suspension cable clamps, which also fix the cables in their geometry, using a clevis.

The cables are held in the grooves of the suspension cable clamps with clamping shells.

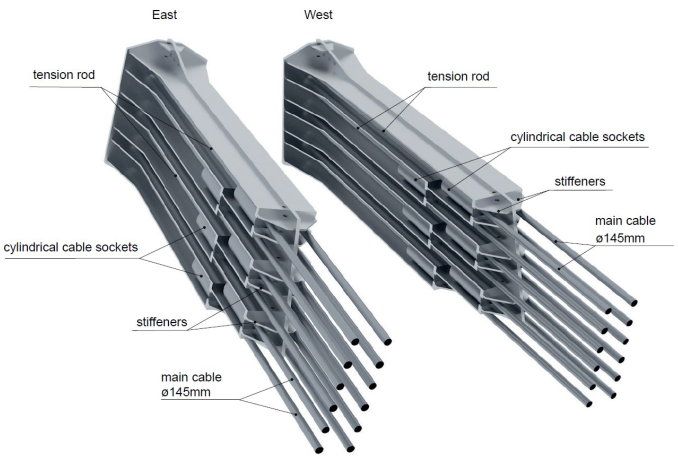


Figure 9: Support cable anchorage
schlaich bergermann partner

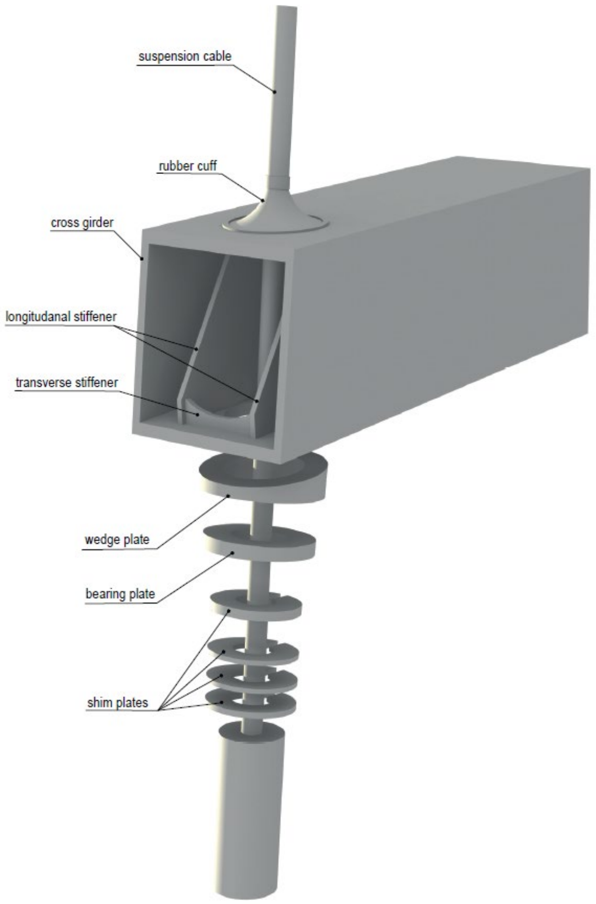


Figure 10: Suspension cable clamp with hanger connection
schlaich bergermann partner

The tangential forces can be transmitted via friction due to the pre-tensioning of the HV bolts.

The length of the suspension cable clamps depends on the permissible lateral pressure and the required "run-out trumpets" for the cable deflection.

The suspension cables are also fully locked spiral cables with a diameter of 95 mm and individual lengths of approx. 4.5 - 27 m. They are 14.55 m apart in the longitudinal direction of the bridge.

ANCHORING STRUCTURES

Considering the special geographical location of the bridge in the Danube Valley with its steeply rising rocky slopes, the bridge's main cables are anchored directly in the rock of these mountain slopes.

As a result, the bridge visually "hovers" above the Danube and blends into its surroundings in a visually weightless manner.

Only two cable anchorages and two abutments are required for the structure. The forces of the 2 x 12 main cables are each transferred to the northern and southern anchoring blocks via an anchor sword. Both blocks are anchored in the ground with over 100 permanent grouted anchors.

On both sides, the two end cross girders of the bridge deck are supported on abutments in the entrance area of the tunnels.

Figure 11: Abutment & tunnel portal south / ASFINAG

Vertical support is provided by spherical bearings that can move in all directions and are arranged on the outer sides of the bearing cross girders.

In the horizontal direction, the main box girder is supported on separate horizontal bearings in the central axis of the bridge.

The fixed point is on the south abutment; on the north side, there is a transversely fixed, longitudinally movable bearing. This bearing system at the north allows a rotation of the wide bridge deck and avoids any additional longitudinal forces due to lateral wind.

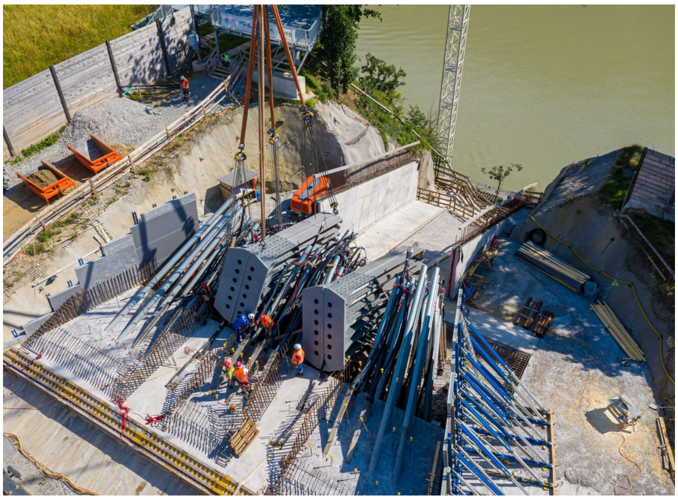


Figure 12: Anchor Block North / ASFINAG

Figure 13: Anchor Block South / ASFINAG

CONSTRUCTION PROCESS

After various approval procedures, construction of the A26 Linz Highway began in January 2019.

The centrepiece of the first development stage includes the approximately 300 m long earth-anchored suspension bridge over the Danube River.

The unique topography and geological conditions in this area of the Danube Valley enable the forces to be diverted over the adjacent rock faces to the south and north side of the Danube, creating a genuine suspension bridge.

The suspension bridge was assembled in five main steps:

1) Construction of anchor blocks north and south including the bridge anchoring and abutments;
2) Erection of cable support structure (suspension cables, hanger clamps and hanger cables);
3) Assembly and installation of the steel deck girder;
4) Production of the roadway slab including the roadway structure;
5) Bridge equipment and finishings.

Construction of anchor blocks north and south

Before construction of the anchor blocks and the bridge anchoring could begin, the rocky subsoil had to be prepared.

This preparation included above-ground blasting work, the construction of rockfall protection walls and rock cross-linking, the excavation of the construction pits for the anchor blocks and cable tunnels, including excavation support and subsequent ground improvement.

The soil was improved by removing the weathered rock, subsequent concrete backfilling, and additional grouting.

These measures allow the anchor forces in the inverted joint to be transferred evenly to the underlying rock.

Once the preparatory work had been completed, 217 permanent grouted anchors with a maximum anchor length of around 70 m were installed using a guided and controlled drilling process.

With the installation of the bridge anchors complete, the anchor block was prepared for the upcoming concreting.

In addition to formwork and reinforcement work, the installation of the 45-ton anchor swords was carried out with an installation tolerance of ± 5 mm.

In the final state, the force is transferred from the cable support structure to the anchor sword, via the reinforced concrete block to the bridge anchors and finally in the 15 m long bonding section of the bridge anchors to the rocky subsoil.

In order to meet the high safety and engineering requirements of the structure, the anchor blocks were concreted in a single pour.

The installation of the approx. 600 m³ of reinforced concrete was completed in one day, considering the proximity to the neighbouring residents.

Continuous monitoring of the concrete temperature was installed to prevent cracks.

Cooling was achieved by introducing cooling water into the existing empty pipes of the bridge anchors.

Figure 14: Anchor Block south before concreting / ASFINAG

Erection of cable support structure

A wide range of equipment and auxiliary constructions was required to assemble the cable support structure.
These include, among others:

- Two cable cranes over the Danube including Balloon rope to secure the airspace;
- Auxiliary ropeway for transferring the main carrying cable;
- Cable winches and hydraulic strand jacks;
- Uncoiling machine and braking machines for controlled uncoiling and retraction of the main suspension ropes;
- Various lifting equipment (rail crane lifting capacity > 80 tons, tower cranes, etc.) and safety equipment (work baskets for use over the Danube, working platforms, etc.).

In addition to the availability of the auxiliary structures, the safety requirements for the interaction of the equipment posed a particular challenge.

Another major challenge for the construction of the anchor blocks and the cable support structure were the cramped and alpine conditions. Two cable cranes with a load capacity of 2 x 5 tons were erected to serve the areas between the anchor blocks.

Figure 15: Auxiliary cableway suspension cable installation ASFINAG

In order to pull the large 70ton ropes across the Danube, an auxiliary cable bridge consisting of two 52 mm cables and 40 cable riders had to be erected in advance using the cranes.

With this auxiliary cableway, the pulling force during the pulling operation was reduced significantly.

The individual cables (diameter 145 mm with a breaking load of 2100 tons) were unrolled one after the other from a motorized reel and inserted into a cable tensioner unit which ensures controlled movement.

The end of the cable was then connected to a 16ton winch on the south side using a 24 mm pulling cable. This allowed the cable to be pulled from north to south over the 40 riders in a force-controlled manner. Once the cable arrived at the south end, both cable ends were connected to a hydraulic strand hoist.

The auxiliary cable bridge (52 mm diameter cables with 40 riders) was then lowered and moved transversely so that the main suspension cable could hang freely above the Danube in an elevated position.

Afterwards, both centrally arranged strand jacks were successively lowered as the free cable sockets had to be inserted into the bearing pockets of the anchor sword.

During the lowering process, the cable moved transversely to the bridge axis into its corresponding end position.

Figure 16: Cable drums / uncoiling wheel, cable tensioning unit/anchor block north ASFINAG

Figure 17: First installed suspension cable
schlaich bergermann partner

Figure 18: Moveable installation platform for clamp and hanger cable installation / ASFINAG

The installation of the main cables began at the end of 2021 and was completed in the first half of 2022.

Once the main cable assembly was completed, the two vertical cable levels (12 / 2) of each main cable bundle were temporarily separated to create space for inserting and aligning the 3 ton hanger clamps.

A total of 2 x 20 hanger cable clamps and further 2 x 10 distance holder clamps had to be installed.

Following the cable clamp assembly, 40 hanger cables were installed.

To get the two main suspension cables (west and east) into their final position for the deck assembly, seven temporary spreader beams had to be installed along the two main cables.

For this operation, custom-designed lightweight spreading devices were created, facilitating the separation of the main cable by 18 m using two-strand jack systems.

With the temporarily spread main cables approaching the final cable geometry, the steel deck installation could commence.

Figure 19: Completion of cable clamp and hanger cable installation
ASFINAG

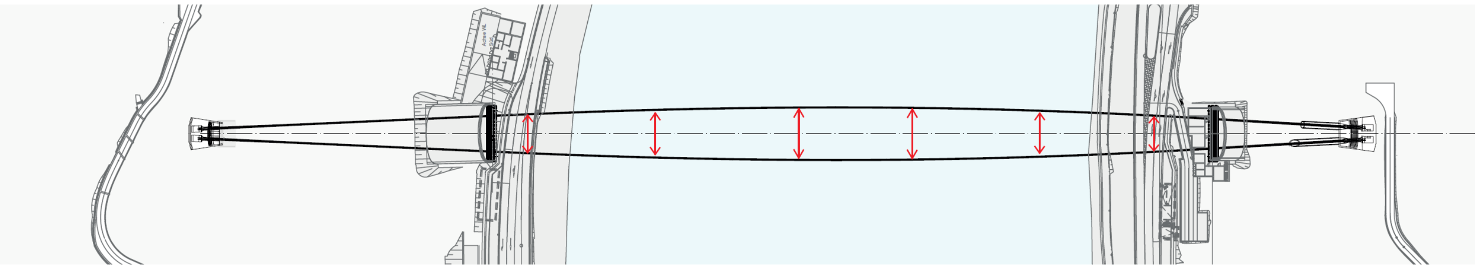


Figure 20: Visualization of the suspension cable spread / schlaich bergermann partner

Figure 21: Strand jack widening unit at the time of spread beam installation / schlaich bergermann partner

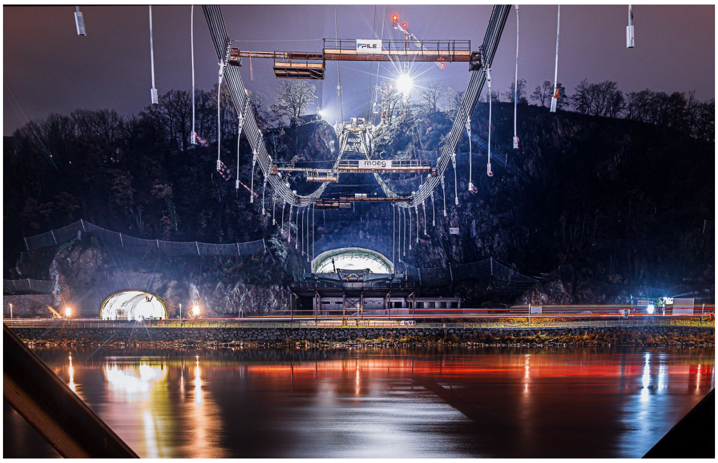


Figure 22: Completion of the cable structure ASFINAG

Installation of the steel deck, erecting the deck slab and remaining work

During the erection of the cable support structure, two out of nine steel deck segments were installed at the abutment area in front of the tunnel portals North and South on a temporary protective framework.

The remaining seven steel deck segments were prepared at a pre-assembly area, 16 km downstream of the construction site.

After completing the cable assembly, the seven lifting segments of the steel deck girder, starting with the middle one, were transported across the Danube to their destination.

To ensure a controlled assembly process in the face of the high flow velocity in this section of the Danube, a stilt pontoon was employed for transportation and as a foundation during the strand lifting process.

Figures 23 and 24: Pre-assembled deck segments 1 and 9 (South / North) ASFINAG

The various assembly steps resulted in numerous intermediate assembly states, requiring careful planning and calculation.

Beyond the planning of these erection stages, geometry control throughout the entire construction played an important role in the project's success for all parties involved.

Crucial for the successful deck assembly was the stress-free trial assembly and the installation of temporary locking devices between the individual steel deck segments.

This ensured that each segment could be effortlessly suspended and pinned to the cable structure. Subsequently, the corresponding segments above the Danube were progressively welded in place.

Installation of the concrete deck slab began in the autumn 2022 after completion of the steel deck girder.

The light semi-finished precast slabs could be laid over the entire bridge using the cable crane.

However, the very thin semi-finished slabs had to be temporarily supported to accommodate the weight of fresh concrete.

For this purpose, the 8 cm precast was suspended with a light scaffolding system in order to achieve the required precamber.

After the entire bridge was equipped with all semi-finished precast slabs, concreting could begin according to a defined sequence.

Figure 25: Lfting of the first deck-segement / ASFINAG

Ensuring a uniform load application/concreting is crucial for the still-soft, cable-supported steel deck.

Therefore, the assembly process and a stage-wise concreting sequence were meticulously simulated in a detailed FE Model, encompassing all time-dependent shrinkage effects.

After all concreting steps were completed, the edge beams were concreted in place, followed by sealing and mastic asphalt.

After completing all concreting steps, the concrete bridge parapet cap was in-situ concreted, followed by the application of waterproofing and mastic asphalt.

Figure 26: Steel deck lifting
schlaich bergermann partner

Figure 27: Steel deck installation completed
schlaich bergermann partner

Figure 28: Temporary precast slab supporting schlaich bergermann partner

Figure 29: Steel Deck Completion

Figure 30: Installation of Precast Slabs

Figure 31: Stage-wise Concreting of the Deck Slab

To complete the 4th Danube Bridge in Linz by 2024, the finishing work is in full swing.

In addition to finalizing all bridge equipment such as functional road lighting, plumbing, joints, railings, etc., the main suspension cables will be coated, and the architectural bridge lighting will be installed in 2024.

Partial commissioning of the bridge is anticipated in mid-2024, in parallel to the start of project Phases 2 and 3 of the overall A26 project.

Thanks to the very slender and highly transparent, minimalized construction, which fits perfectly into the ecologically highly sensitive planning area and the beautiful landscape of the Danube Valley, the New Danube Bridge is already a unique landmark in Linz and the surrounding area.

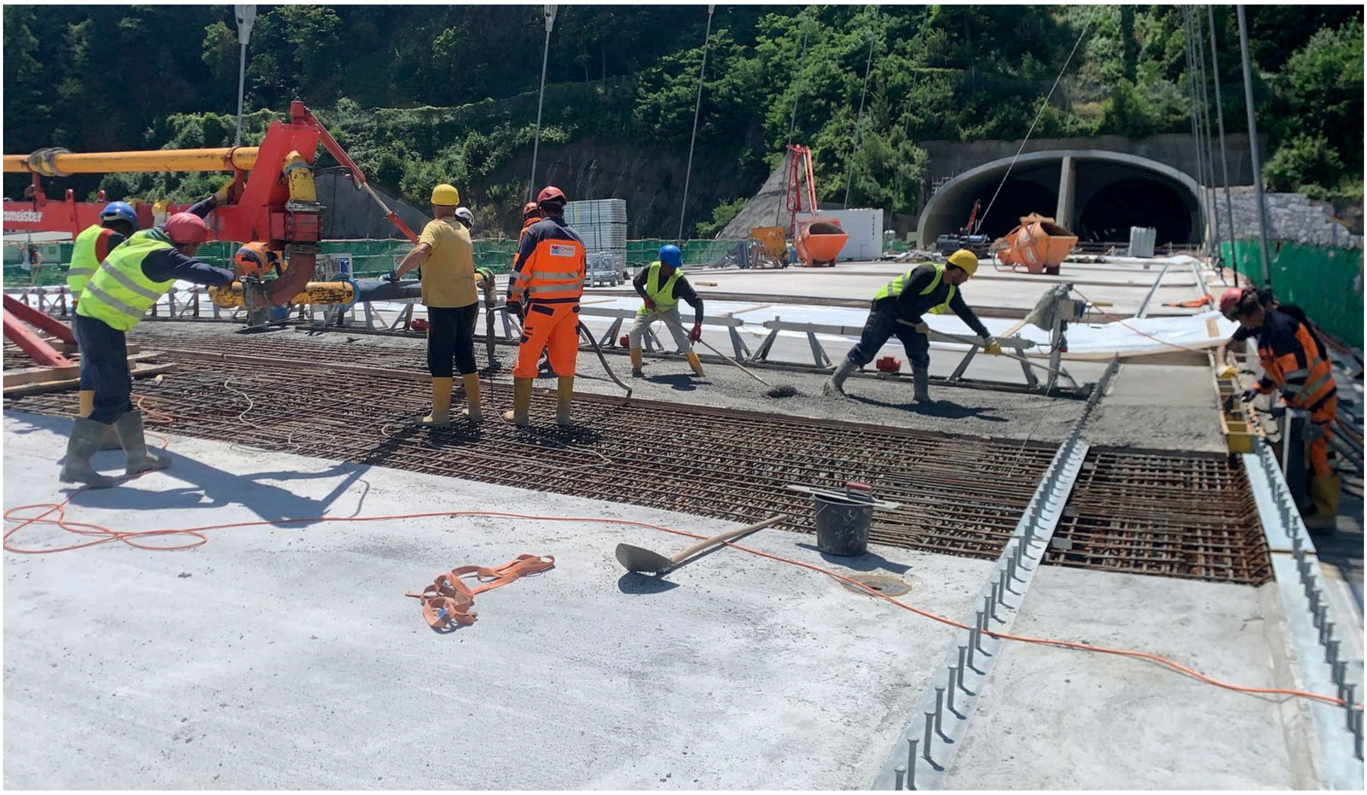


Figure 32: In-situ concreting of deck slab / schlaich bergermann partner

Figure 33: The New Danube Bridge Linz / ASFINAG

LA JOYA BRIDGE AND ACCESS VIADUCTS, PERU

Bruno Pronesti, Giovanni Sammartano, Alessandro Catanzano
CIMOLAI S.p.A., Italy

Figure 1: View of the construction site with part of the arch completed

INTRODUCTION

La Joya Bridge, with its access viaducts, forms part of a larger road infrastructure project intended to create a motorway that will connect the city of Arequipa, in the region of the same name in the southern part of Peru, to the 'Panamerica Sud' roadway, the main artery that crosses the whole of South America, from Colombia to the Land of Fire.

