LOKO OWETO BRIDGES ON THE BENUE RIVER, NIGERIA

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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.

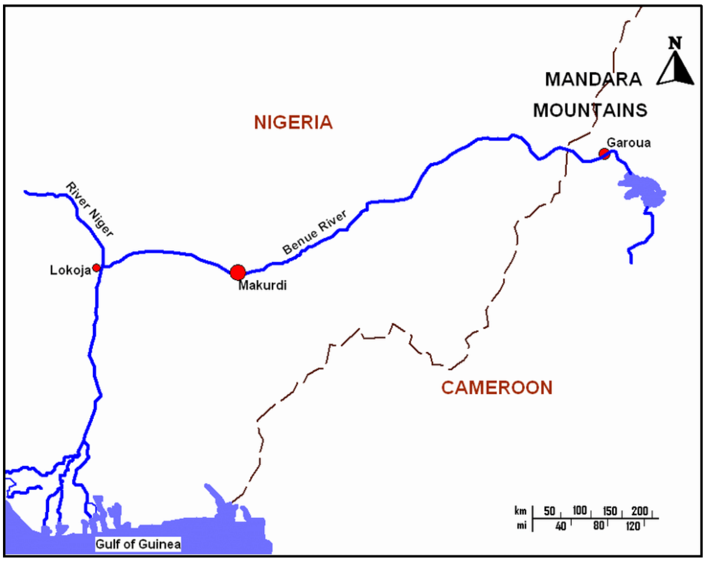

Figure 5: Benue River in Niger. CC Licence

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.

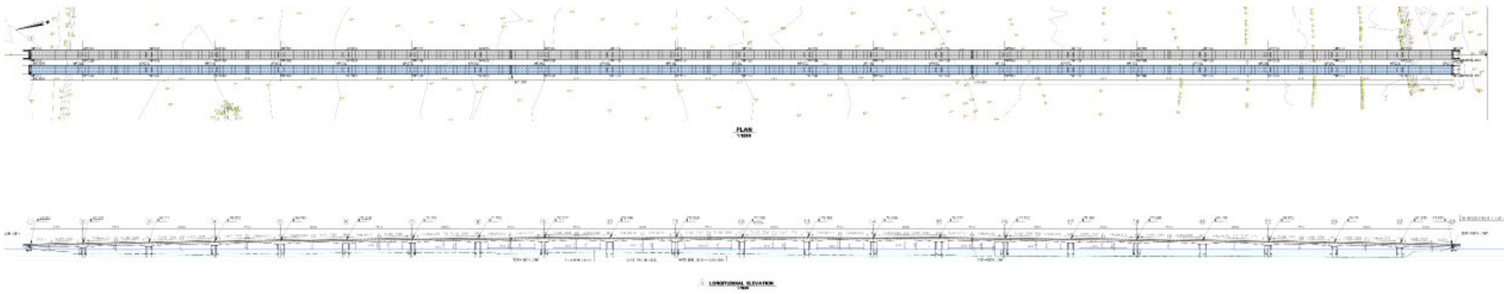

Figure 6: Bridge Plan and Elevation. Click on the image to open it in a higher resolution

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.

