Construction of the concrete legs

Deck elements being raised onto the span

MAKING MOZAMBIQUE

Africa's longest suspension bridge is set to open to traffic by the end of the year. Jörn Seitz and Cao Changwei look at some of the key features of Mozambique's new landmark

Africa's longest suspension bridge – the Maputo-Katembe Bridge in Mozambique – is due to be opened by the end of this year. The bridge has a main span of 680m and with the north and south approach bridges, a combined length of more than 3.1km extending both sides of Maputo Bay *(Bd&e issue no 85).*

The crossing is considered to be the most important infrastructure project built in the country since Mozambique achieved independence in 1975. It will carry the national highway EN1 across the bay and beyond to the city of Ponta Do Ouro in the extreme south of Mozambique, some 130km away. Construction of the bridge and approximately 184km of link roads, which started in 2014, has cost an estimated US$725 million.

The design and construction of the bridge is being carried out by China Road & Bridge Corporation and is based on the *FIDIC Silverbook Engineering, Procurement & Construction* contract. German consultant Gauff Engineering was appointed to oversee quality control, to carry out the complete site supervision and to verify the design against Eurocodes. This was considered very important by the owner Empresa de Desenvolvimento Maputo Sul, a development corporation set up by the Mozambique government to oversee the project and future management of the infrastructure.

The Maputo-Katembe Bridge is comprised of three different bridge types. A reinforced concrete, post-tensioned T-beam is used for the south approach structure, a balanced-cantilever reinforced concrete box girder for the north approach bridge, and a suspended steel box girder main span across Maputo Bay which is 60m above sea level.

The design speed for this highway project was defined as 80km/h and different construction methods had to be chosen due to localised constraints. On the north, the approach bridge is a balanced-cantilever reinforced concrete box girder construction with a length of 853m with another connecting 240m-long prefabricated post-tensioned T-beam section to the abutment, rising up towards the suspension bridge with a gentle S-curve in plan.

The southern approach bridge was built using prefabricated post-tensioned T-beams of 30m-long and 45m-long spans to create a total length of 1.2km of the approach bridge from ground level to the southern tower.

The approach bridges connect on each side to the single-span double-hinged suspension bridge made up of 57 steel box elements. The steel box girders were manufactured in China and were delivered to the site in September 2017, being immediately erected and their provisional installation on the hangers completed at the end of October 2017. The main cables are 1.3km long and have a diameter of 509mm - each is formed of 91 galvanised strands. The steel box girders were connected to them by hangers, which are parallel wire tendons with pin-connections. The upper connection to the cable clamp and the lower to the steel girder are achieved with Y-shaped lugs.

A double sheath of 8mm-thick PE is used to wrap the tendons for protection and the hangers are at a standard interval of 12m. The interval from the tower centreline to the nearest hanging point is 16m. Each hanger consists of 61 lengths of parallel steel wires – 73 pieces for the hangers at each extreme of the bridge. These are 5mm-diameter galvanised high-strength steel wires of grade 1,670MPa.

Each of the 57 steel box girders is 12m long, 3m high and 25.6m wide including the wind fairings. All the box girders were shipped across the Indian Ocean from China to Mozambique, and the ship docked at the international harbour of Maputo, very close to the site.

The bridge has a combined length of 3.1km including approach bridges

A special lifting gantry was installed to erect the deck elements, which weigh up to 137t. To keep the main cable in uniform shape, erection started from the centre of the main span and continued symmetrically in both directions towards the towers. As a result of the continuously increasing weight on the cable, the angle between the steel box girders changed until the last element was in place. Therefore the elements were temporarily bolted together as they were erected, and the permanent welding work did not start until the last box girder had been raised onto the cables. In addition to the main circumference weld, the u-ribs on the bottom were welded and the u-ribs on top were connected using prestressed bolts.

During installation of the stiffening beam, the load in the main cables increased and resulted in bending in both of the towers; to bring them back to a vertical position, a horizontal movement of up to 1.6m of the two main saddles was necessary.

The main cables are guided over splay-saddle buttresses which are anchored into two massive anchor blocks, one on each side of the bay. These structures had to be built to a substantial size due to the poor geological conditions and high water table at this location. Each has a diameter of 50m and the shaft depth during excavation was up to 37.5m. making them among the largest anchor blocks in the world. They contain chambers of sand and concrete for mass, with the south anchor block being particularly large, weighing an impressive 170,000t in its final form.

The cables extend from anchor block to anchor block and are placed over the top of the two portal-frame towers which are positioned on each side of the bay. On the Katembe side on the south bank, the tower has a final height above ground of 137m, and the Maputo tower is 138m high. One interesting aspect of the tower design is the fact that each leg is inclined at 2° towards the centre line of the bridge for added stability; in addition to this, each tower is founded on 24 piles with a diameter of 2.2m which extend to depths of 110m on the south side and 95m on the north. Again this is due to the poor geological conditions, which dictated the need to design substantial foundations. In total 331 piles were constructed for the main bridge and its approaches, with an average depth of 50m.