The bridge is located in the area called Uchumayo, a few kilometres south of the City of Arequipa, and crosses the Chili River, at an altitude of about 2,300 m above sea level.

Arequipa, known as 'La Ciudad Blanca' (The White City) because of the characteristic colour of the locally quarried tuffaceous stone with which most

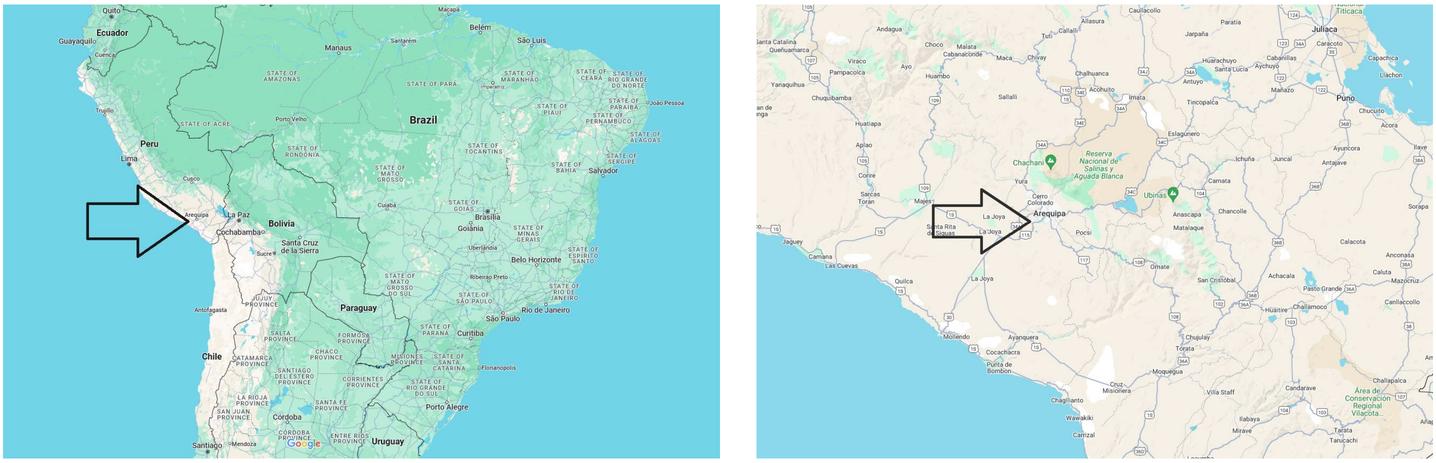


Figure 2: Location of the Bridge on the map   Source: Google Maps

buildings have been constructed since its origins, has over 900,000 inhabitants and is the second most populous city in Peru.

It is an important hub for the south of the country due mainly to the presence of mines, especially copper mines, in the vicinity. 'Cerro Verde' mine, currently the most important in the country, is located here.

With the realisation of this project, the aim is to connect the 'Panamericana Sud' road with the 'Arequipa Regional Road', which is already existing and operational, allowing an easy flow of heavy vehicles arriving from the country in the direction of Puno, another important town north-east of Arequipa.

Currently, traffic is constantly congested from the first light of day, when heavy vehicles arriving from all over the country head for the nearby mines and the country's hinterland.

Similarly, in the late afternoon, the flow in the opposite direction, in order to get the vehicles back onto the 'Panamericana Sud', produces similar unwanted results.

The entire section subject to the project intervention is characterised by the particular orographic complexity of the site, culminating in the crossing of the natural canyon of the 'Rio Chili', with a depth of more than 100 m.

The "La Joya" or "over the Rio Chili" bridge, with its access viaducts, is characterised by being a steel arch bridge with a main span of 175 m, a north

<u>Main Client:</u> REGIONAL GOVERNMENT OF AREQUIPA, Peru

<u>General Contractor:</u> Consorcio La Joya II (IMPRESA PIZZAROTTI & C S.P.A., Italy and ERALMA CONSTRUCTORA S.A.C., Peru)

<u>Designer:</u> Consorcio Ingenieria Arequipa - La Joya

Cesma Ingenieros

<u>Supervisor:</u> JNR CONSULTORES S.A., Peru

<u>Steel structures and assembly engineering:</u> CIMOLAI S.p.A., Italy

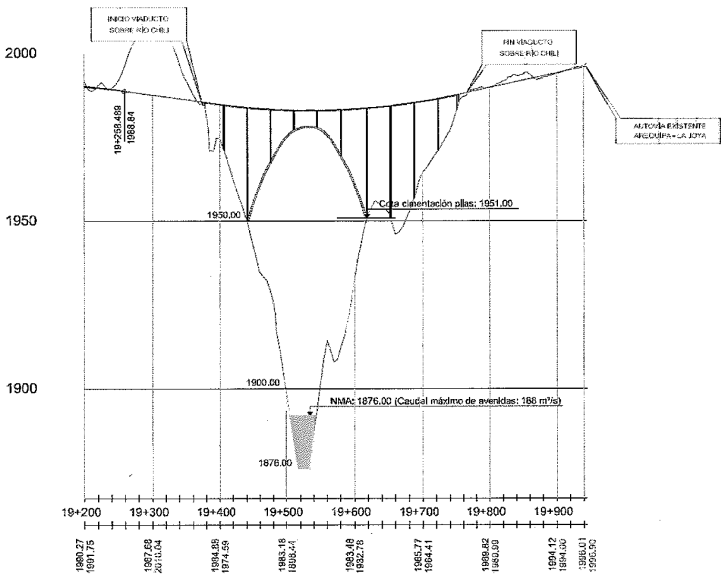


Figure 3: Altitude of the bridge

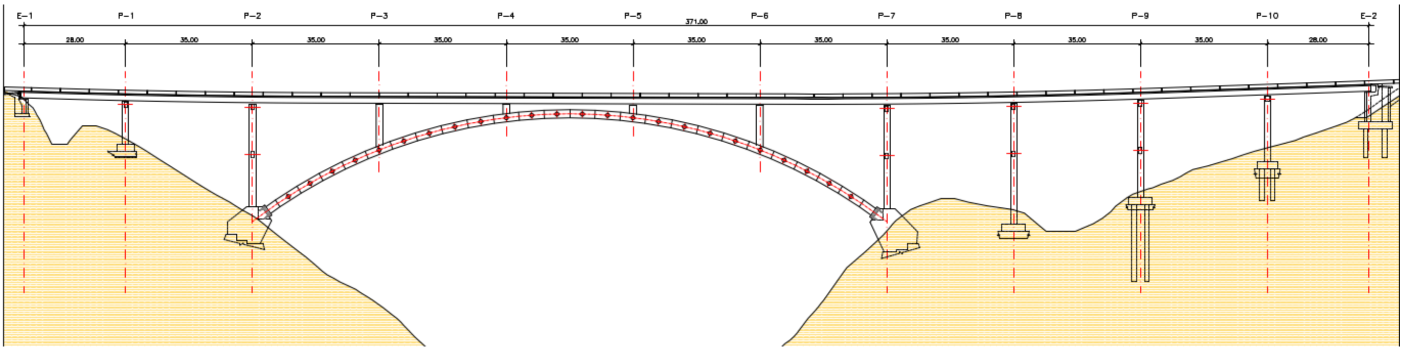


Figure 4: Elevation of the bridge

side access viaduct (with 35 m, 35 m, 35 m and 28 m spans) and a south side access viaduct (comprising spans of 35 m and 28 m).

The total length of the upper road deck is therefore 371 m.

In addition to allowing the crossing with the 'Rio Chili', the bridge overpasses the industrial railway line that connects the mines in the Arequipa area with the port of Mollendo, 100 km away, on the Pacific Ocean.

This is a very important means of communication for the transport of minerals for which it is necessary to guarantee total and constant availability since its interruption would have serious consequences for the flow of minerals and the logistics of the extraction sites which are fundamental for the economy of the entire region.

The cross-section of the bridge (and of the access viaducts) accommodates 2 separate carriage-ways, each with 2 lanes in addition to the hardstrips and traffic barriers, and is therefore characterised by an overall width of 21 m.

Each carriageway has a width of 7.2 m, with hardstrips of 1.5 m and 1.0 m between the traffic barriers. The carriageways are separated by a central New Jersey-type barrier and the side ends of the bridge are also protected with the same type of barrier.

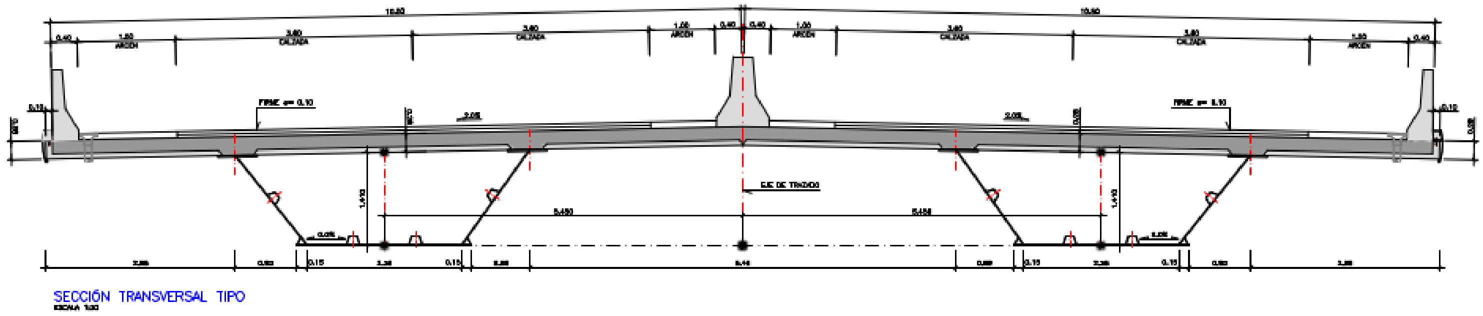
The superstructure, structurally of mixed steel/concrete type, is formed by two parallel longitudinal sections each consisting of a trapezoidal cross-section caisson with inclined webs and an average height of 1,410 mm, lower width of 2,660 mm and upper width of 4,560 mm.

The two parallel caissons are joined transversely to each other by transverse caissons arranged at the pier supports and abutments.

The road section consists of a reinforced concrete slab with overhangs on both sides of 2.86 m, formed by prefabricated, 8 cm thick precast slabs with welded steel trusses and lower reinforcing bars embedded in the cast-in-place prefabrication, and finished with a constant 20 cm thick cast-in-place top section, for a total slab thickness of 28 cm, completed at the top by asphalting.

The arch that supports the main crossing of the bridge is formed by two twinned and parallel steel caissons, with a circular tubular section with a diameter of 2,250 mm and plate thicknesses varying from 32 to 38 mm along the longitudinal development, and 44 mm at the most heavily

Figure 5: View of the construction site before installation of the bridge



Figue 6: Deck Cross-section

stressed interlocking sections at the ends. The two tubular profiles, whose longitudinal axes are 10.9 m apart, are joined by further circular tubular profiles with a diameter of 1,500 mm and a thickness of 25 mm with centre-to-centre spacing of 7 m, forming a structure that is particularly rigid in all directions. The steel is ASTM A709 Grade 50.

Resting on the arches are 4 steel portals with a box section, formed by piers with a cross-section of 1,400 mm x 1,750 mm, and heights respectively of 12,531 mm at pier P03, 3,575 mm at P04, 3,488 mm at P05 and 12,265 mm at P06, with a plate thickness of 25 mm, crowned at the top by a transverse caisson, also with a rectangular box section measuring 1,500 mm x 1,040 mm and a plate thickness of 19 mm.

The access viaducts to the arch rest on 6 reinforced concrete portals (named P01, P02, P07, P08, P09 and P10) and 2 abutments (named E1 and E2).

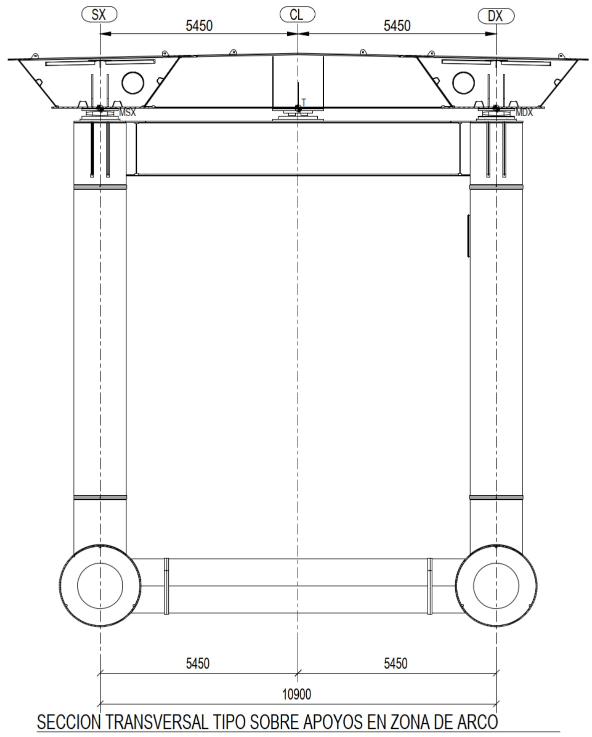
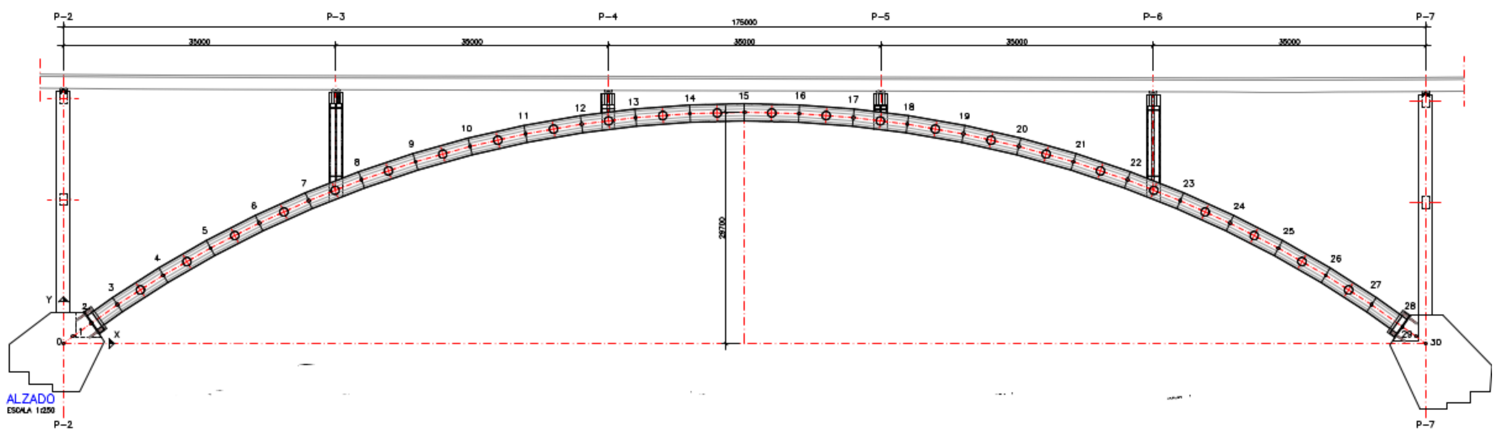


Figure 7: Steel Portal Supports of the deck



Figue 8: Arch and steel portal elevation

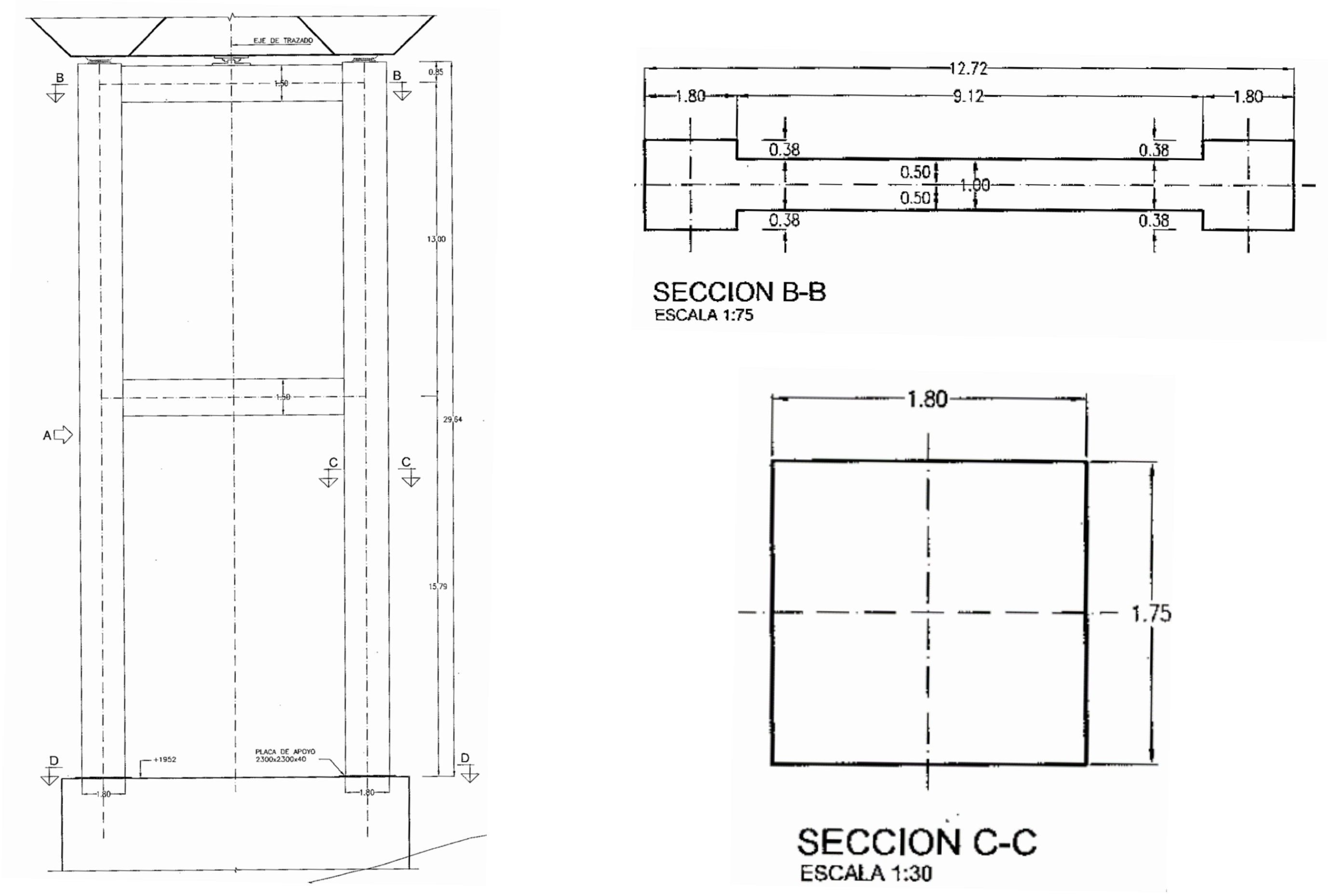


Figure 9: Access Viaduct Pier details

The reinforced concrete portals consist of 2 shafts with a cross-section of 1.80 m x 1.75 m and a height varying from 10.85 m to 33.14 m, which are joined together by reinforced concrete transverse beams with a cross-section of 1.50 m x 1.00 m.

