Loko Oweto Bridges on the Benue River, Nigeria

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Abstract

The Loko Oweto Bridges on the Benue River in Nigeria are designed and constructed in order to connect the north and south of the country with an upgraded road system and are currently under construction. The project includes two bridges, 1,835 meters long each, and two bridges of 220 meters. 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 meters.

Keywords: Bridges, Balanced cantilever method, Form traveller, Post tensioning, Mid-span Expansion joint, Nigeria, Benue River, Finite Element Method, RM-Bridge, Lusas.

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

1. General background

Nigeria is a federal republic located at West Africa to the coast of the Gulf of Guinea and Its area has a total of 923,768 km2 and has an estimated population of 180 million. Nigeria can be traditionally divided in two to 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 economical aspect, since the south is rich in nature resources as oil and tin, the majority of the countries industry and wealth is located at the south. The mentioned unofficial partition reflects in tension in the population related to religion, authority and economical justice.

The Nigerian government decided to invest in improving the connection between the parts of the Republic for developing the economy and population conditions. Since wide rivers are crossing Nigeria and physically divide 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 that will cross the Benue River and allow an additional connection between the north of the country and south (See figure 2). Another road connection will significantly upgrade the Nigerian economy since it allows additional access between the north and center of economic and business at the south.

2. 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, through final design and detailed design documents and construction supervision for the four bridges. To Nigerian Ministry of Works, several alternatives were introduced and after their approval, the design began. The detailed design has been controlled by the Ministry local engineers.

The project includes the following Bridges:

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

This paper presents a review of Bridge 1 East - the process of planning, construction and engagement, as designer, at the various stages in respect to a segmental Bridge constructed in the cast in site balanced cantilever method above the river and the challenges involved in the design derived from the length of the bridge.

3. About the Site

The bridge is located in a remote area far from 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 3). The villages surrounding the bridge site make their living mostly from farming and fishing. A construction site located in an isolated area is a greatly challenged in the logistical aspect mainly concerning the supply of raw materials. In order to reduce the dependence of the site, wells were drilled, an electricity station was built and a concrete plant was established.

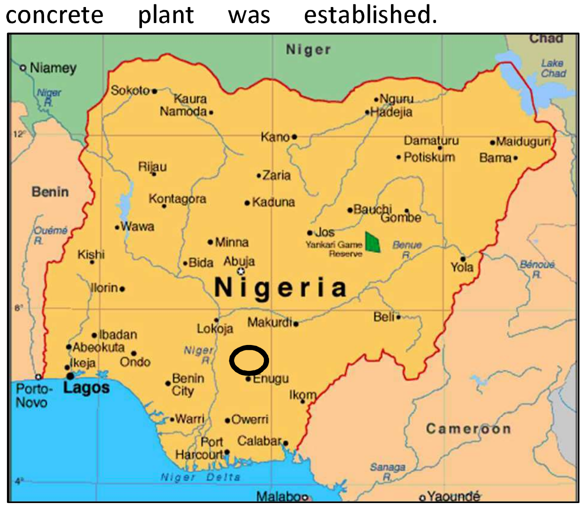

Figure 2. Project location – Benue River in Nigeria

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

The length of the river Benue is about 1,400 kilometers from Cameroon in the north to its connection with the Niger near the city of Lokoja. Benue River flows throughout the year and is a main marine transportation route. The seasons are divided to 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 meters and during the dry season is reduced to a width of a few hundred meters, and in addition, the level of the river varies between seasons eight (!!) meters in height.

The site is heavily influenced by the changes in the width of the river and the water level and it was necessary, for all work stages, to prepare the methods and equipment that will enable the execution of the works 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 was the balanced cantilever method.

Figure 3. Local village with mud houses near the bridge

The site soil is characterized by a top layer consisting mainly of sand with thin layers of clay to a depth of about 18 meters and then a thick layer of Lime stone exceeding 40 meters in depth. the bridge foundations, with respect to the layers of soil and drilling in the flowing river water, was 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 round the bridge columns and piles was carried out according to the equation of the Colorado State University (CSU) and it occurred that 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 7.0 meters and the additional global scour at the bridge location is a few tens of centimeters more. 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.

4. Bridge Description

The Loko Oweto bridges, crossing the Benue River, are 1,835 meters long each and are divided into 22 spans where there are 20 typical spans, 85 meters in length and two end spans with a length of 67.5 meters each (See figures 4,6). The slab width of each bridge is 11.6 meters and each bridge carrying two traffic lanes and a pedestrian sidewalk (See figure 5). The Bridges have a straight planimetric path, without skew and the vertical alignment of the bridge is parabolic in order to provide a vertical clearance of eight meters above the rivers high water level and 12 meters at the center of the bridge to allow boats 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 center of span and at the end spans. The slab bottom curve is parabolic and it was designed to optimize the stresses along the construction stages. The hollow box cross section hat two transverse cantilevers of 335 cm on both sides, the webs are vertical so that with the change of height, bottom flange width will remain fixed, 460 cm. The superstructure is designed using the balanced cantilever cast in site method where the Pier Segment is casted on top of the columns in a technique that allows work in the river as described further on. To the pier segment, two form travelers are installed on both sides for seven rounds of casting of seven pairs of segments, 485 cm in each. Between the two sections of neighbor axes a closure segment will be casted.