Keeping the goal of the highest quality of the concrete in mind, compressive strength concrete cubes were manufactured for testing at 7, 28, 90 and even 365 days.

View of the bridge and its substantial approach viaducts

Altogether more than 51,600 cubes were tested for the nearly 350,000m^3 of concrete that was used during the construction period.

Mandated durability testing was done continuously, according to South Africa National Standard specifications. Another very specific aspect of the concrete on this project was the substitution of up to 40% of cement by fly ash; this not only offers immediate cost savings but also long term benefits.

The subsitution was proposed by the contract due to the fact that the environment at the site is considered severe, requiring a very durable concrete that could only be obtained with such substitutions. Durability indices are now standard requirements for concrete, as well as compressive strength.

Despite the fact that the fly ash had to be imported, this substitution still resulted in a cost saving of 7% and an estimated reduction in carbon emissions of 30%. Such substitutions have no drawbacks, although they do depend on the presence of coal-fired power stations for supply of the material.

The fly ash was supplied to the site from South Africa and has resulted in concrete with an extremely high durability, a fact which was confirmed by the University of Cape Town's Concrete Materials & Structural Integrity Unit which tested samples cored from the bottom slab of the north anchorage. The high quality concrete received a commendation at the Fulton Awards 2017 for its sustainability.

Mastic asphalt was used for the first time in Africa for a suspension bridge with an orthotropic steel deck. The bridge carriageway is 18.6m wide with a pavement area of 12,648m^2 and the deck carries a dual carriageway with a total of four lanes, two in each direction. The steel deck pavement consists of a sand-blasted corrosion protection treatment, waterproof bonding layer, 35mm-thick Gussasphalt GA-10 and 38mm-thick modified asphalt SMA-10. The requirements of the surface after the sand-blasting was specified in both Chinese and European codes in terms of cleanness and roughness. The asphalt mixing plant was 120km away, so the laying of the Gussaphalt and SMA-10 asphalt had to be carried out with specialist equipment from Europe to guarantee the highest quality and accuracy of the layers and their compaction.

It took 14 days to complete the process of sandblasting, applying the anti-rust primer, waterproofing layer and high strength adhesive. A further 20 days was necessary to apply the Gussasphalt, followed by six days for the SMA layer.

The cable anchors are substantial structures in their own right

A specialist subcontractor from China was commissioned to do the Gussasphalt paving, and the SMA layer was done by the Chinese in-house team; all pavement works were completed in May 2018. Gussaphalt was chosen because it has a longer lifespan than regular asphalt; case-studies from Europe demonstrate that it can last up to 20 years with a minimum of maintenance work.

A dehumidification system was installed on the main cable, anchorage chambers, saddle rooms and steel box girder deck. This will inject hot air into the closed section of the main cables and also separately into the steel box girders to reduce the humidity and prevent corrosion – the system is designed to run 24 hours a day, seven days a week throughout the year. Humid air is extracted from the structure at a number of exhaust sleeves, and the circulation of the air is controlled via a data collection system, with measuring devices installed in a separate monitoring room. Its operation will be monitored for six months and then approved once it reaches a constant level of humidity. The wrapping of the main cable is a three-ply laminated construction with a thickness of 3.6mm.

The long-term dehumidification and online monitoring function includes two sets of main cable dehumidification systems, four sets of saddle room dehumidification systems, four sets of anchorage room dehumidification systems, four sets of steel box girder dehumidification systems. These are intended to create an internal relative humidity of the steel box girder, anchorage room, saddle room of less than 45%; the trigger level for the system to start running is 60% humidity.

Although the key technology of the main cable dehumidification system has been proven and in use for the last decade, this is the first time that a bridge dehumidification system has been used in Africa.

When the bridge reached structural completion, a bridge loading test was required by the client, due to the irregular geometry and form of the structure, and this was carried out at the beginning of June 2018.

For the main bridge the elements being controlled were the main cable deflection and force at the anchorage saddle, the force in the hangers, the deflection, displacement and strain in the stiffening beam, and the displacement and strain in the bridge towers. Only strains and deflections were controlled for the cast in situ box girder.

Different test scheduling plans were created for each bridge. For the suspension bridge, a total of 11 conditions were tested, with the number of trucks varying from 12 to 56 on four different test sections across the span. Because of the symmetry of bridge, static load was only tested on the southern part of the main bridge. For the north approach bridge, seven conditions were tested, with the number of trucks varying from 14 up to 20.

Dynamic testing was also performed by moving the trucks at different speeds, and braking in between the movements. The maximum elastic deformation under the static loading was approximately 1.14m and the elastic deformation of the towers was measured as 108.5mm towards the middle of the bridge – these values were in the predicted range.

Handover of the new bridge to the Mozambique Government is currently scheduled to take place before the end of this year, forever changing the skyline of Maputto

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