The arch and deck constitute two structurally independent systems, of which the former has interlocks at the base at the foundations of the P02 and P07 reinforced concrete piers, by means of 24 pre-tensioned bars, embedded in the concrete and constrained at the base of the steel arch by means of two flanges stiffened by 24 ribs, while the deck rests on multidirectional spherical bearings.

The transverse restraint of the deck is ensured by means of shear keys placed at each of the supporting portals of the deck.

Finally, at abutment E2, there are 4 longitudinal seismic dampers, 2 for each of the longitudinal caissons of the deck, which complete the restraint system and will only be activated in the presence of an earthquake as they are limited by fuse elements positioned under the caisson at the same abutment.

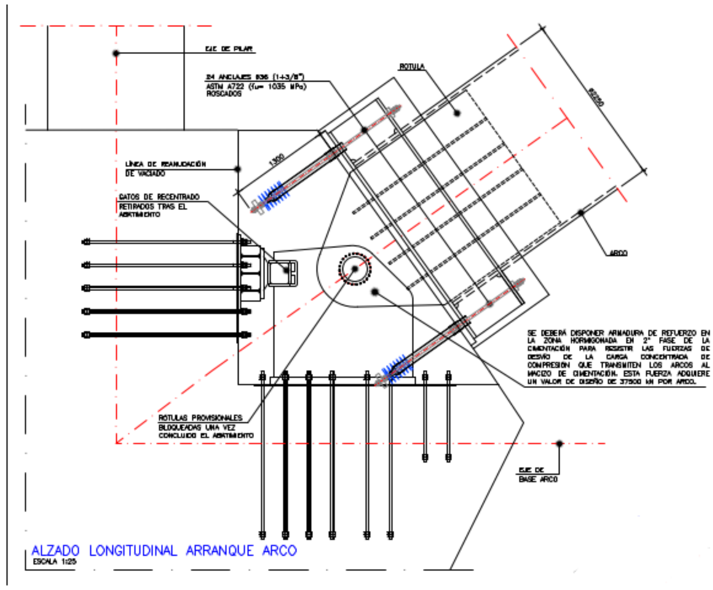


Figure 10: Interlocks at the arch base

STEEL STRUCTURE ENGINEERING AND MODELLING

The entire steel structure of the La Joya Bridge and the Access Viaducts, therefore composed of both the arch system and the upper deck, was studied by Cimolai in order to verify and optimise every single phase of the production process and overall execution.

To begin with, the construction details of the steel structure were analysed and developed, identifying possible criticalities within the planned execution phases, and/or possible optimisations to the production processes as well as to the specific contingencies of the project, i.e. the materials workshop and site connections, handling, transport, lifting, the entire assembly process, couplings and management of tolerances within the structure, the interfaces between the steel structure and other parts of the project (supports, joints, civil works in general).

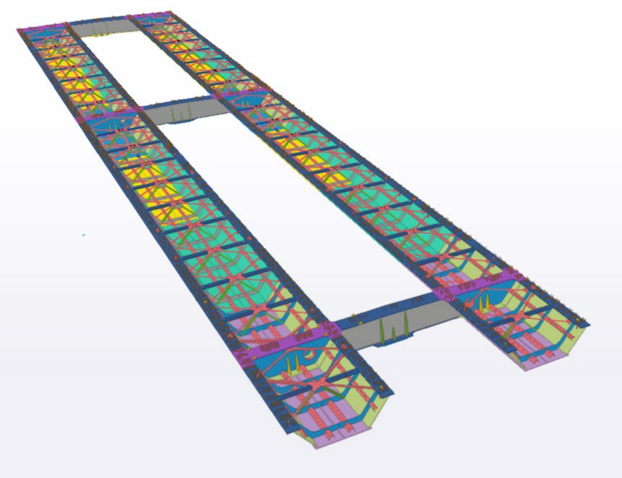
In this first phase, all aspects of the project were analysed, developed, and resolved, allowing it to be perfectly coupled with both Cimolai's own systems and technologies and with the entire execution process.

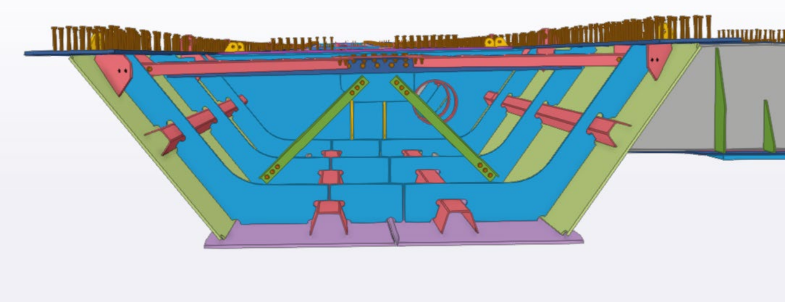
The structure was adapted to all the various phases necessary for its complete installation, which included not only compatibility with the raw material and the construction phases in the workshop but also and above all with the logistical requirements of multimodal transport and with the installation phases on the building site, which are particularly demanding given the conditions of both the structure and the laying environment.

Similar attention was also paid to the in-depth analysis and resolution of problems concerning the service life of the structure, and therefore to the maintenance of functional and aesthetic characteristics over time, to safe inspection and preventive and corrective maintenance of the structures.

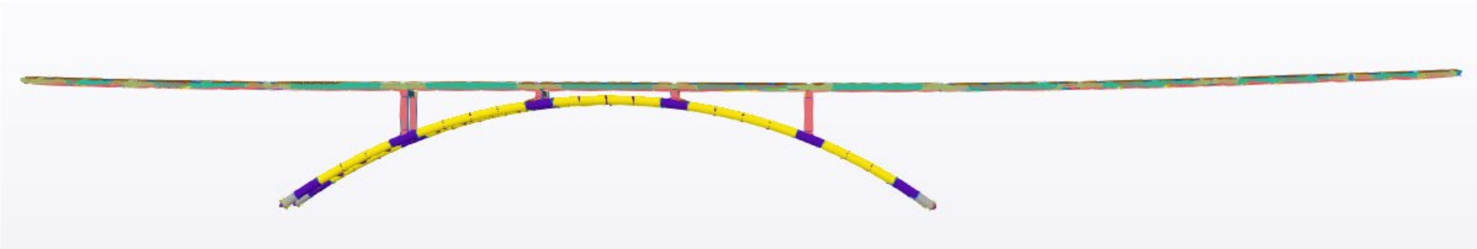
This in-depth study, carried out in close collaboration with the Client, Supervisors, Designer and the Contracting Entity, through the formal and controlled management of RFIs (Requests For Information) was always accompanied by objective evaluations and state-of-the-art technical solutions and aimed not only at the aforementioned issues but also at reducing global execution times and improving global and punctual safety conditions.

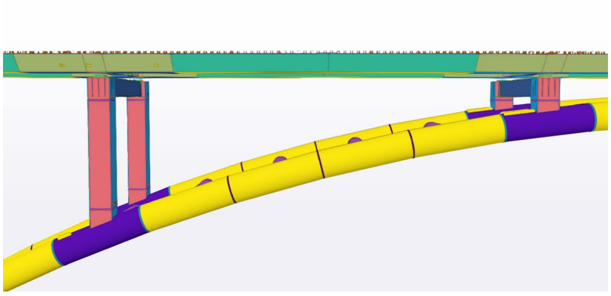
The entire steel structure was modelled in BIM software (Tekla) that allowed for the identification of every single element of both the bridge's permanent and temporary structures, developed directly by Cimolai according to the needs and characteristics of the assembly phases, feeding all the workshop CAD-CAM production process and the use of all numerical control processes for cutting, chipping, bending and welding of the workshop production cycles.

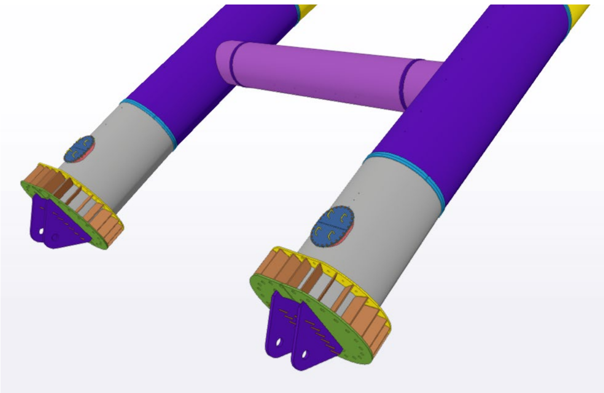




Figures 11 and 12: Models of the bridge







Figures 13 - 16: Models of the bridge

WORKSHOP PRODUCTION

The shop floor production of the arch and portals was carried out at Cimolai's Italian factory in San Giorgio di Nogaro.

One of the fundamental objectives of the project was to obtain global geometries with sufficiently tight tolerances to guarantee both the perfect execution of the assembly stages and the final global geometry of the structure and especially the design sharing.

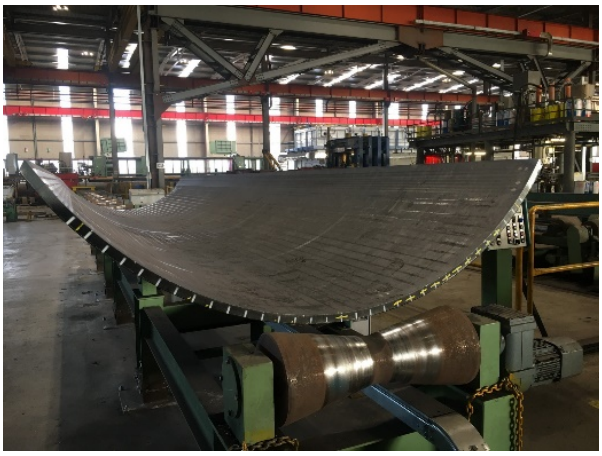
For this reason, along with a detailed engineering study, aimed at accurately predetermining intermediate deformations during assembly and final deformations during service, advanced production processes and redundant intermediate control protocols were applied.

The cylindrical tubular profiles of the arches, both longitudinal (2.25 m diameter) and transverse (1.50 m diameter), were produced by bending sheet steel to form shells which were assembled together with the internal elements to form the monolithic elements of each module.

In the case of the longitudinal arch elements, the tube was formed by the longitudinal welding of 3 shells, which were assembled together with the internal elements (ring diaphragms and transverse and longitudinal stiffeners, where present).

The bolted flanges were made by welding various elements and the integral Numerically Controlled milling of the contact surfaces, together with perforation, also by Numerical Control, ensuring a perfect coupling of the surfaces, eliminating the imperfections determined by the rolling tolerances of the raw material and thus allowing the total control and homogeneity of the compression stress flows, which characterise the structural element of the arch.

The couplings of the various segments were subjected to complete pre-assembly in the




Load Capacity: 12,5 t

workshop in order to guarantee with absolute certainty the overall geometry of the elements and therefore not only of the overall arch but also, and above all, the coupling in situ of the central joint, which will be realised, as will be seen later in the text, in situ through the closure of the two semi-arches, and therefore under operating conditions that did not allow for uncertainties or imperfections.

All the elements were geometrically controlled by means of topographical control instruments (total station and laser scanner) that allowed the total control, then testing on site, of all the geometries.

All welded joints were performed in the workshop, except for those that had to be performed on site due to the limitations imposed by transport container dimensions.

In this way, not only was it possible to improve the control of the hot processes and the consequent deformations produced by the shrinkage during the cooling phase of the welds through their execution in the protected and easily controllable environment of the workshop, but also the execution time on site and the risks deriving from the assembly at height and in uncomfortable conditions were limited to a minimum.

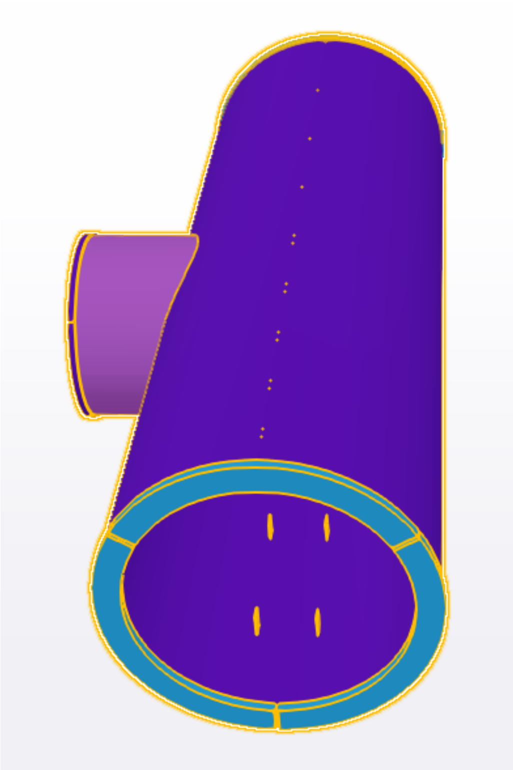
Video 1: Workshop production video

Click on the image to play the video

TRANSPORT OF ARCH AND STACKS

Fundamental to the development of the bridge construction project were the requirements dictated by the multi-modal transport between Cimolai's Italian production workshops and the construction site, as well as the handling of the individual monolithic elements, both in the workshop and during loading, unloading, transfer and assembly at the construction site.

The monolithic elements of the steel structure were manufactured at different production sites, both in Italy, where Cimolai's main machine shops are located, and in Peru.



Figures 17 and 18: Tubular monolithic element of the arch, model (left) and final element (right)

Due to their construction characteristics and the need for precision assembly with low geometric and coupling tolerances, the elements of the arch and the related steel portals were manufactured in the Cimolai workshops in San Giorgio di Nogaro, in the province of Udine, in the north-east of Italy.

The transfer of these elements required multimodal transport by truck from the workshop to the Italian port of embarkation, by sea in containers from the port of embarkation to the Peruvian capital, again by land in containers to a consolidation and reloading warehouse in the city of Lima, and then by land in loose elements from the capital Lima to the city of Arequipa, the site of the shipyard, at 2,300 m above sea level, some 1,000 km from Lima.

The technical requirements of workshop production and site assembly, together with those of convenient and efficient transportability, led to a series of choices aimed at optimising the process.

The choice of container instead of break bulk transport was forced by the contingency of inter-oceanic maritime transports during 2022, which had not yet regained the flexibility and breadth of pre-pandemic times.

The severely limited usable dimensions of the containers then forced major adaptations of the execution process, imposing certain separations of the monolithic elements that could instead have been conveniently completed in the workshop.

Each standard tubular monolithic element of the arch, with its flanged protrusion connecting the transverse elements between the two arches, had a footprint of approx. 7.00 x 2.25 x 2.70 m and thus exceeded the dimensions of a standard 40' CTR, moreover weighing approx. 15 tonnes.

The transport was characterised by a high volumetric incidence, which would not allow the optimisation of the weight/volume capacity of the individual containers.

To solve the bulk problem, special 40' OOG (Out of Gauge) containers were chosen. This type allowed the elements to be loaded with the flanged socket located at the top, which protruded from the top of the container.

Video 2: Container Loading. Click on the image to play the video

Figures 19 and 20: Lifting of an element and its placing in the container

For this reason, all the elements could be transported, but only through a loading plan whereby they were placed on top of the stack of stowable containers in the ship.

The optimisation of the combination of volume/weight to be transported, on the other hand, was tackled through the creation of special packaging equipment, which allowed the transverse tubular elements, with a smaller diameter, to be placed partially inside the main tubular elements (telescopic configuration) so as to improve the performance of each individual transport.

ERECTION OF STRUCTURES ON SITE

The La Joya Bridge assembly project is divided into two major phases:

- the acrobatic manoeuvres for the installation of the supporting arch, and
- the subsequent twin launching of the double deck of the upper deck.

The combination of techniques and equipment used or purpose-built arose from the study of the site, the limits of the capacity domains of the structure as temporary conditions changed, and the need for economy, which in complex conditions is not a limitation, but an excellent indicator of the simplicity and excellence of the design choices.

As a result of close cooperation and coordination with the Pizzarotti company, which was present at every stage of this important construction project, it was possible to complete the first important phase.

Arch Erection

The canyon, which is the basic datum of the definitive work, presents very limited accessibility for cranes. The final load-bearing concrete piers, some of which are without piles due to the horizontal configuration of the bridge's static bearing scheme, were found to be completed.

Since there was no possibility of constructing any temporary tower in the canyon, nor of cantilevering the arch segments, weighing up to 60 tonnes at a distance of 90 m, the option of vertically stacking the two complete semi-arches on the final plinth, setting them on a rotation hinge, adjustable with jacks on a horizontal plane of Teflon stainless steel, appeared to be the safest and most economical.

Tipping stability of the semi-arch towards the canyon during the surge phases was achieved for the first segments with a temporary hinge connection.

At a certain height, after six modules, two temporary stays with 200t strand jacks came into play, then, at module 11, two more 200t pulls, to which the two that were at module 6 were re-joined, following the development of the stability, resistance and aeroelastic stability domains of the semi-arch and its joints, in its different configurations of weight, restraint and deformability.

Of particular relevance for these operations is the wind data statistics, in terms of intensity, direction and frequency, which is then supported in the field by three-day weather forecasts for the management of operations.

Tilting stability towards the shoulder, on the other hand, was obtained simply by exploiting the position of the centre of gravity due to the curvature of the arch so that the wind could not prevail in the equilibrium to the rotation even with the multiplier and de-multiplier coefficients normally used.

Video 3: Time Lapse

Click on the image to play the video

Arch Closure

The strand jacks, however, rising from posts anchored where possible in existing foundations or in the depth of the ground by means of injected anchors, do not have a direct pull on the arch, but are set back on a saddle conceptually similar to that of suspension bridges, mounted on top of a luffing mast, consisting of a steel braced portal in turn bayonet-connected to one of the final concrete portals, creating a mixed portal.

These portals were without piles so that the necessary lateral stability and verticality was achieved by additional downstream and upstream cable-stayed strand jacks, anchored to existing foundations or to the ground, again with injected strands.

Once the vertical construction of the two semi-arches at a height of more than 90 m was completed, closure took place by releasing the strand jacks, which were gradually tensioned as the reach increased, progressively loading the saddle, held upright by the portal stay strand jacks, with the deflection of the strands.

The closure lasted a few days and allowed the flanging of the keyed end of the arches, recreating the congruence through the use of up to the horizontal plane adjustment of the hinges at the impost, in combination with the use of strand jacks, with such precision that, in none of the 98 flanges with diameters up to 2,200 mm and M36-10.9 bolts, was it necessary to insert any compensating shims, the coupling being perfectly realised over the 200 m of arch development.

The benefit of the speed and precision of execution was significant compared to other techniques of the past, with all the benefit of the durability of the work.

Finally, the two temporary shuttering hinges were cast, bringing it to the interlocking state by means of anchor bolts.

The phases were studied by considering the different situations of vertical soaring of the arches and the different positions of closure.

All results in terms of nominal and characteristic forces and deformations were then reported on the working drawings to allow the site management to check them and move on to the next phase.

The simultaneous launching of the two box sections of the deck

The launching of the twin longitudinal sections of the steel deck on roller batteries takes place over nine spans of thirty-five metres and the two abutments of twenty-eight metres.

The need to launch the two sections at the same time and therefore with a double bow, double thrusting system, double roller tracks on the piers, results from the presence of the caisson stringers connecting the two decks, which could not have been assembled later.