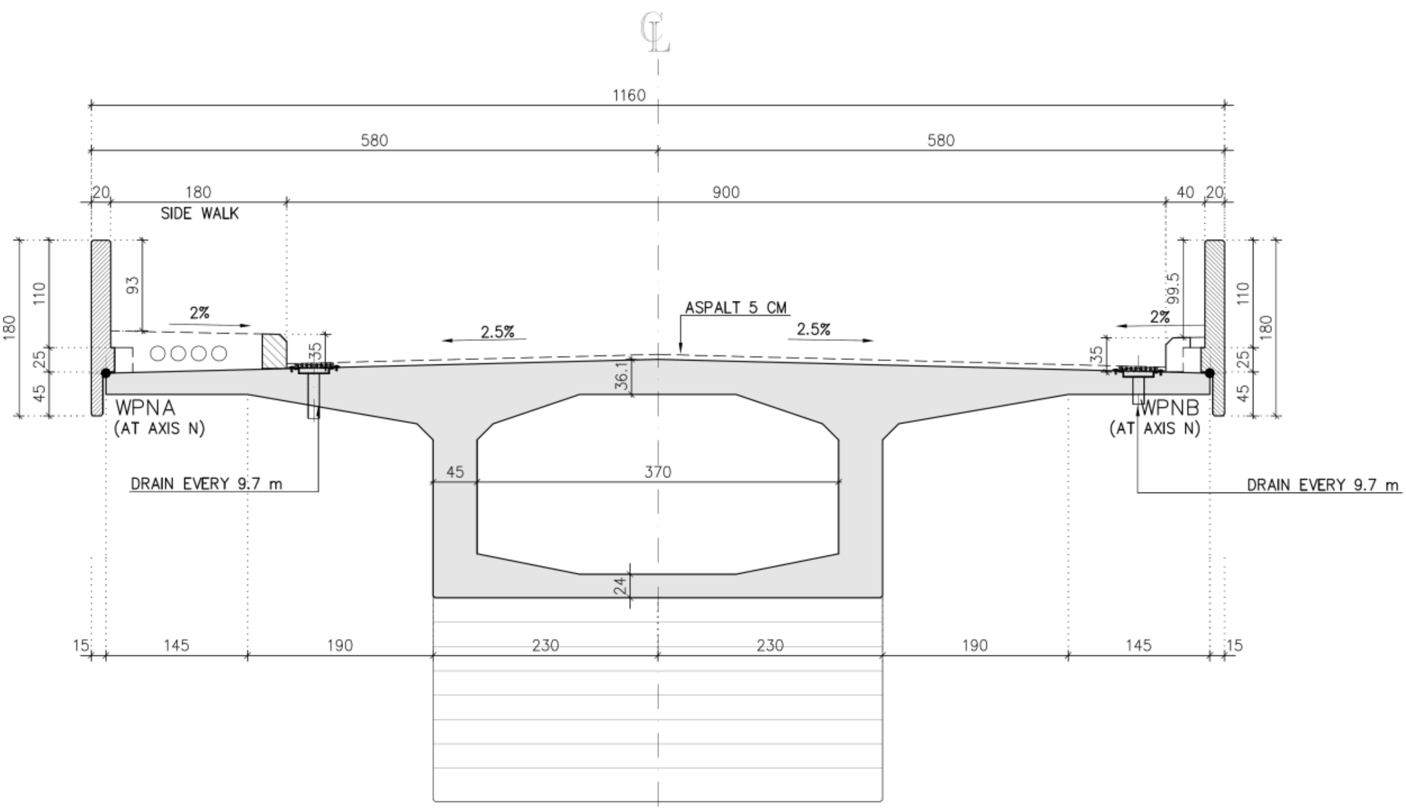

Figure 7: Bridge Cross-section - hollow box with a variable height

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

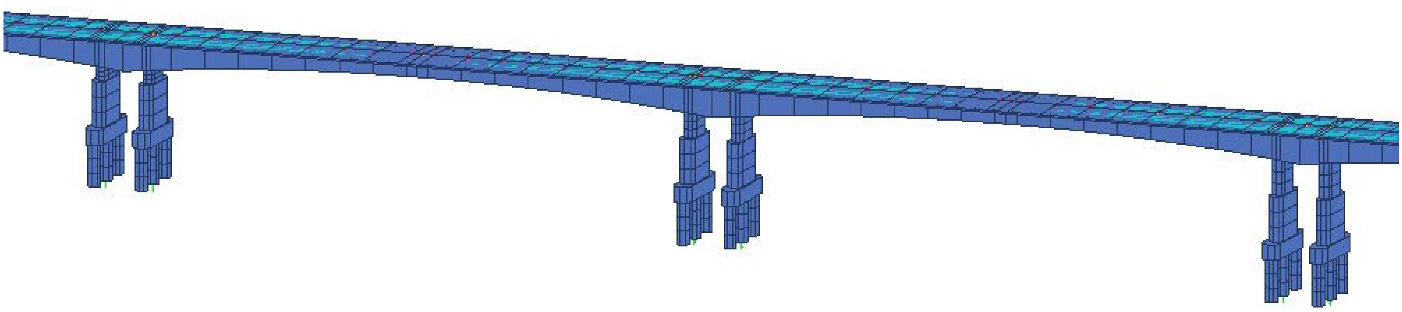

Figure 9: Construction stages and stressing were carried out using RM Bridge software