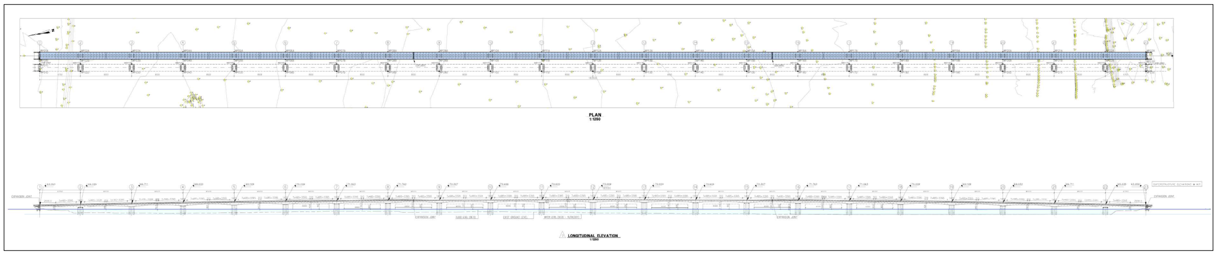

Figure 4. Bridge Plan & Elevation

In order to allow a temporary restraint between deck and columns during segment casting, before reaching continuity, the deck is vertical stressed against the columns using four cables of 100 tons each. At this stage, temporarily concrete blocks are casted between bearings in order to reduce the load on the bearings. This enables the capacity at an Un-Balanced segment situation in case of an error.

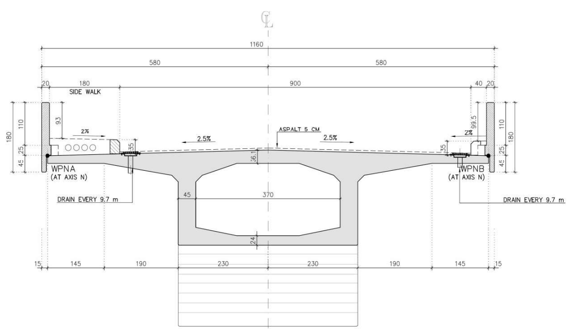

Figure 5. Bridge Cross-section - hollow box with variable height

The Bridge consists of 21 mid piers, each one contains 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 center. The columns include a bottom section with a height of 5.7 meters 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 casted, 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 meters high. On top of the columns, bearing are installed or the pier segment is casted, depending on the static longitudinal scheme.

Figure 6. River and Bridge. The typical span length is 85 meters

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 length of 620, 595, 620 meters by installing expansion joints at the center 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 casted in steel casing pipes allowing drilling thru the river. Each mid pier column includes three piles, 180 cm in diameter and 32 meters in length. Abutments have four piles with a diameter of 180 cm and a length of 40 meters.

The global modeling of the bridge was carried out using Bentley RM Bridge software and its aim was to conduct 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.

Calculation of construction stages and stressing using the RM software which includes modules designated for segmental bridges including camber design taking into account the additional weight of each new segment as wet concrete ranging from 120 tons to 80 tons, the form traveler weight of 60 tons and time schedule which is required to cast the sections since with extra segment at each casting stage, the cantilever that is bending down, will reach, after casting the final section, its final position (See figure 47).

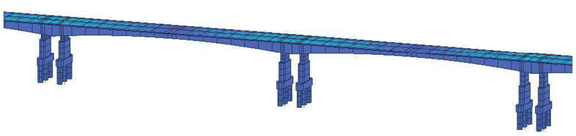

Figure 7. Construction stages and stressing were carried out using RM Bridge software

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 stressing data. Measurement is carried out before casting to verifying the correct level and after casting and stressing an additional measurement is performed whereby the designer decides whether level corrections are necessary. In fact, during the construction measurement data are documented in our office and continuously monitor the bridge geometry.

Calculation of 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 height of the deck (See figure 8). Transverse direction and the local behavior of the cross section are designed as reinforced concrete. Values of reinforcing steel required in this calculation are summed together with reinforcing values which 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.

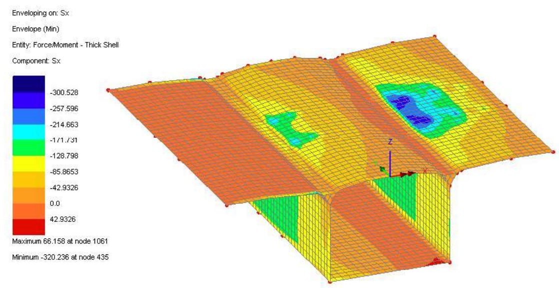

Figure 8. Transverse calculation using LUSAS

5. 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 different bridge axes via 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 of 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 casted in the river water using steel casing pipes of 16 meters in length. In order 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 casted without the need for stable soil or forms. The internal element height is 200 cm and it has a total length of 10.65 meters composed of four parts interconnected.