The thrust system is realised with the same strand jacks used for the closure of the arch, but inverting the pull and realising it horizontally, matching the foundation in the ground, which is therefore designed to receive two thrusts of almost opposite directions with different working angles.

The restraint system was also realised with the closure strand jacks, mounted horizontally by means of a specially made surface foundation.

The launching phases were studied considering the route imposed by the altimetry but in the form of a basin of the final concrete stiles and taking into account the construction countermeasure.

All results in terms of nominal and characteristic reactions and deformations were then reported on the operational drawings to allow control by the site management and move on to the next phase.

CONCLUSION

The execution of the Project is currently in the final stages concerning the launching and lowering of the metal deck, which will be followed by those of slab formation, asphalting and street finishing.






ANALYSING EMBODIED CARBON FOR RURAL TRAIL BRIDGES IN EAST AFRICA

Nicola Turrini, Faustin Bajeneza
Bridges to Prosperity

Miriam Graham, Lucy Cryer, Charlotte Murphy, Romee van Es
Arup

Figure 1: Construction of the Bishenge-Masuma bridge above the Gasumo River

1. INTRODUCTION

When rivers swell in rural communities, walks to school, the doctor, work, or the market become life-threatening without safe and reliable transportation infrastructure. Bridges to Prosperity (B2P) envisions a world where poverty caused by rural isolation no longer exists, and operates with the core belief that connection is the foundation to opportunity.

B2P provides critical access by working closely with governments and communities to build trail bridges in isolated communities around the world. Since its founding in 2001, B2P has constructed or supported more than 500 trail bridges (to date) that serve over 1.8 million people in 21 countries around the world.

Utilising standardised bridge designs that have been refined through years of experience has meant B2P is able to reduce costs. A construction process that has been honed for remote environments where the use of heavy machinery is limited also supports that goal - the cost of a B2P-designed trail bridge is lower than that of many other traditional infrastructure.

B2P aims to source materials locally, and those that aren't locally available they then look to repurpose material where possible, including steel pipe and cable from large construction sites and ports. This innovative and efficient model significantly decreases the cost of rural connectivity, and when combined with a cost-share approach, makes it feasible for budget-constrained governments to invest in their own rural infrastructure programs and serve a greater number of constituents per dollar.

Several studies have shown trail bridges have a high ROI, returning at least 6x the cost in increased economic activity [1]. Additionally, communities with new trail bridges saw a 75% increase in farm profits, a 60% increase in women entering the workforce, a 36% increase in employment income, and a 30% increase in overall household income.

The standardised construction system described above, in addition to guaranteeing lower costs for the bridge we build, has clear advantages on reducing the embodied carbon of projects as well: the fact that the entire structure is completely built by hand and there is a focus on sourcing construction materials either locally or from re-use clearly plays a big role in reducing the final embodied carbon of such a structure.

However, these aspects of B2P's bridges had not previously been studied, making it impossible for a data-driven organisation like B2P to share this great characteristic of their work. This year B2P have collaborated with engineering consultancy firm Arup to upskill their staff on embodied carbon calculations.

This article presents the initial outcomes of the work that B2P and Arup have done to allow B2P to understand their embodied carbon and discusses how B2P can use this data within their work. This work has provided the much-needed starting point to increase B2P's wider impact, and provides an initial considerations on how to reduce the embodied carbon of B2P's bridges even further.

It will also demonstrate to B2P's partners evidence on how rural infrastructure could be both more economic and more sustainable than other types of infrastructure interventions.

2. CARBON FACTORS

2.1. Understanding Carbon Factors

Embodied carbon, measured in terms of carbon dioxide equivalent (CO_2e), represents the quantity of greenhouse gas emissions released into the atmosphere during the lifecycle of a structure, such as a bridge.

This measure is derived from the key formula:

Embodied Carbon = Quantity x Carbon Factor

Here *'Quantity'* denotes the material mass or process amount, and *'Carbon Factor'* represents the amount of CO_2e emitted per unit, for instance, kilograms of material.

The total embodied carbon encompasses emissions from various stages, including raw material sourcing, manufacturing, transportation, wastage, and installation, maintenance, or disposal processes during the structure's lifespan.

The carbon factor associated with a material varies between manufacturers and countries. This is because emissions depend on the energy sources (e.g., fossil fuels or renewable energy) for the manufacturing processes and transportation, as well as the efficiency of energy and material use.

As the processes and energy sources will change over time, the carbon factors will also change over time. Therefore, it is important to regularly update the carbon factors used.

Embodied carbon factors are an estimation based on the information available on processes and energy sources. The more accurate and precise this information is, the more reliable the carbon factor will be. The information available for a supply chain, source country, and material will determine the appropriate method for determining what carbon factor to use.

2.2. Approach to Determining Carbon Factors

2.2.1. Life Cycle Stages

The carbon emissions, such as for a bridge, are often broken down into life cycle stages, as shown in Figure 2.

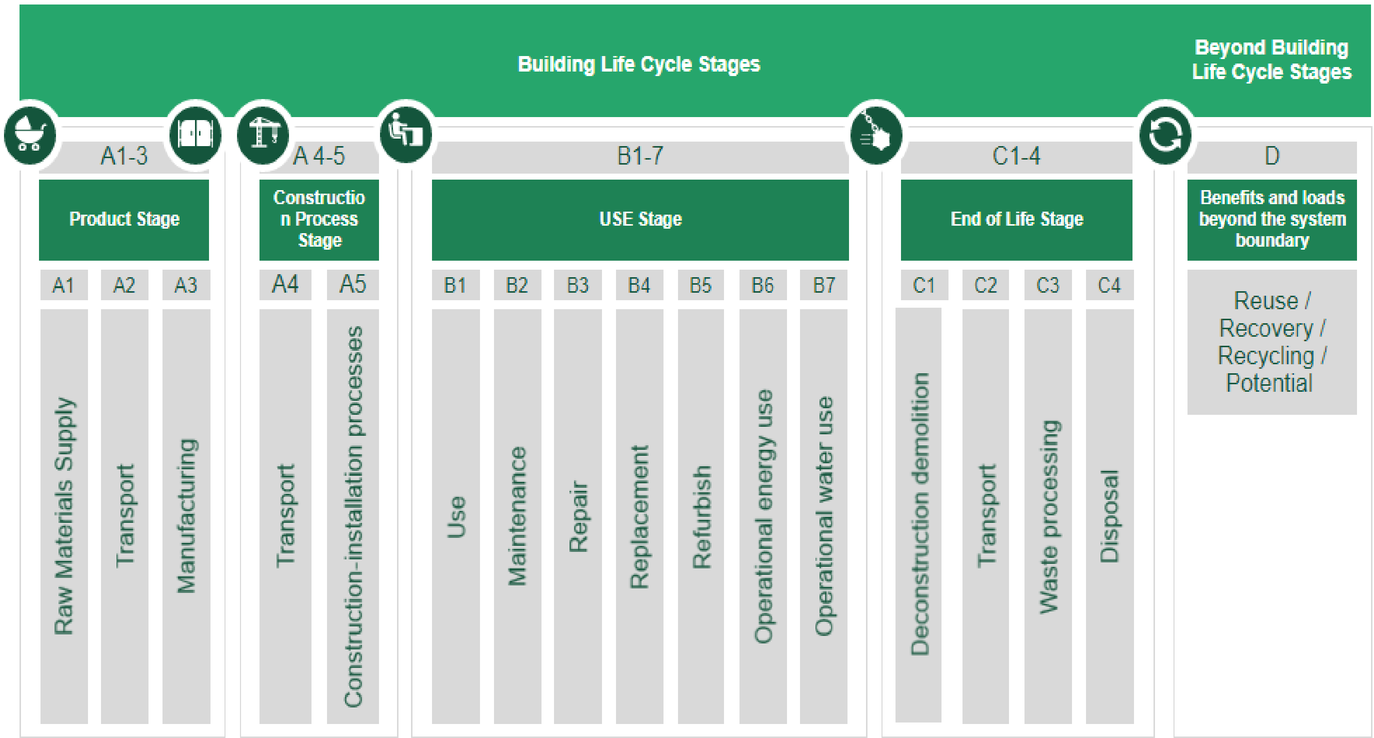


Figure 2: Life Cycle Stages [2]

The scope for the initial assessment of B2P's embodied carbon emissions included A1-5 emissions. The material carbon factors form the A1-3 emissions - including A1 raw materials supply, A2 transport to manufacturing, and A3 the manufacturing itself. A4 is then the transport from the gate (where the component production is complete) to the site of construction, and A5 emissions are those associated with construction.

The initial assessment undertaken for B2P does not include module B - in use and maintenance), C – end of life, or D – wide impacts beyond the system boundary. These require further insight, for example into the rate of replacement of components, or a wider understanding of how material extraction impacts the surrounding area.

In decisions surrounding materials, all these compounding factors should be considered to generate sustainable outcomes for the project.

2.2.2. Materials Carbon Factors

To determine the carbon factors for the materials B2P use, a hierarchical approach was adopted. This hierarchy, stated from the most accurate approach to the least accurate, includes:

Supplier Specific Factor – Obtaining an Environmental Product Declaration (EPD) from the supplier, giving $kgCO_2e$ per unit of the product. If an EPD is unavailable, other sources to use with caution include Life Cycle Assessments (LCAs), or supplier records.

Location Specific Factor - Organisations (eg ICE, WorldSteel), or governments may provide location or region specific factors.

Tailored Factor - Using the carbon factor from a different country or region and tailoring this to reflect the country required. This typically involves tailoring the electrical energy used from the grid, by factoring with grid emission factors for the different countries.

World Factor - Using a carbon factor that is an average of factors that can be found in the world. These can be a large over- or under-estimate of the true value.

When determining carbon factors, it is imperative to ensure the factor corresponds to the country of origin for the material, and then accounts for transport, as opposed the country the material is used and constructed in.

To determine carbon factors for B2P, a tool was developed to record relevant supply chain data and guide the user through the process of carbon factor determination following the hierarchy stated above.

2.3. Determining Carbon Factors in Rwanda

Currently B2P is most active in Rwanda. Therefore, this study focuses on assessing its bridges constructed in Rwanda.

Firstly, by identifying and contacting B2P's material suppliers for the country we aimed to obtain supplier specific information. Environmental Product Declarations (EPDs) provided by material manufacturers are scarce in Rwanda and the broader East Africa region. For B2P's materials in Rwanda, only one EPD was provided for a minor steel product shipped from the USA. Therefore, understanding the level of information available and contacting suppliers directly was important.

Supply chains generally consisted of more than the end supplier, and typically when contacted the supplier would provide information of the region and processes for their portion of work, and where they sourced their material from. Then a process of tracing back the steps in the journey of the material took place - to where it was fabricated, manufactured, and then continuing to the origin of the raw material. These steps, including the different processes and transportation methods, were then incorporated into the carbon factor for that material.

Over time, as research and development in the field increases, EPDs will steadily become available for products in the East Africa region. This will increase the accuracy of the embodied carbon assessments and reduce the effort for B2P to obtain accurate values. As information, knowledge and updates become available, updates to the factors used in calculations will need to be updated.

2.4. Material Specifics for B2P's Carbon Factors

The section below shows the considerations that are specific to the B2P Rwanda supply chain in comparison with the world factors for those materials. This shows the impact that the carbon factor that you use can have on the results. It highlights that, for accurate results, the factors developed for the B2P Rwanda supply chain, cannot be directly applied to supply chains in other countries.

2.4.1. Cement

The cement used was quarried and manufactured in Rwanda. At the time of assessment there was no specific EPD or value for this product, however a 30% pozzolana content was established, then material carbon factors from ICE database matching the specification were tailored to Rwanda.

Energy tailoring included taking the secondary energy associated with grid power supply and factoring this according to the carbon insensity of the grid in Rwanda, as opposed to the energy mix of the original EPD. Given Rwanda has a higher carbon intensity grid this increased the Carbon Factor. The pozzololana content was confirmed by the supplier, this is a cement replacement with a much lower carbon than of Portland cement. Therefore the benefits of this have been factored into the value used, and this lowers the Carbon Factor.

2.4.2. Sand and Aggregate

The aggregate and sand used in B2P's Rwandan bridges were sourced locally to the site and predominantly processed by hand, meaning their carbon factors are negligible.

Food for human consumption is not included in Carbon Factors. When compared to other materials this becomes insignificant, and is therefore taken as zero.

2.4.3. Steel

The majority of steel within the bridges was sourced from a manufacturer based in Kenya. This manufacturer sources their steel in hot rolled coils from a range of countries across Asia, therefore the World Steel factor for Asia for hot rolled steel coils was deemed the most appropriate for the initial stage.

A separate addition was then used to account for an approximation of the manufacturing processes in Kenya from coil into the sections used.

2.4.4. Cables

The main cables used are reclaimed steel from a previous use in the the USA, with no additional processing besides checking for faults, so the only emissions from the cables lie in transportation from the USA. Whereas the fixation cables are new material, sourced from Asia, therefore a separate carbon factor is used.

Material	A1-3 Carbon Factor - World/UK ($kgCO_2e/kg$)	A1-3 Carbon Factor – Calculated for B2P's Supply Chain in Rwanda ($kgCO_2e/kg$)	Difference (%)
Cement	0.912 Average CEM1 cement, ICE V3.0 (DB, 2019)	0.814 30% pozzolana + Rwanda adjustment based on grid emissions	-11%
Sand and Aggregate	0.00747 Market average UK, ICE V3.0 (DB, 2019)	0 Sourced locally and processed by hand	-100%
Steel Section	2.38 Hot rolled coil (global), (World Steel, 2023)	2.78 Hot rolled coil (Asia), World Steel + processing	+14%
Main Cables	2.38 (World Steel, 2023)	0 Reclaimed cables	-100%

Table 1: Comparison of Carbon Factors

2.4.5. Carbon Factor Comparison

Table 1 shows an approximate comparison of the carbon factors from the basic world factor to the tailored version calculated for B2P's supply chain and context. The differences shown demonstrate the importance of tailoring factors to the supply chain.

3. ANALYSIS OF CARBON IN THE B2P BRIDGES

The following section gives an overview of the bridge types that B2P builds and then discusses their embodied carbon. The scope of the project uses B2P's Bill of Quantities to the compare the embodied carbon of the bridges, and does not review or comment on the structural validity of the designs.

3.1. Bridge Types

The two standard design concepts primarily used by B2P for the trail bridges, are the Suspended Trail Bridge and the Suspension Trail Bridge.

A suspended bridge is used in cases where the side banks of the valley are high enough to accommodate a bridge where the deck follows the line of a hanging cable between two main rock abutments – similar to a hammock.

The abutments include a stone masonry walls to create a pit, a concrete anchor foundation and saddle, this is then backfilled with stone and topped with concrete to form a ramp.

In contrast, the suspension bridge design is used where the difference in height between the banks and riverbed is not sufficient to facilitate a hanging walkway profile.

The suspension bridge design consists of two steel towers with main cables between the tops of the towers, the deck is then lifted by vertical members into an arching profile, which allows adequate space for freeboard. The main cables of the bridge are attached to concrete anchor systems embedded in the ground.

More recently, for sites with a high height difference between the river and bank on one side, and a low height difference on the other, a hybrid trail bridge design has been adopted. Here a suspended abutment is used for the high height difference, and a suspension for the low height difference.

Only the suspended and suspension designs have been considered in the scope of this article, however the same methodology would apply for a hybrid design.

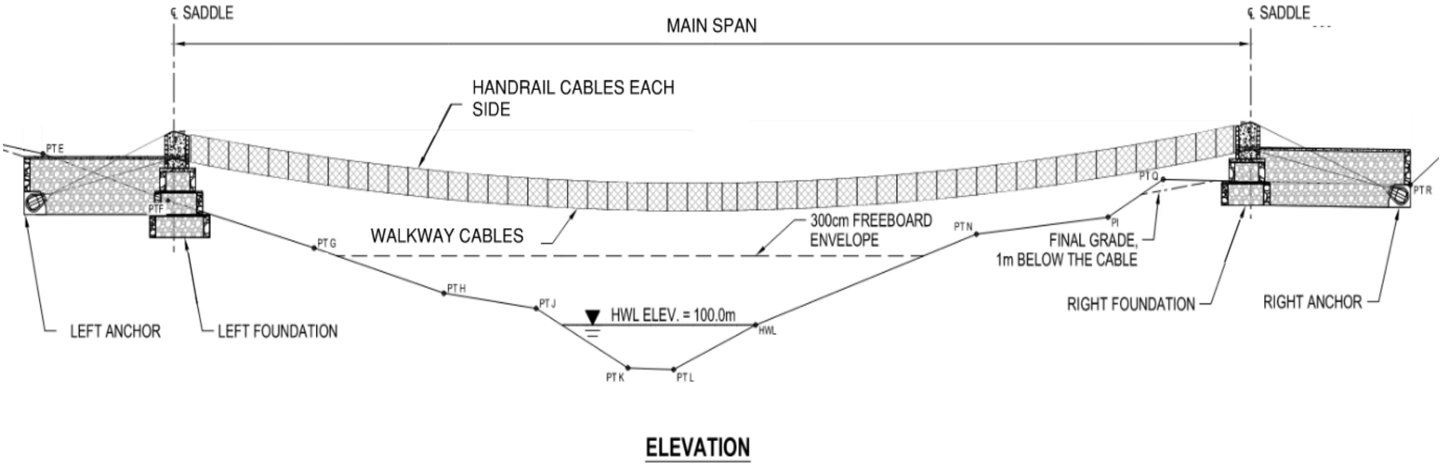


Figure 3: Suspended Trail Bridge

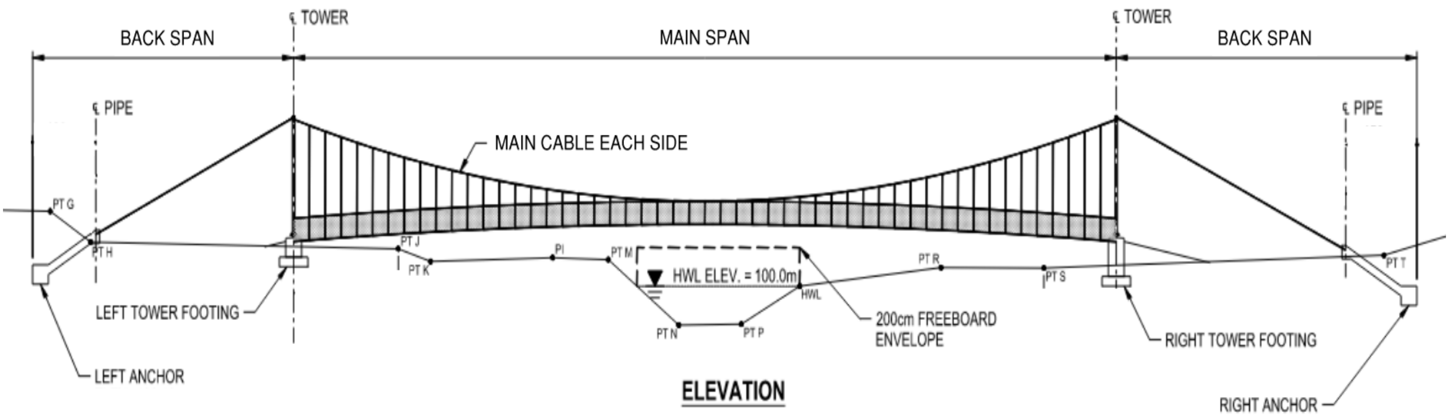


Figure 4: Suspension Trail Bridge

3.2. Carbon Calculation Approach

An Excel-based embodied carbon calculation tool was developed by Arup for B2P. The tool allows the carbon factors to be determined from B2P supply chain input information, as described in Section 2.2.

The tool then calculates the A1-A5 embodied carbon from the bill of quantities generated by B2P for their procurement processes. Information for existing B2P suspended and suspension bridges constructed in 2022 were used as input.