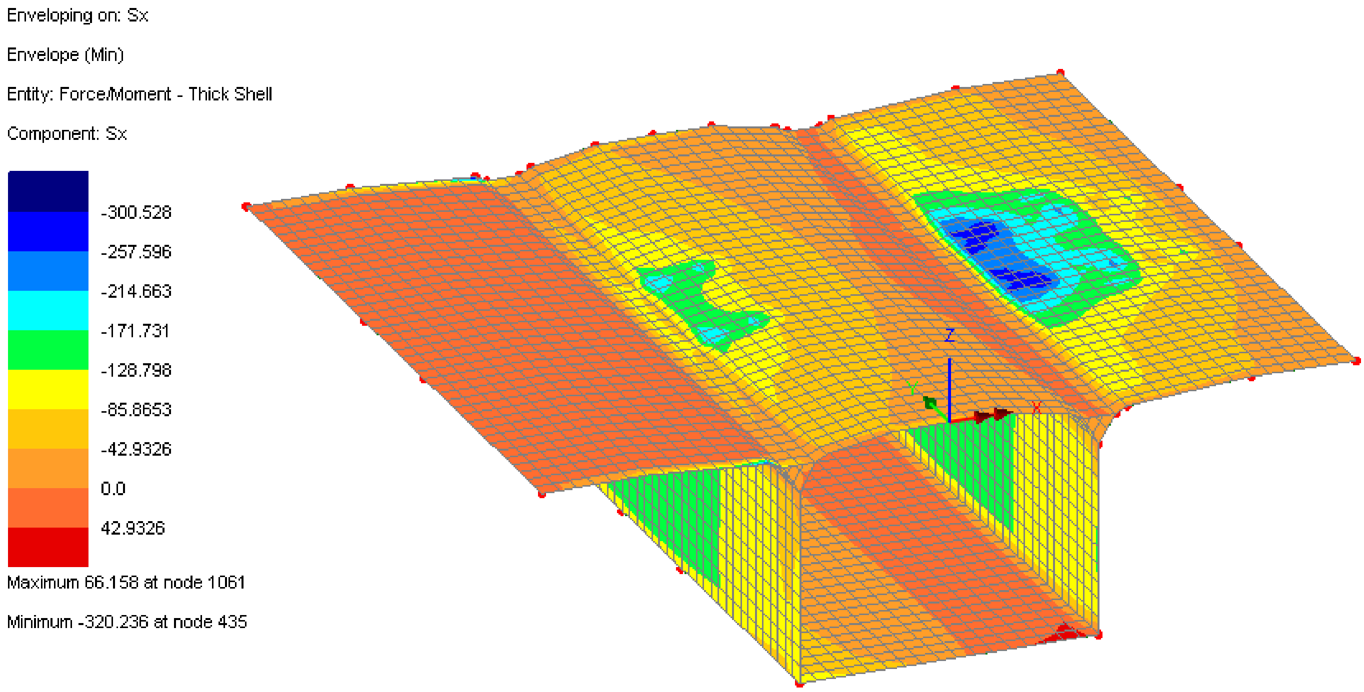

Figure 10: Transverse calculation using LUSAS

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.