For 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 at all seasons. These girders use to support the column forms at early stage supported by the pile cap shoulders (See figure 9).

Figure 9. Temporary support girders for casting above water level

6. 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 the bridge division, the deformations at abutments would reach almost one meter and horizontal load, which was acting on columns would require extra piles. At a balanced cantilever bridge locating an expansion joint above the columns is not recommended since the method requires continuity over the column during construction. Hence it was decided to place the joint at the middle of the spans between axes 8-9 and 15-16 so that concrete deck will have a gap of 57 cm. The Expansion Joint at mid-span, in order not to leave two cantilevers from both sides, 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 two steel girders installed inside the deck which are fixed at one edge of the deck and at the other end are installed inside steel sleeves that allow the girder to slide, a similar situation to a piston. 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 meters long, 130 cm high and 70 cm wide. After installation they are fully casted with concrete to improve their capacity as a composite cross-section (See figures 10,11). The final stage includes installing of a girder expansion joint which allows obtaining the deformations, several centimetres daily and over the life of the bridge will be about 30 cm.

Figure 10. Insertion of steel girder into the bridge deck

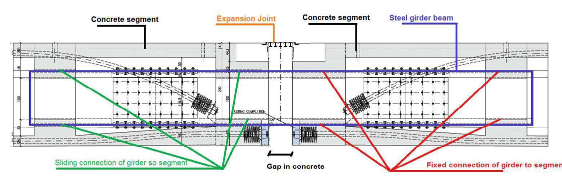

Figure 11. Mid-Span Girder - Sliding on the left, Fixed at the right, Gap at the Middle

7. Design team tasks and responsibility

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 elements dimensions and global calculations. At this point optimization of the static scheme was performed and construction solutions were discussed and agreed with the client. A calculation report, BOQ and a set of drawings was submitted.

The detailed design included a full calculation of all elements for the 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. In addition, the geometry control calculation included the producing of "Christmas trees" and erection manual document for 21 axes (322 segments).

Every engineering project and certainly a complex project of this nature require 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, survey and images send by email prior to casting. Of course, assistance to the site team is provided on a daily basis by telephone and in a variety of media available with most of the work is done in front of the site engineer.

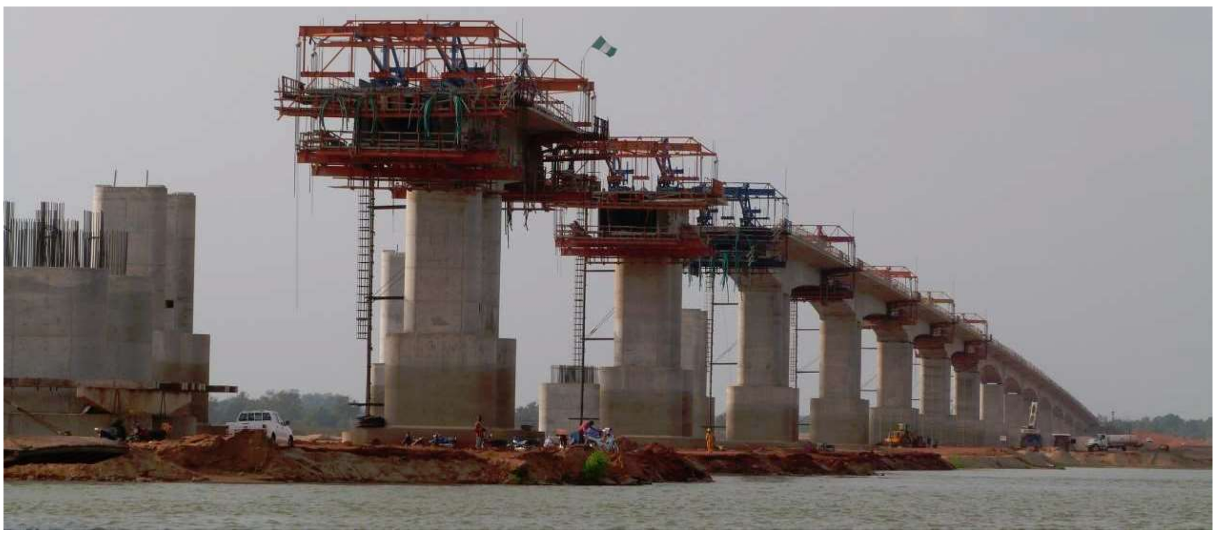

Figure 12. Work during river Low level. The column shows the upper water level mark

8. Summary

Loko Oweto Bridges are currently under construction and soon work will begin on the western bridge Superstructure. All the piles in the project are casted, segments are casted along nearly 1,500 meters and at a large part, parapets are installed.

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 all the design team in parallel while coordinating all planning products and their control. Bridges with a length of almost two kilometers above the river is a tremendous challenge for a design team but a very satisfying one.

9. Project Functionaries

- Owner: Ministry of Works, Nigeria
- Contractor: RCC - Reynolds Construction Company, Nigeria
- Soil and foundation consulting: Fugro Nigeria, Israel Keller
- Bridge Design & Planning: Kedmor Engineers, Israel