The results of these calculations are used in this section.

3.3. Embodied Carbon of a Suspended Bridge

For an 80m span suspended trail bridge, the distribution of embodied carbon between the bridge components is as shown in Figure 5.

For this bridge type and length, approximately 60% of the embodied carbon lies in the abutments. The emissions here are largely from the cement used for concrete elements and mortar within the abutment walls.

The sand and aggregate in the concrete elements contribute negligible emissions as they are locally sourced and processed by hand.

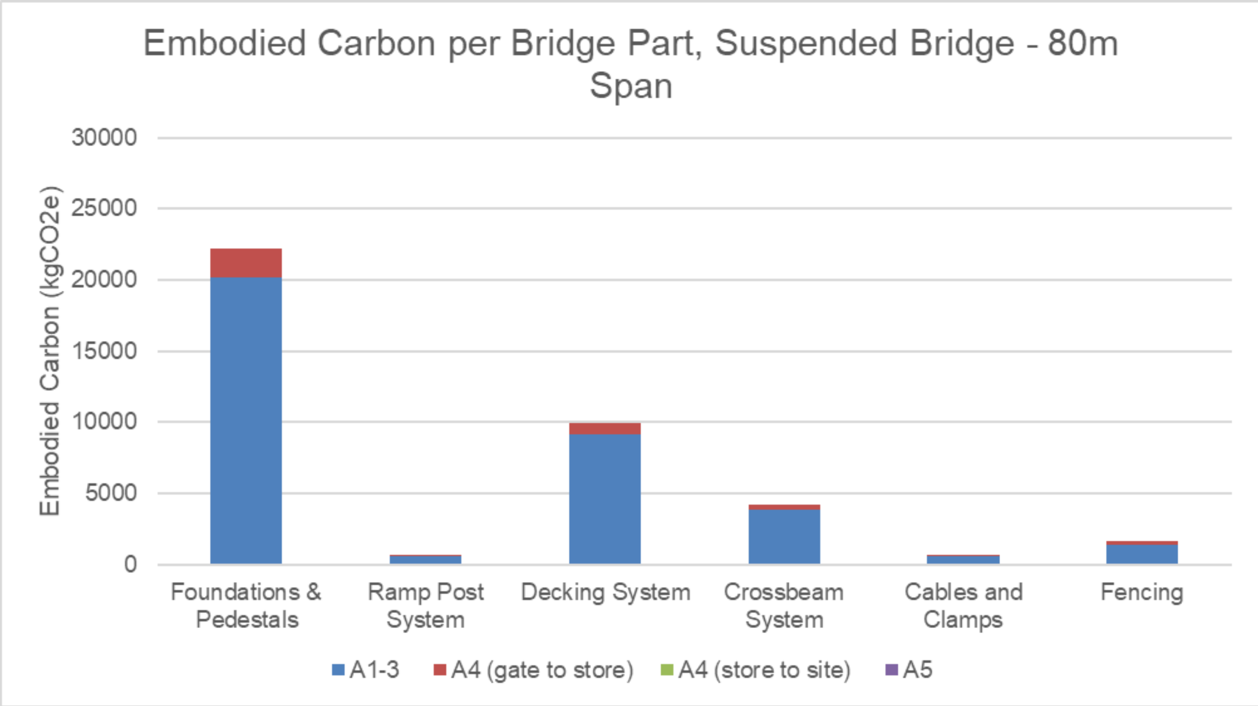


Figure 5: A1-A5 embodied carbon distribution of 80m span suspended bridge

The other 40% of the embodied carbon is from the steel items in the superstructure.

3.4. Embodied Carbon of a Suspension Bridge

The typical distribution of embodied carbon across a suspension trail bridge with a span of 80m is shown in Figure 6.

Here, approximately 40% of the embodied carbon is found in the substructure, and 60% in the superstructure, which includes the deck and tower system. Similarly, the dominant material contributing to the embodied carbon is cement for the substructure, and steel for the superstructure.

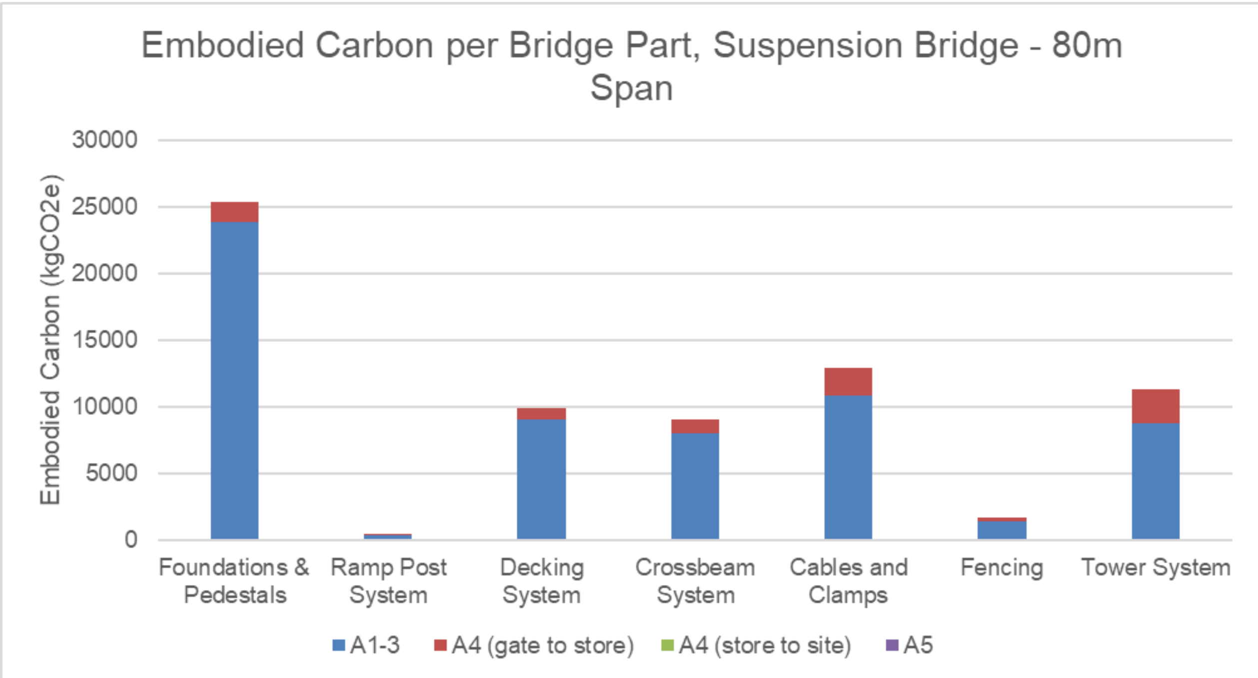


Figure 6: Embodied carbon distribution of suspension bridge, 80m span

Larger cables and greater quantities of cables are used for a suspension bridge, compared to a suspended bridge, which contribute to almost 20% of the embodied carbon for a suspension bridge.

3.5. Comparison of the two bridge types for an 80m span

For the same typical span, the suspension bridge has a higher embodied carbon for both the sub- and superstructure.

For the substructure, although the anchor of the suspension bridge is smaller in volume than that of the suspended bridge, a higher proportion of it is concrete, leading to approximately 10% higher embodied carbon.

For the superstructure, the embodied carbon in the decking system of the two bridges is the same. However, there is a higher amount of embodied carbon in the hanger system in the suspension bridge as the distance between the cables is greater, and therefore the hangers are longer.

Also, the cables used are larger. The additional steel towers for the suspension bridge also increase embodied carbon.

This leads to the suspension bridge super structure having approximately 80% higher embodied carbon than the suspended bridge.

3.6. The relationship of embodied carbon and functional area

The relationship between embodied carbon and functional area for each bridge type is investigated by using the data from 12 suspension and 50 suspended bridges constructed in Rwanda in 2022.

The data presented in this section demonstrates the impact the location and bridge type can have on embodied carbon.

3.6.1. Definition of Functional Area

The leading international guidance for carbon management in infrastructure, PAS 2080 [3], recommends that a functional unit is used when assessing the embodied carbon of an infrastructure asset. This approach is adopted when displaying the data in this article to allow for comparison of this data with other infrastructure.

As shown in Figure 7, when applying this to B2P trail bridges, the functional width is taken as the walkway width of the bridge.

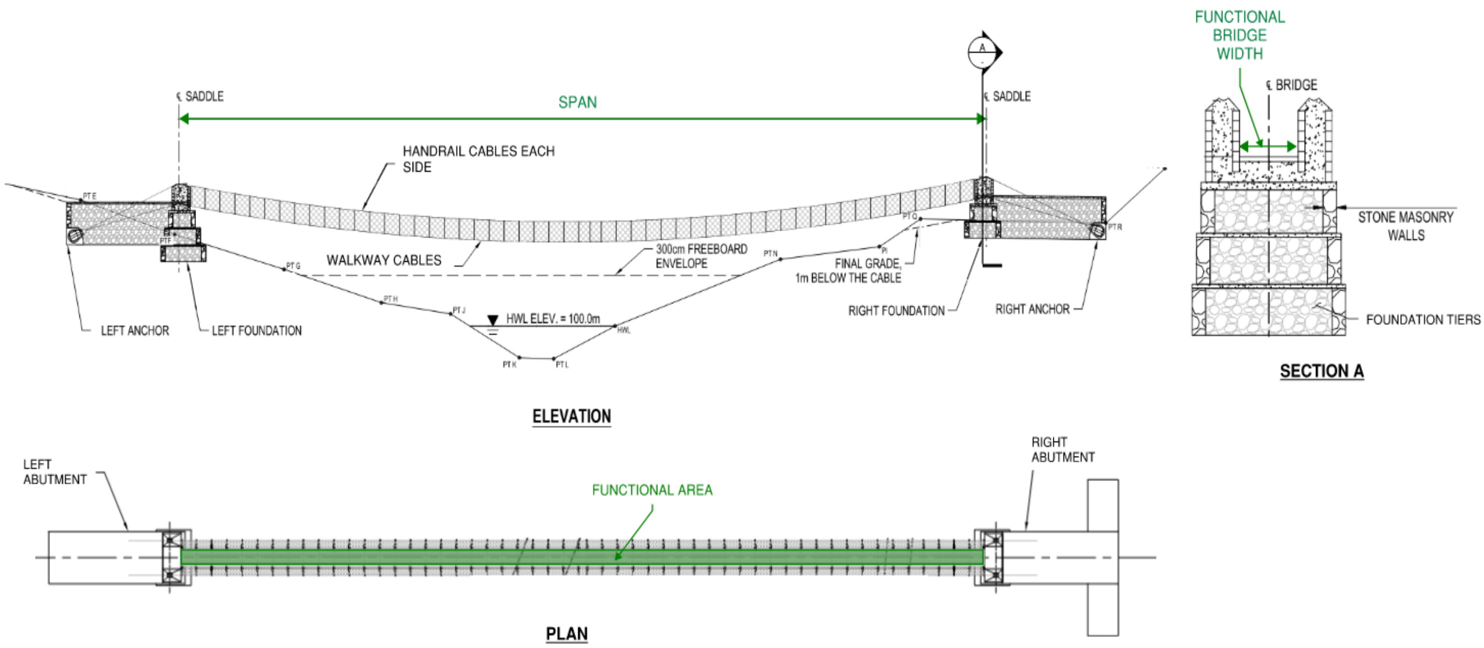


Figure 7: Functional Area definition

Since the functional width is constant in B2P's design of suspended and suspension bridges respectively, the trend for both span and functional area will be the same.

Functional area [m2] = span [m] x functional bridge width [m]

3.6.2. Accounting for A4 Carbon

The comparisons between bridges of different spans in this section is intended to highlight how the selection of the bridge location and type can impact the embodied carbon. B2P have a warehouse in Kigali where all materials are initially sent to before they are distributed to the bridge site.

The impact of the distance of a bridge from Kigali is removed from the data by splitting the A4 emissions into two parts, Gate to Store and Store to Site. This can be seen in Figure 8.

Rwanda is a small country so the Store to Site distances are small and are driven by the community need for a bridge.

A bridge which is 50km from the B2P store in Kigali would have a Store to Site A4 carbon emission value of 500kgCO2e. This is a very small contribution in comparison to the A1-3 and A4 carbon from Gate to Store.

In addition, it was decided this data was not relevant to the design decisions to be made using the analysis insights, therefore Store to Site emissions were neglected in the analysis.

3.6.3. Total Embodied Carbon and Functional Area

Figure 9 shows the distribution of total embodied carbon for A1-5 with functional area for both suspended and suspension trail bridges. The data shows that the embodied carbon of a suspension bridge is always greater than that of a suspended bridge for a given functional area. The explanation of this trend is presented in Section 3.5.

As the functional area increases, which is equivalent to the span increasing, the total embodied carbon for both a suspended and suspension bridge increases.

For both bridge types with functional areas below 175m^2 (span of 160m), the relationship between the increase of functional area and embodied carbon is approximately linear. This can allow a quick initial estimate of the embodied carbon to be made based on the function area from Figure 9.

However, the linear relationship does not appear to be applicable for suspension bridges with a functional area greater than 175m^2.

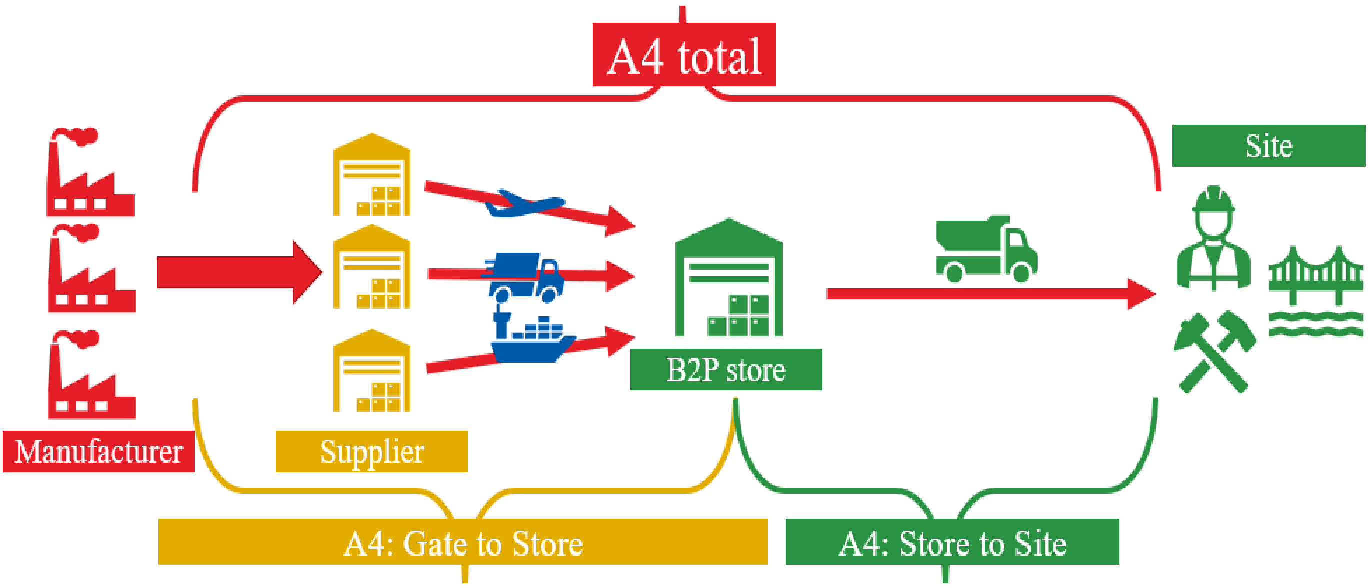


Figure 8: A4 stage definition

This is due to a significant increase in substructure size – this may be because longer suspension bridges require wind ties, which in turn require their own foundations.

3.6.4. Substructure Embodied Carbon and Functional Area

Figure 10 shows the relationship of embodied carbon in the substructure and the functional area. The trend is approximately the same as for the structure as a whole. This graph shows the suspended bridge substructure embodied carbon is lower than that of the suspension bridge for the same functional area.

For less than 175m^2, the rate of increase in embodied carbon as functional area increases is approximately constant.

The scatter of the suspended bridge is larger than for the suspension bridge. This is expected as the size of the substructure for a suspended bridge is not only dependent on the span but is also influenced by the ground profile.

For example, a shallower slope could lead to a foundation requiring 4 tiers, as opposed to the average of 3, and different extent of walls required.

The increased material, predominantly the increase in cement for the mortar joints, will impact the substructure embodied carbon for the bridge.

As was seen on the graph for the whole bridge, the suspension bridges with a functional area greater than 175m2 have a different trend for how embodied carbon in the substructure varies with functional area.

This relationship suggests that even longer suspension bridges would lead to bridges that have much higher embodied carbon.

3.6.5. Superstructure Embodied Carbon and Functional Area

Figure 11 shows the relationship of superstructure embodied carbon to the functional area. Similarly, the suspended bridge embodied carbon is lower than for a suspension bridge of a given functional area, as discussed in Section 3.5.

Both bridge types show a linear trend between embodied carbon and functional area. The rate of increase suspension bridges is greater than for suspended bridges. This is because for increasing length, the suspended bridge simply has more of the same deck and suspender system.