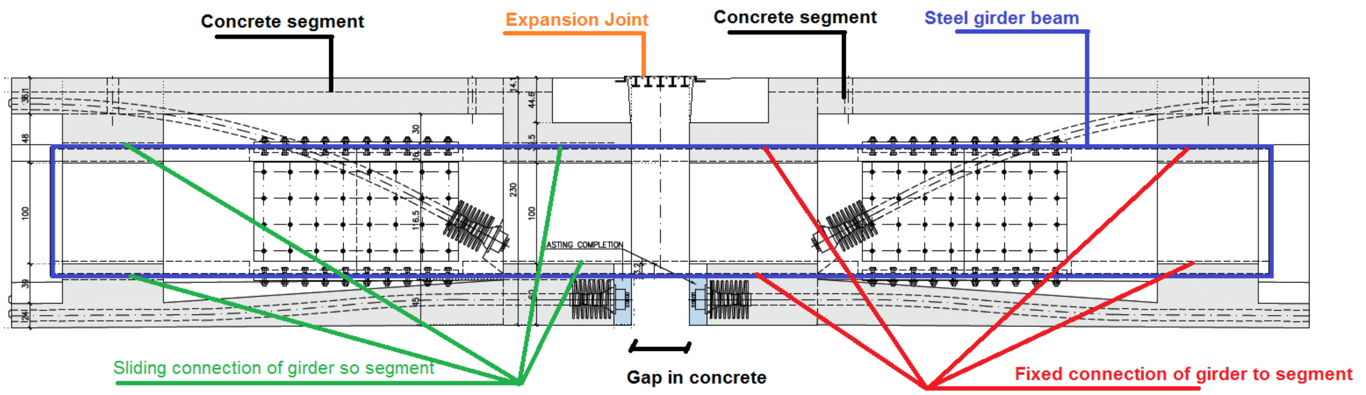

Figure 12: Mid-Span Girder - Sliding on the left, fixed on the right, gap in the middle

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.

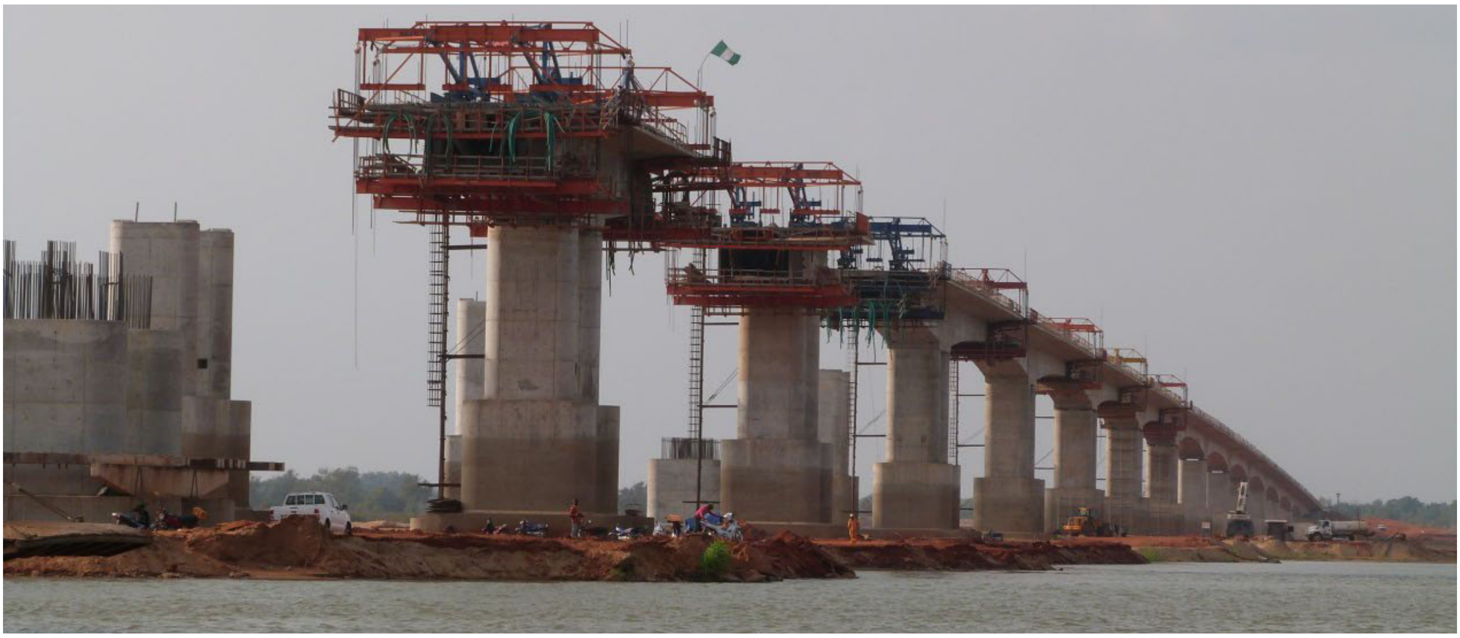

Figure 14: Work during river low level. The column shows the upper water level mark

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.