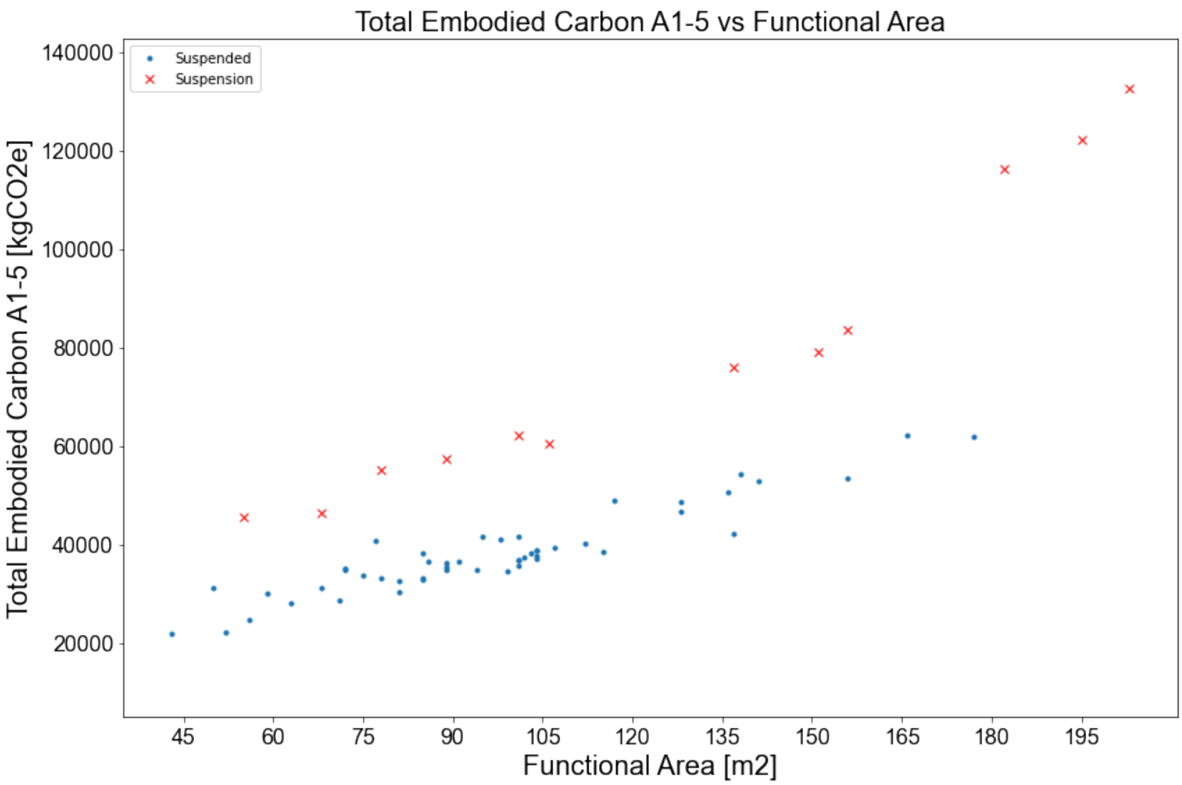


Figure 9: Total Embodied Carbon A1-5 with Functional Area

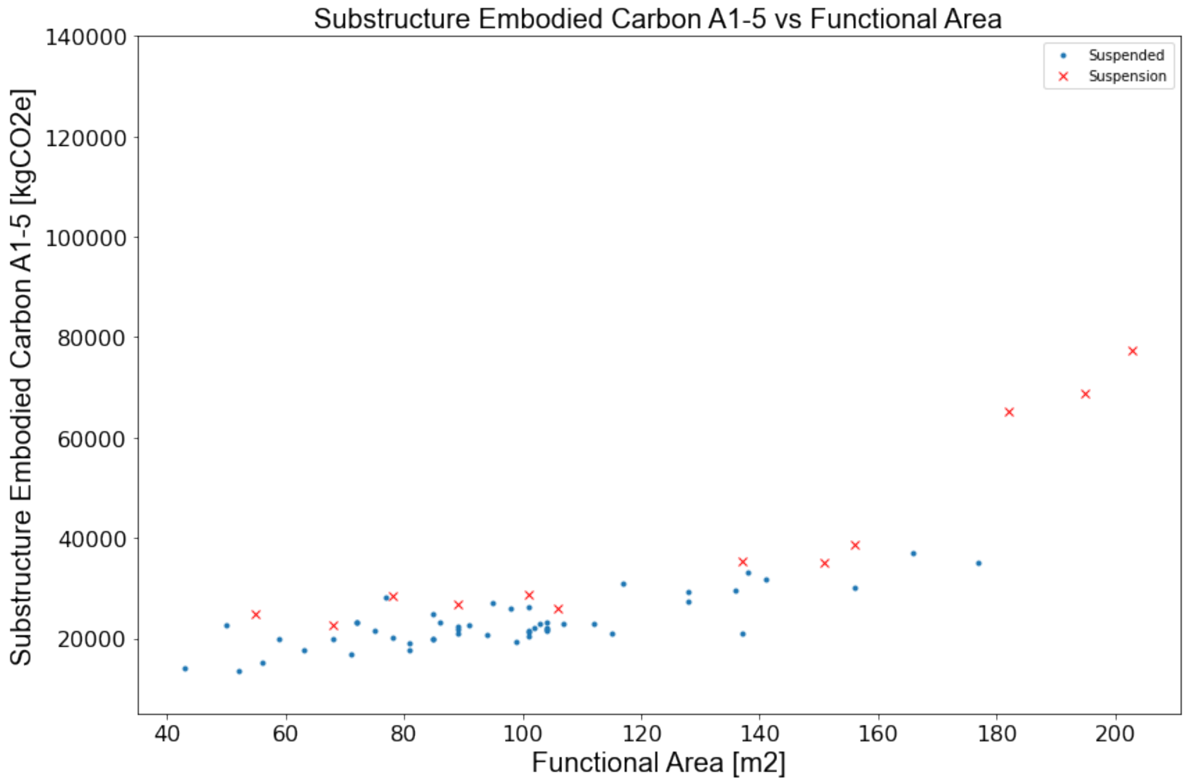


Figure 10: Substructure Embodied Carbon A1-5 vs Functional Area

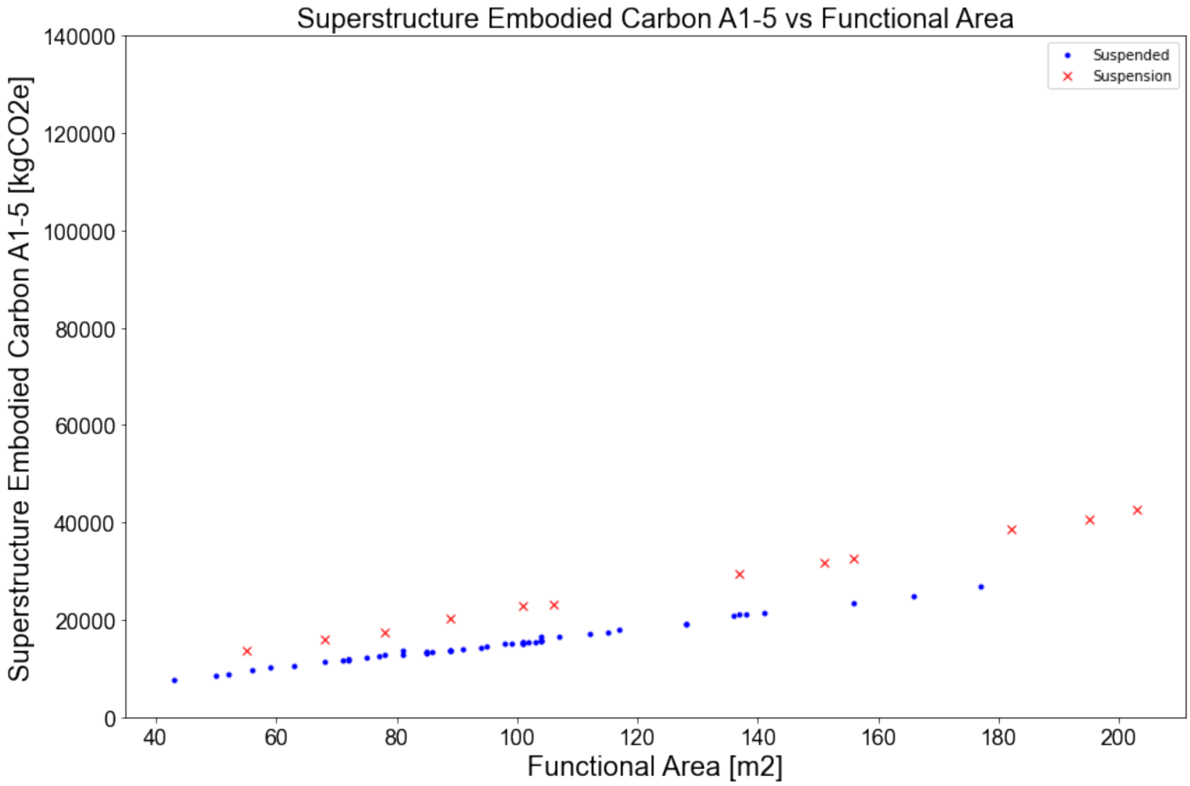


Figure 11: Superstructure Embodied Carbon A1-5 vs Functional Area

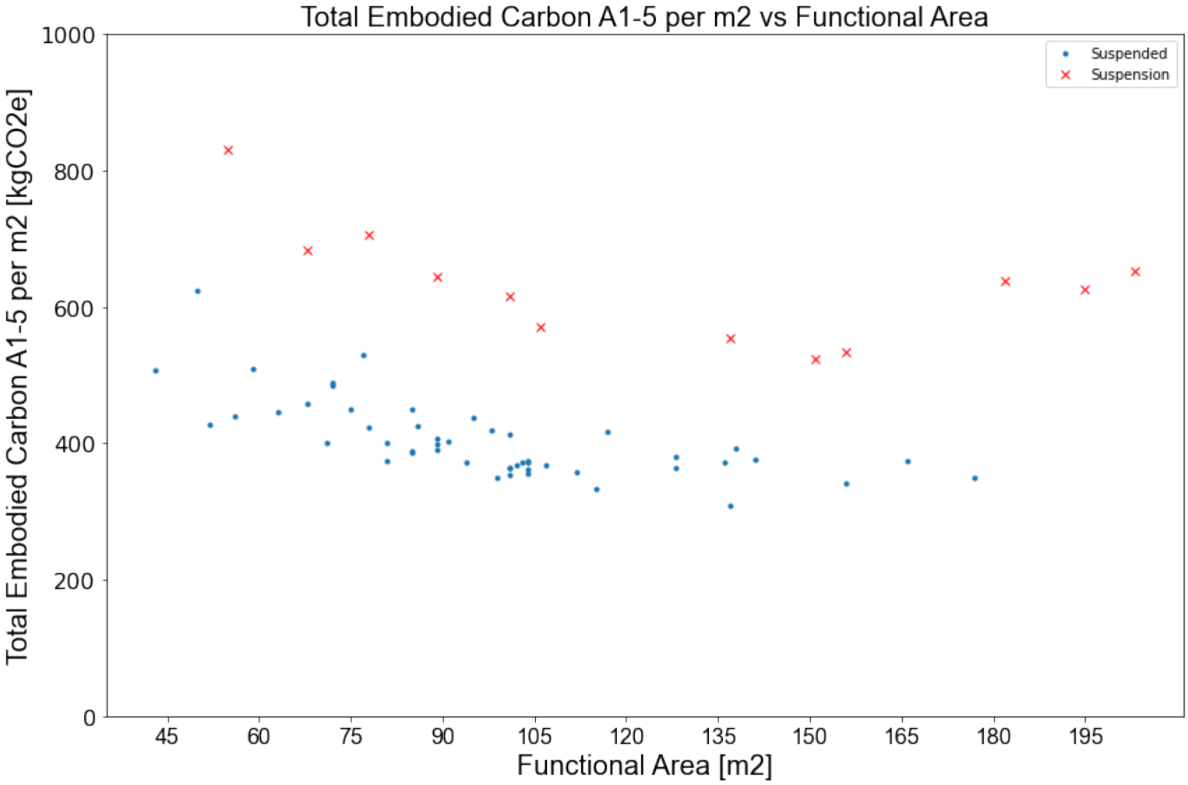


Figure 12: Total Embodied Carbon per m² vs Functional Area

Whereas in the suspension bridge, the tower height, and the length of the hangers between cables increases as the length increases.

3.6.6. Embodied Carbon per m² to Functional Area

Additional insight into the efficiency of the bridge types in relation to their embodied carbon can be found by investigating how embodied carbon per m² changes with functional area. The embodied carbon per m² is defined as the total embodied carbon in the structure divided by the functional area of the bridge. The results of this are shown in Figure 12.

For both bridge types with a functional area below 120m² (span of 110m), the carbon per m² decreases as functional area increases. This implies that efficiency increases in terms of embodied carbon as the span increases. Suspension bridges have a greater embodied carbon per m² than suspended bridges across all functional areas and are therefore a less efficient structural form.

As the functional area increases beyond 120m², this relationship plateaus for the suspended bridge, and reverses for the suspension bridges. Therefore, the most efficient structure for a suspension bridge is around 150m², and beyond this point the structure will be less carbon efficient.

3.7. SCORS for Bridges Rating

A version of the IStructE's Structural Carbon Rating Scheme ('SCORS') for buildings [4] has been proposed for bridges [5] and can be used to communicate the carbon performance of a bridge project. The rating system used is shown in Figure 13. The SCORS rating system is solely based on the A1-5 embodied carbon per functional area of a bridge.

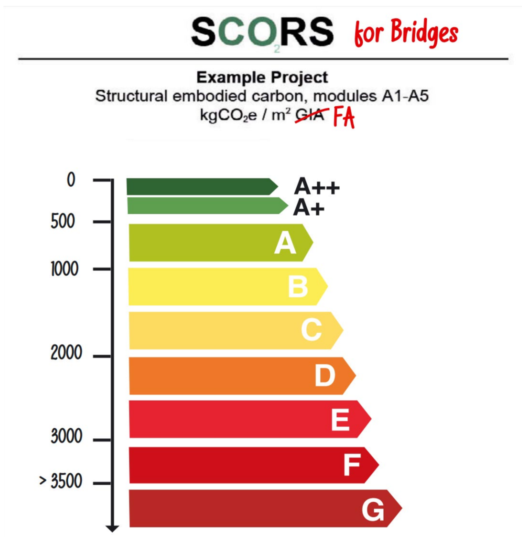


Figure 13: Proposed SCORS for Bridges [5]

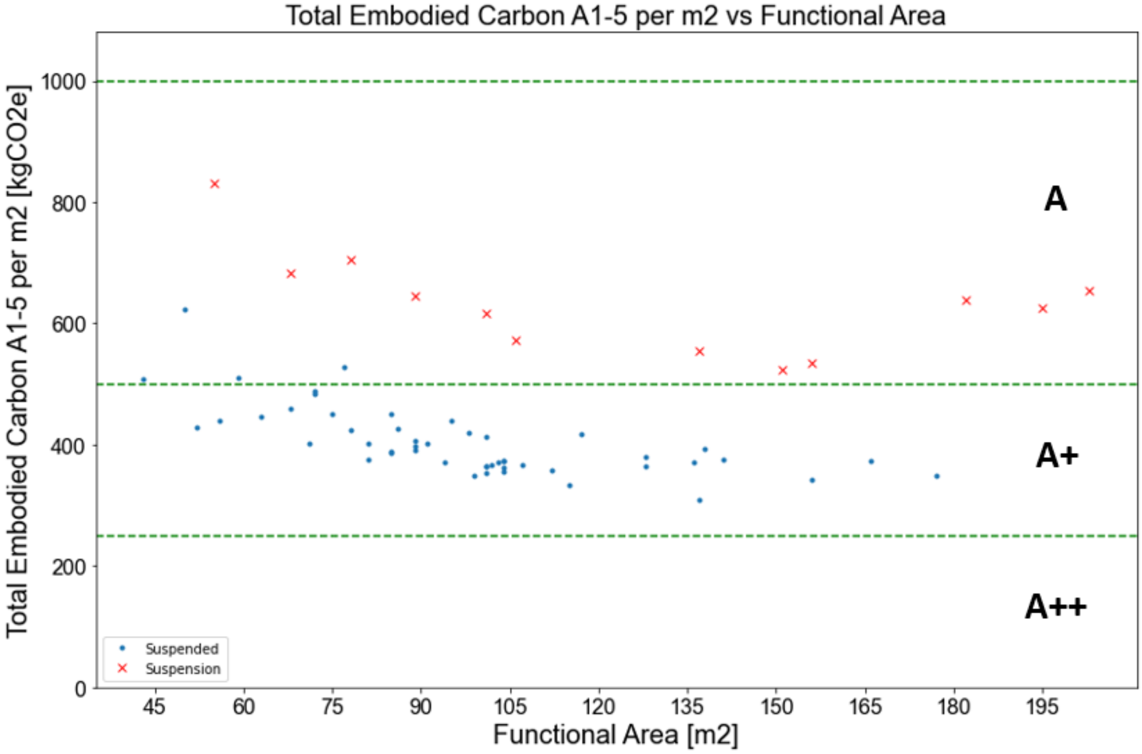


Figure 14: SCORS rating for bridges in sample data

The distribution of SCORS ratings calculated for the bridge data used in this analysis is shown in Figure 14. The B2P bridges sit in the A and A+ rating categories. All suspension bridges sit in the A category and most suspended bridges are A+. Note, a few suspended bridges with the shorter spans sit in the A category.

The fact that the B2P trail bridges score well on the SCORS ratings is not surprising as the rating system is designed to be applicable for all types of bridges (including road and rail bridges). Ideally, this would be compared with bridges with similar functions, requirements, and surroundings to gain insight into the efficiency of B2P's designs. Nevertheless, it is still positive to see that the B2P bridge designs score well.

3.8. Looking to the Future/Insights

The data presented above can be used by B2P in a variety of ways. Some of the key insights from the study are presented below.

It should be noted, this assessment was undertaken for the current B2P supply chain in Rwanda, if this changes, or to apply this to another country, the carbon factors used should be adjusted to the new supply chain and processes.

Information will also improve over time, and hence the factors updated as the likes of EPD's become available.

It is important to recognise the scope of an embodied carbon assessment does not incorporate all the factors surrounding material impacts. For example, the localised impacts of quarrying, or the human impact of manual construction techniques. Similarly, the analysis undertaken does not account for the lifespan of components and how regularly these will require maintenance and replacement. This may have a large impact of the whole life carbon of the bridge. An appraisal and recognition of these factors should be considered alongside the A1-5 embodied carbon. For example, understanding the lifespan of the reused cables compared with using the new alternative.

The wider impact of B2P's operations was also not assessed or accounted to the bridges – for example the operational energy used in offices or the emissions associated with cororate partner engagement. As the scope of this assessment was to assess the embodied carbon A1-5 of the bridge construction, to compare materials, supply chain and design, these aspects were seen to be outside of the scope, however could be developed by B2P in the future.

3.8.1. Adjusting design and/or procurement to reduce embodied carbon

From the embodied carbon factors development, B2P can now understand the embodied carbon of the materials and products they currently use in Rwanda.

During any changes to material sourcing, having this information and basis of understanding will enable B2P to find the right information about future suppliers to compare their carbon impact.

Possible means of reducing embodied carbon emissions may include:

- Reviewing and increasing pozzolana content in cement mixes.
- Varying specification of cement and mortar mixes in different components.
- Assessing the design of the layers of cement in within rock fill of the abutments – looking for ways to make sure this does not fill unnecessary voids.
- Refining the thickness in construction of mortar joints in masonry walls.
- Establishing the lifetime of steel members and how regularly they need replacing, and looking for ways to reduce this.
- Looking at whether further reclaimed material could be used, although accounting for lifespan considerations of this.

In addition to these more specific design parameters, these results could lead the B2P's engineering and procurement departments in taking stronger decisions when advising government partners at the conceptual design stage in relation to the type of bridge to be used for a specific valley, or the span needed, taking into account the impact on the embodied carbon on top of the rest of the data.

Considering the speed of construction in Rwanda during the coming 5 years (with a minimum of 35 new bridges built every year), small considerations to reduce the embodied carbon of B2P projects could have an overall bigger impact.

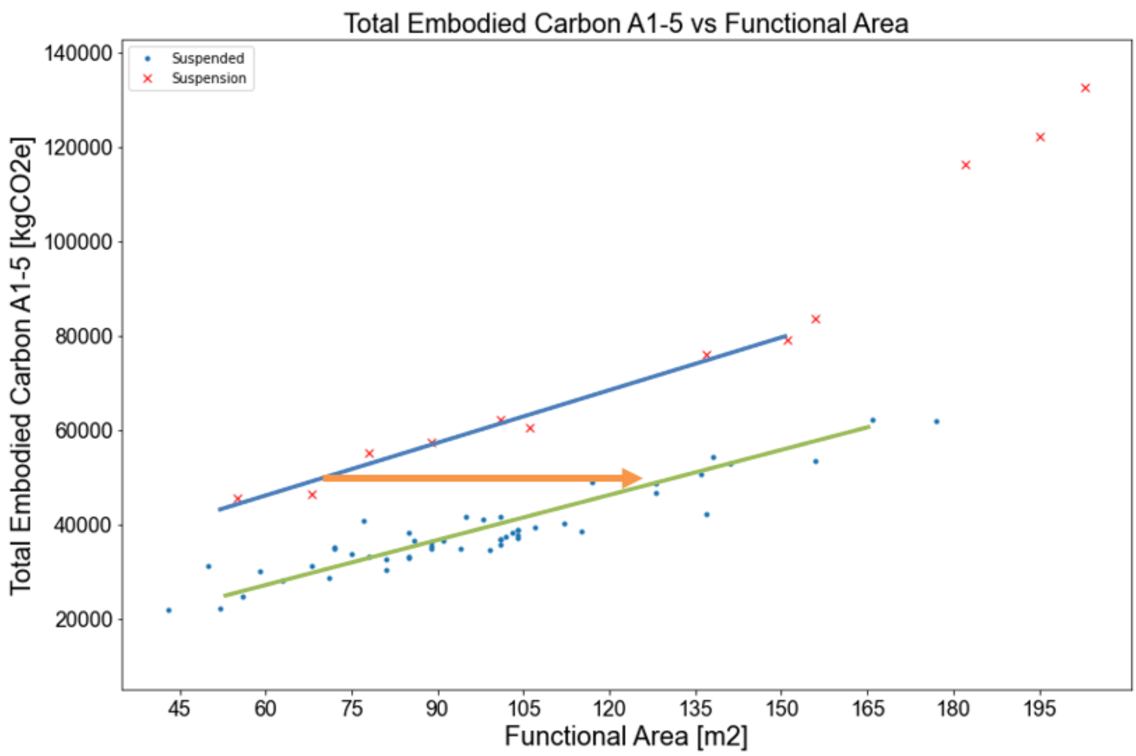


Figure 15: Using relationships to inform design decisions

3.8.2. Embodied Carbon Estimation

The data has shown that there are robust linear trends between embodied carbon and functional area.

B2P can use these trends to estimate the carbon impact of their designs quickly in the early stages of project development. This will allow B2P to easily incorporate carbon considerations into their design process. For example, a B2P staff member who is doing a site investigation to determine the best location for a bridge can use these relationships as shown in Figure 15. The data has shown that a suspension bridge with a 68m^2 functional area has the same embodied carbon as a suspended bridge with a 136m^2 functional area.

Therefore, for the two bridge types considered, extending the bridge length to enable a suspended bridge to be constructed can result in a lower embodied carbon solution. In the future, B2P could look at developing alternative bridge types for shorter spans which may have lower embodied carbon.

3.8.3. Identification of Design Optimisations

As stated above, the embodied carbon per m^2 trends can be used to highlight which bridge designs have optimal material usage and where improvements can be made. The data shows that shorter spans do not perform as well on carbon efficiency. B2P could use this insight to investigate their designs to understand whether shorter bridges could be made more efficient. This could help reduce the carbon and probably also the cost of the shorter bridges.

3.8.4. Comparisons with other Infrastructure Solutions

B2P now have the ability to calculate the SCORS rating of their infrastructure. This will allow B2P to have carbon-based discussions with infrastructure planners and allow them to assess proposed infrastructure.

Furthermore, the ability of assessing the embodied carbon of their bridges and potentially of other infrastructures, could place B2P as a leader in this topic in the countries they work in. This would allow B2P to support partners to consider carbon intensity of infrastructure alongside other environmental, social and economic parameters when creating infrastructure policy and plans.

4. CONCLUSION

The work carried out by Arup in collaboration with B2P is a first important step towards understanding more about how rural infrastructure contributes to the embodied carbon emissions of the construction industry.

On one hand, it gives the B2P the ability to shape their standardised designs to not only be cost-structurally efficient, but also creates a framework for assessing environmental impact. Considering the pace of B2P's construction in Rwanda only in the coming years (an average of 35 bridges/year) the impact of these decisions will be multiplied and spread throughout the entire country.

On the other hand, B2P will finally have evidence to discuss embodied carbon with their partners. B2P continues to scale and expand its reach and partner with other implementers, governments, the private sector, and funders to maximise investments. As the organisation grows, being able to transmit the importance of considering the embodied carbon when planning infrastructure can influence policies beyond rural infrastructures and trailbridges.

While there is room for more work in this direction, this first step provides B2P with new tools to improve the quality of their work, and guide their future decisions and their partners' ones in the direction of more sustainable, low-carbon infrastructures.

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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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LOKO OWETO BRIDGES ON THE BENUE RIVER, NIGERIA

Eng. Micha B. Petri
Kedmor Engineers LTD, Israel

Figure 1: Construction of the Loko Oweto Bridges above the Benue River

INTRODUCTION

The Loko Oweto Bridges on the Benue River in Nigeria were designed and constructed to connect the North and South of the country with an upgraded road system. They are currently under construction.

The project includes two bridges, each 1,835 m long, and two bridges of 220 m.

The water level of the river rises up to eight meters between seasons and both creative and unique solutions were required during the design and construction.

The long bridges have 22 spans with a typical length of 85 m.

GENERAL BACKGROUND

Nigeria is a federal republic located in West Africa to the coast of the Gulf of Guinea. Its area has a total of 923,768 km^2 and has an estimated population of 200 million.

Nigeria can be traditionally divided into two parts - the North and the South of the country.

This General division follows the location of the Equator crossing Nigeria and is reflected in several aspects.

The North is a Savana, close to the Sahara Desert, and the South is rainy and tropical and therefore green and fertile.

In the economic aspect, since the South is rich in natural resources such as oil and tin, the majority of the country's industry and wealth is located in the South.

Another aspect is religion, with Muslims in the North and Christians in the South.

The above-mentioned unofficial partition reflects the tension in the population related to religion, authority and economic justice.

The Nigerian government decided to invest in improving the connection between the parts of the Republic for developing the economy and population conditions.

OWNER: Ministry of Works, Nigeria

BRIDGE DESIGN AND PLANNING:

Kedmor Engineers, Israel

CONTRACTOR:

RCC - Reynolds Construction Company, Nigeria

SOIL AND FOUNDATION CONSULTING:

Fugro Nigeria, Israel Klar

Since wide rivers are crossing Nigeria and physically dividing it, it became necessary to increase the number of river cross points.

As part of these efforts, the Nigerian Ministry of Works promoted the Loko Oweto Bridges Project which will cross the Benue River and allow an additional connection between the North and the South of the country.

The road connection will significantly upgrade the Nigerian economy since it allows additional access between the north and the centre of economy and business in the south.

Figures 2 and 3: Location of the bridges on the map. Source: Google Maps

PROJECT DESCRIPTION

The project is a Design-Build project carried out by Reynolds Construction Company (RCC), which has major projects in Nigeria, especially roads and bridges. KEDMOR ENGINEERS LTD was hired to design the bridges for RCC.

The project included all the design stages from preliminary design to final design and detailed design documents and construction supervision for the four bridges.

Several alternatives were introduced to the Nigerian Ministry of Works, and after their approval, the design began.

The detailed design has been controlled by the Ministry's local engineers.

The project includes the following Bridges:

- Bridge 1 East – Segmental Bridge of 22 spans; 1,835 m long.
- Bridge 1 West - Segmental Bridge of 22 spans; 1,835 m long.
- Bridge 2 East - Segmental Bridge of 3 spans; 220 m long.
- Bridge 2 West - Segmental Bridge of 3 spans; 220 m long.

In this article, I will, as a designer, describe Bridge 1 East - the process of planning, construction and engagement.

I will focus on various stages concerning a segmental bridge constructed with the cast-in-situ balanced cantilever method above the river and the challenges involved in the design derived from the length of the bridge.

ABOUT THE SITE

The bridge is in a remote area far from an urban environment and it is rural and tribal with few transportation routes and no asphalt, no electricity and no running water where people live in huts made of mud and twigs, see Figure 4.

The villages surrounding the bridge site make their living mostly from farming and fishing.

The construction site located in an isolated area is greatly challenging in the logistical aspect mainly concerning the supply of raw materials.

In order to reduce the dependence on the site, wells were drilled, an electricity station was built and a concrete plant was established.

The bridge crosses the Benue River which is the main tributary of the Niger River crossing Nigeria.

Figure 4: Local village with mud houses near the bridge

The length of the river Benue is about 1,400 km from Cameroon in the North to its connection with the Niger near the city of Lokoja, see Figure 5.

The Benue River flows throughout the year and is a main marine transportation route.

The seasons are divided into a rainy season and a dry season and the river changes between seasons.

The width of the river at the peak of the rainy season reaches 1,700 m and during the dry season is reduced to a width of a few hundred metres, and in addition, the level of the river varies between seasons by eight (!!) metres in height.

The site is heavily influenced by the changes in the width of the river and the water level.

It was necessary, for all work stages, to prepare the methods and equipment that will enable the execution of the works both in the deep river water and from the dry ground when the river reaches its low level.

It should be noted that the bridge design is also influenced by the fact that there is no option of placing shuttering and scaffolding on the ground and therefore the selected technology is the balanced cantilever method.

The site soil is characterized by a top layer consisting mainly of sand with thin layers of clay to a depth of about 18 m and then a thick layer of Lime stone exceeding 40 m in depth.

The bridge foundations, with respect to the layers of soil and drilling in the flowing river water, were chosen to be deep piles using bentonite drilled through a steel casing sleeve.

At the bridge site four pile load tests were carried out confirming the ground data obtained from 23 logs drilled at the bridge axes.

Calculation of the scour around the bridge columns and piles was carried out according to the equation of the Colorado State University (CSU).

For a group of round piles, according to the flow and depth data of the river, the local maximum scour expected at mid piers is 7 m and the additional global scour at the bridge location is a few tens of centimetres more.

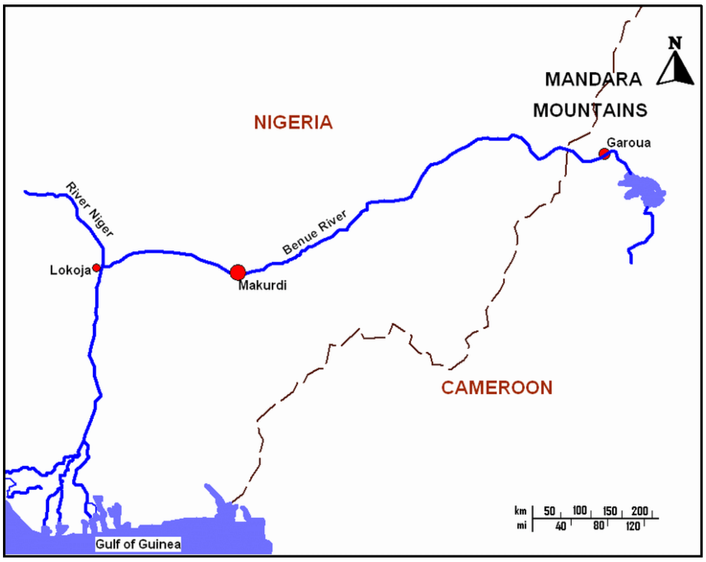

Figure 5: Benue River in Niger. CC Licence

The Bridge and piles were calculated considering the scour and also neglecting the scour in terms of sensitivity of pile stiffness and capacity in the horizontal direction and the vertical direction.

BRIDGE DESCRIPTION

The Loko Oweto Bridges, crossing the Benue River, are 1,835 m long each.

They are divided into 22 spans where there are 20 typical spans, 85 m in length and two end spans with a length of 67.5 m each.

The slab width of each bridge is 11.6 m and each bridge carries two traffic lanes and a pedestrian sidewalk.

The bridges have a straight planimetric path, without skew and the vertical alignment of the bridge is parabolic to provide a vertical clearance of 8 m above the river's high water level and 12 m at the centre of the bridge to allow boat passage under the bridge at each span.

The bridge superstructure is a hollow box cross-section with a height varying between 450 cm above columns and 240 cm at the centre of the span and at the end spans.

The slab bottom curve is parabolic and it was designed to optimize the stresses along the construction stages.

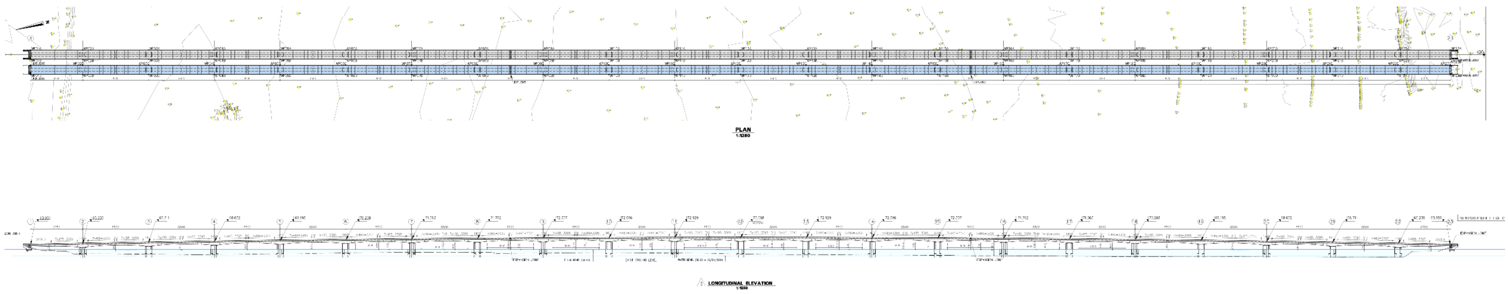

Figure 6: Bridge Plan and Elevation. Click on the image to open it in a higher resolution

The hollow box cross-section has two transverse cantilevers of 335 cm on both sides, the webs are vertical so that with the change of height, the bottom flange width will remain fixed at 460 cm.

The superstructure is designed using the balanced cantilever cast-in-situ method where the pier segment is cast on top of the columns in a technique that allows work in the river as described further on.

To the pier segment two form travellers are installed on both sides for seven rounds of the casting of seven pairs of segments, 485 cm in each.

Between the two sections of neighbour axes, a closure segment will be cast.

To allow a temporary restraint between the deck and columns during segment casting, before reaching continuity, the deck is vertically stressed against the columns using four cables of 100 tons each.

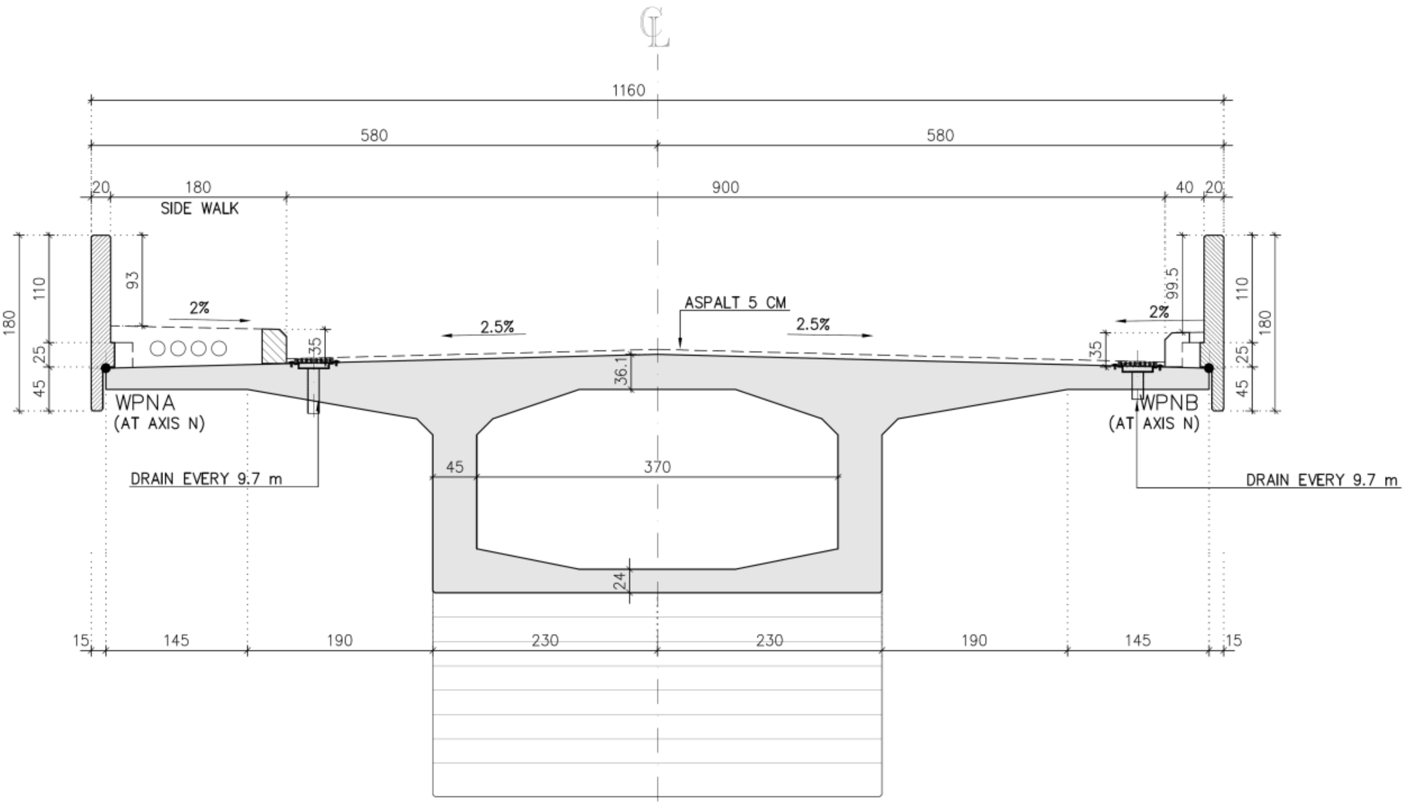

Figure 7: Bridge Cross-section - hollow box with a variable height

Figure 8: River and Bridge - the typical span length is 85 m

At this stage, temporary concrete blocks are cast between bearings to reduce the load on the bearings.

This enables the capacity at an unbalanced segment situation in case of an error.

The bridge consists of 21 mid piers, each one containing two concrete columns with rounded edges, in accordance with the properties for structures located in a flowing river.

The use of a pair of columns in each axis ensures the stability of the deck duration segment construction and eliminates the use of temporary support towers to stabilize the deck, which would be required if each axis had a single column.

The column height varies from the ends of the bridge centre.

The columns include a bottom section with a height of 5.7 m and a thickness of 210 cm, the height of this section was designed to keep the column 'shoulders' above the highest water level and to enable the temporary support system to be located above water as described further on.

Above the bottom section, a top column section is cast; its height varies along the bridge and its thickness is 180 cm.

The highest columns are located at the center of the bridge and are 17.5 m high.

On top of the columns, bearings are installed or the pier segment is cast, depending on the static longitudinal scheme.

The longitudinal static scheme of the bridge is continuous along the entire length but concerning the bridge length and the effects of axial loads and strains, it was decided to split the bridge into three sections with the lengths of 620, 595, and 620 m by installing expansion joints at the centre of spans as described below.

Each bridge section is continuous where at the middle, at two axes, the columns are connected monolithic to the deck and at the rest, the columns are connected using sliding pot Bearings.

The columns are cast on 200 cm high pile caps with a hydrodynamic rounded geometry.

Each pile cap connects three piles.

The abutments are based on piles and include wing walls at the embankments.

The piles are drilled and cast in steel casing pipes allowing drilling in the river. Each mid-pier column includes three piles, 180 cm in diameter and 32 m in length.

Abutments have four piles with a diameter of 180 cm and a length of 40 m.

The global modelling of the bridge was carried out using Bentley RM Bridge software and it aimed to conduct a calculation of loads acting on the structure and its components in accordance with the British Standard BS5400 practiced in Nigeria and loads due to the construction stages.

For calculation of construction stages and stressing the RM software was used, see Figure 9.

It includes modules designated for segmental bridges including camber design taking into account the additional weight of each new segment with wet concrete ranging from 120 to 80 tons and the form traveller weight of 60 tons.

It also includes time schedule which is required for casting the sections with extra segment at each casting stage, and the cantilever that is bending down before it reaches, after casting the final section, its final position.

The products of these calculations, besides drawings, are the 'geometry control' documents submitted as manuals with an ID for each segment including casting levels and stress data.

Measurement is carried out before casting to verify the correct level and after casting and stressing an additional measurement is performed whereby the designer decides whether level corrections are necessary.

During the construction measurement data are documented in our office and the bridge geometry is continuously monitored.

Calculation of the deck in the transverse direction was carried out using LUSAS Finite element software at a number of 3D models which referred to the support conditions and various static heights of the deck, see Figure 10.

Transverse direction and the local behaviour of the cross-section are designed as reinforced concrete.

Values of reinforcing steel required in this calculation are summed together with reinforcing values that were required at the longitudinal calculation and reinforcement details were designed combining these two calculations.

Bridge elements were also calculated to withstand barge collision loads according to AASHTO LRFD Bridge Design Specifications for a design speed of 15 km/h.

THE RIVER CHALLENGES

As noted, the width of the river and the water level throughout the seasons change dramatically and that impacts every aspect.

Regarding the project schedule, the construction stages have to be planned to provide access to the

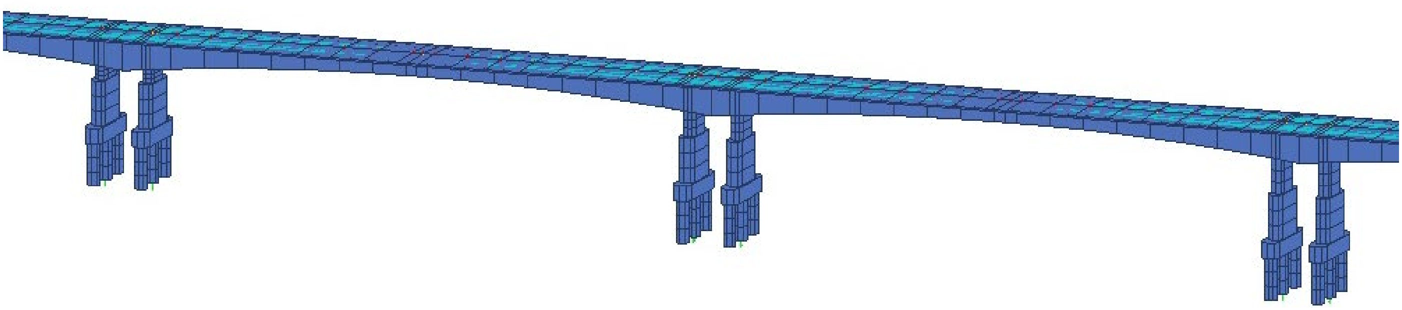

Figure 9: Construction stages and stressing were carried out using RM Bridge software

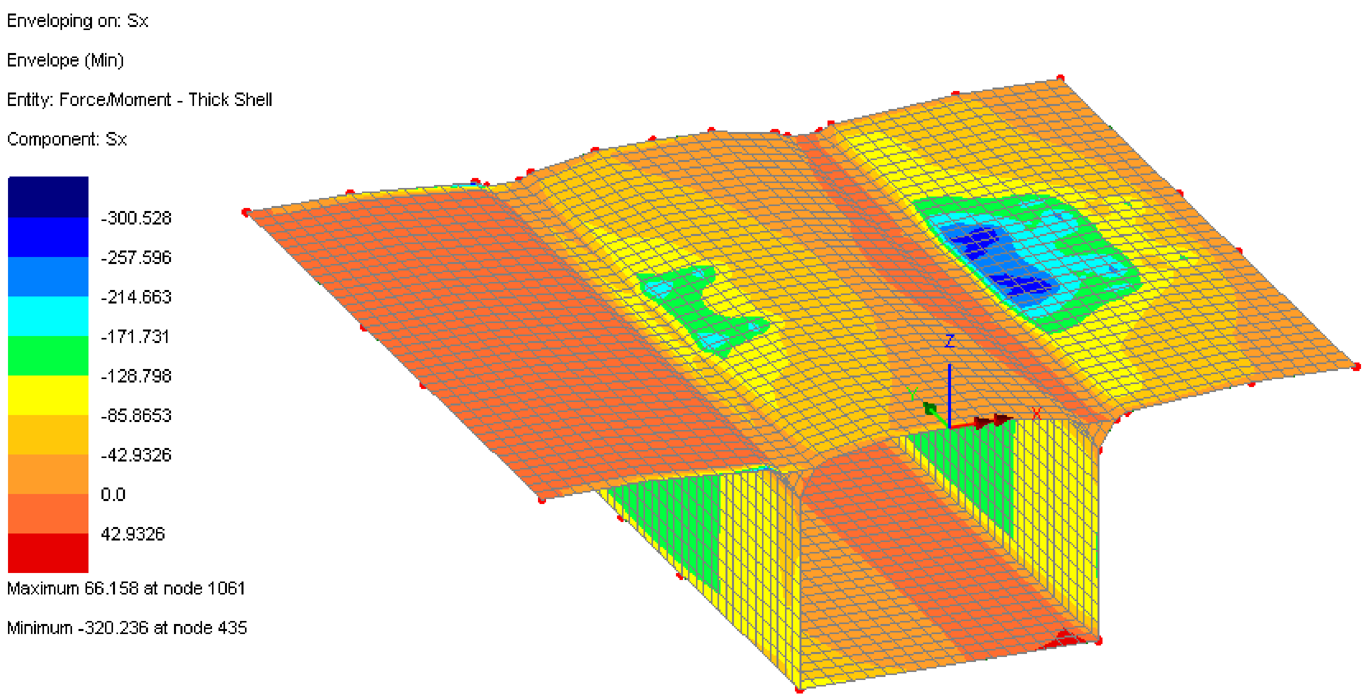

Figure 10: Transverse calculation using LUSAS

different bridge axes by barge, for which deep water is required, or by land, which is possible only with the lowering of the water level, so at shallow water there is a problem of access to some of the bridge sections.

During mobilization for marine works, RCC procured a fleet of 11 barges capable of carrying cranes and equipment which also bears a floating concrete plant. In addition, the fleet includes tug boats, taxi boats and docks to transport workers and equipment.

The bridge piles are cast in the river water using steel casing pipes of 16 m in length.

To cast the pile caps above water level prefabricated concrete molds were designed to be installed in prominent parts on the casing pipes above the river.

In these prefabricated concrete forms, supported on the casing perimeter, reinforcing steel is arranged and the pile caps are cast without the need for stable soil or forms.

The internal element height is 200 cm and it has a total length of 10.65 m composed of four interconnected parts.

For the casting of pier segments above the columns, a temporary support girder system was designed leaning on the column shoulders.

The system includes four main composite girders and a set of secondary composite girders located under the scaffolding tower legs.

This platform enables work above water level in all seasons. These girders are used to support the column forms at an early stage supported by the pile cap shoulders.

MID SPAN EXPANSION JOINT

As mentioned above, the bridge is divided into three sections along its length due to the axial deformations generated by temperature, creep and shrinkage.

Without such a bridge division, the deformations at abutments would reach almost one metre, and the horizontal load acting on columns would require extra piles.

At a balanced cantilever bridge locating an expansion joint above columns is not recommended since the method requires continuity over the column during construction.

Figure 11: Temporary support girders for casting above water level

Hence it was decided to place the joint in the middle of the spans between axes 8-9 and 15-16 so that the concrete deck will have a gap of 57 cm.

In order not to leave two cantilevers from both sides, the expansion joint at mid-span was designed to allow free movement in the axial direction but provide continuity for moment, shear and torsion.

During the design stage, many alternatives were examined for creating conditions including isolation and continuity including prestressed concrete beams and steel girders in different methods.

The solution selected was the installation of two steel girders inside the deck which are fixed at one edge of the deck, and on the other end steel sleeves that allow the girder to slide similarly to a piston are installed inside, see Figure 12.

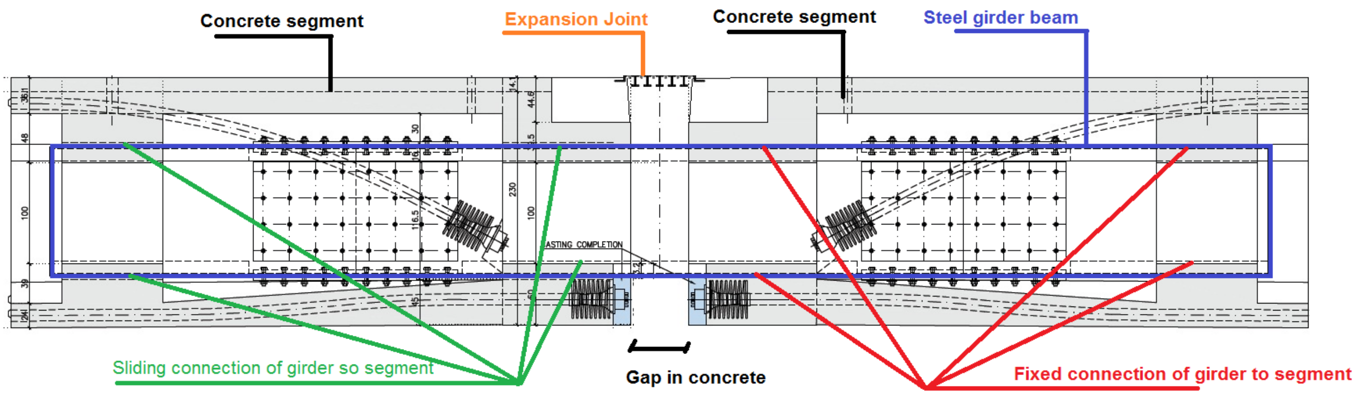

Figure 12: Mid-Span Girder - Sliding on the left, fixed on the right, gap in the middle

Figure 13: Insertion of steel girder into the bridge deck

Connection on each side is at two points so that the 'force couple' allows the transfer of moments and shear and due to the presence of two parallel girders creates continuity for torsion.

The girders are 11.8 m long, 130 cm high and 70 cm wide.

After installation, they are fully cast with concrete to improve their capacity as a composite cross-section.

The final stage includes installing a girder expansion joint which allows obtaining the deformations, several centimetres daily and over the life of the bridge will be about 30 cm.

DESIGN TEAM TASKS AND RESPONSIBILITIES

The design team of the Loko Oweto Bridges was involved in the design stages from the very beginning.

At first, the design included various alternatives regarding the bridge length, span length, width, technology and construction stages.

Bill of quantities, drawings and basic calculations were conducted at this stage.

After the Ministry approved the suggested alternative the final design took place including determining the dimensions and global calculations.

At this point optimization of the static scheme was performed and construction solutions were discussed and agreed upon with the client.

A calculation report, BOQ and a set of drawings were submitted.

The detailed design included a full calculation of all elements for different loads and construction stages as described in this paper including the following elements: piles, including composite cross section for barge collision, pile caps, columns, abutments, approach slabs, bearings, pier segments, bridge segments including all reinforcement and stressing, mid-span joints, various elements and solutions for work above the river.

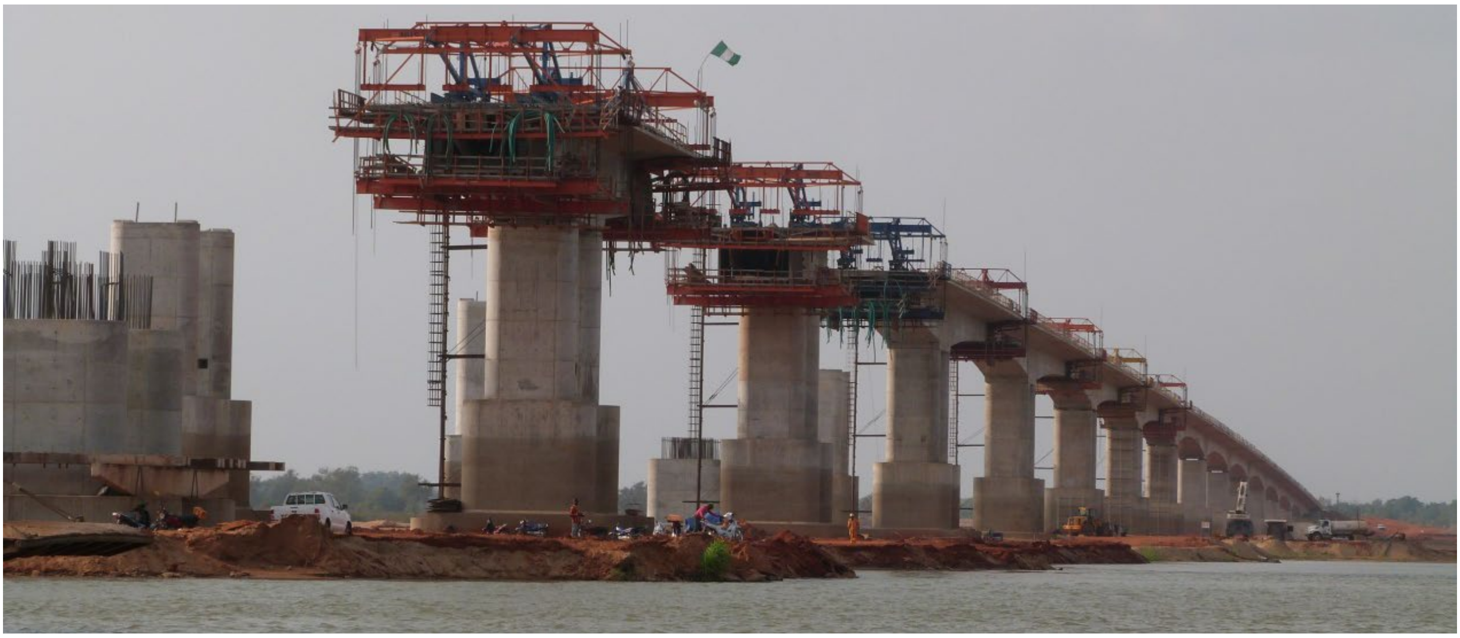

Figure 14: Work during river low level. The column shows the upper water level mark

In addition, the geometry control calculation included the production of "Christmas Trees" and an erection manual document for 21 axes (322 segments).

Every engineering project - and certainly a complex project of such nature - requires a high involvement of the designer during the construction stages.

Throughout all phases of the project site visits are made every few months regularly or before starting a new phase.

In addition to these visits, we provide a full control system including the approval for casting each element.

Such approval includes a checklist signed by the site team, a survey and images sent by email prior to casting.

Of course, assistance to the site team is provided daily by telephone and in a variety of media available with most of the work done in front of the site engineer.

SUMMARY

Loko Oweto Bridges construction was completed at the end of 2022 and the approach roads are under construction.

The project is essentially a mega project and thousands of hours were invested in its design.

The dimensions of the project required much planning and hard work of the design team while coordinating all planning products and their control.

Bridges with a length of almost two kilometres above the river are a tremendous challenge for a design team but a very satisfying one.

Frank Bauchspiess
steel bridges - engineering

FABRICATION OF THE CHENAB RAILWAY BRIDGE, INDIA

ASSEMBLY OF THE CHENAB RAILWAY BRIDGE – PIERS AND ARCH

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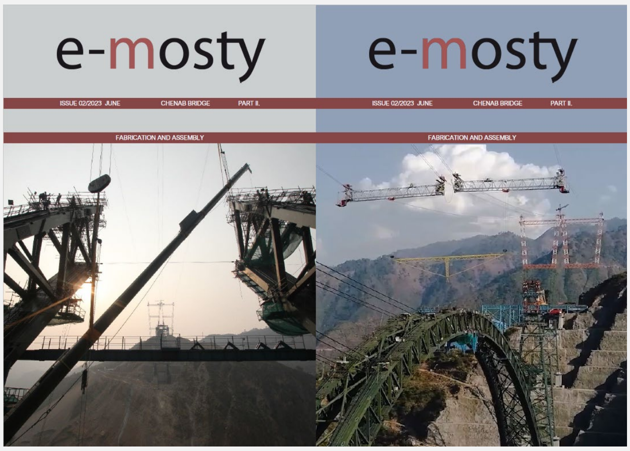

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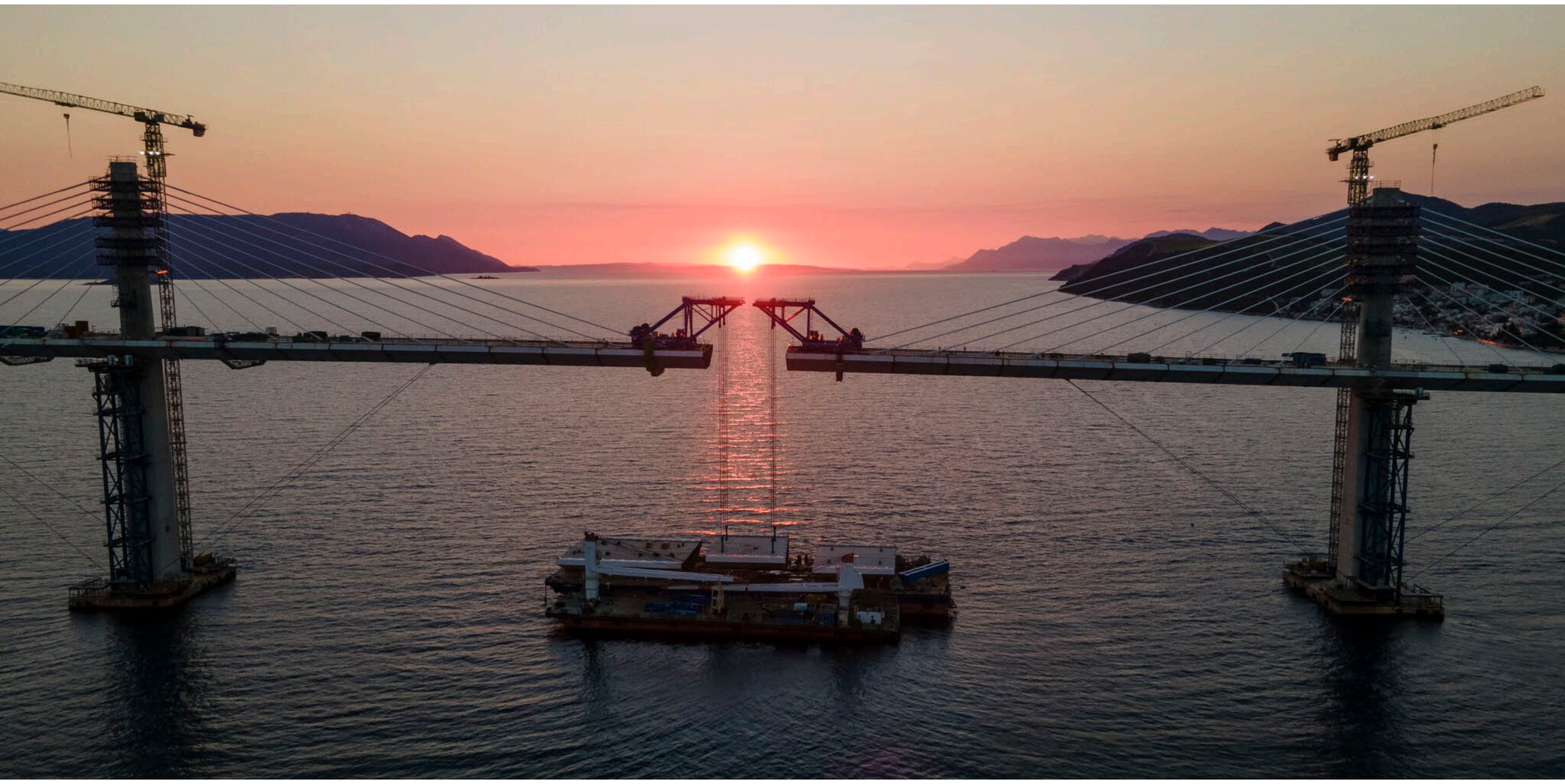

Pelješac Bridge, Croatia

Conceptual/Preliminary/Final design
Joint Venture Faculty of Civil Engineering, University of Zagreb; Ponting; Pipenbaher Consulting Engineers

Ada Bridge over Sava in Belgrade, Serbia

Winning competition design/Preliminary/ICE for final and detailed design

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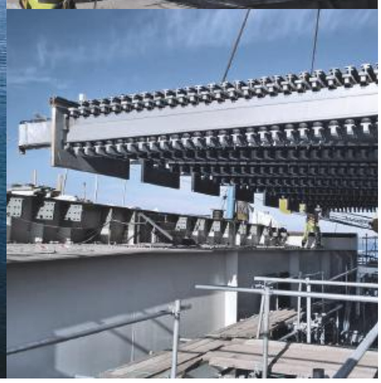

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References:

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