A Modern Engineering Solution for the Decongestion of Maputo

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Abstract

Urbanization is one of the biggest challenges for Mozambique's capital Maputo. An ambitious bridge project that connects Maputo with the underdeveloped opposite shore of the Maputo Bay will release the town from the effects of uncontrolled urbanization. The Maputo-Katembe Bridge will not only be Mozambique's new national landmark, but also Africa's longest suspension bridge and it will create a new connection to the neighbouring countries of South Africa and Swaziland.

Keywords: Urbanisation, suspension bridge, sustainability, fly ash (FA), masterplan

1 Introduction

Since Mozambique has been host to one of the biggest gas discoveries in recent years, increasing capital inflows did not only result in attracting international investors but also large parts of Mozambique's rural population. Therefore urbanization is one of the biggest challenges for Mozambique's capital Maputo in the South of the country. An ambitious bridge project that connects Maputo with the underdeveloped opposite shore of the Maputo Bay will release the town from the effects of uncontrolled urbanization. The Maputo-Katembe Bridge will not only be Mozambique's new national landmark, but also Africa's longest suspension bridge.

While the owner of the project is a Mozambican state company, the construction contract was awarded to *China Roads and Bridge Corporation* (CRBC). *GAUFF Engineering*, a German consultancy company, is responsible for the Site Supervision and Quality Control (Oirere 2017). The project's unique technical design is a result of a long process of feasibility studies and also a large number of limiting factors that are due to the fact that the new construction and its infrastructure has to be integrated into a historically grown city. The unique topography of a city located at the sea, the existing railway and the harbour in the area of the crossing, made it even more difficult to find an acceptable solution that satisfies all stakeholders. For the bridge itself, a suspension bridge design was selected over a cable stayed bridge after numerous studies. The design – especially the height - of a cable stayed bridge's main pylons would have interfered with the flight line of the air traffic of Maputo's international airport.

Figure 1: Maputo Centre – South to North

The north approach bridge is unique in the way it is built (a curved and inclined cantilever bridge) whereas the south approach bridge is built in a straight line towards the main bridge.

A special concrete mix design was developed to compensate the high carbon footprint of a suspension bridge structure and its relevant infrastructure buildings. Up to 40% of the cement content was substituted by FA, a by-product of power generation, which also improves the strength and the durability characteristics of the concrete. Therefore this special mix design also addresses the problem of reduced concrete durability in high saline environments.

Both, the suspension bridge and the free cantilever bridge do not only offer the best technical solution under complex circumstances, they also pay an aesthetic tribute to a city, which was once called the Pearl of the Indian Ocean and is well on its way to reclaiming this title.

2 General remarks

Mozambique is one of the fastest growing economies in Africa. A flush of foreign money, mainly from the extracting industries, leads to a fast urban growth in Mozambique's capital. Therefore one of Maputo's main challenges is the reduction of the negative effects of uncontrolled urbanization. The Maputo-Katembe Bridge Project that connects Maputo with the rural Municipality of Katembe on the other side of the Maputo Bay will create an access to new building land and release pressure from the overcrowded city.

The Maputo-Katembe Bridge and its approach bridges consist of three different types of bridges. The main bridge and new national landmark is designed as a conventional suspension bridge with a lifetime of more than 100 years. The planners developed a unique technical design which is an adaption to a large number of limiting factors such as the existing infrastructure of the historically grown city. The north approach bridge partly consists of a highly sophisticated curved cantilever bridge whereas the south approach bridge is a pre-stressed concrete T- beam bridge.

Furthermore a special concrete mix was developed from local cement and FA from South Africa. This special mix design keeps the carbon footprint of the project relatively low and addresses the problem of reduced concrete durability in high saline environments. A solution for controlled urbanization

The populations of Africa's bigger cities are expected to triple in the next 50 years. As a result more than 60 percent of African's urban population live in areas with some combination of overcrowding, low-quality housing, inadequate access to clean water and sanitation (UN 2001). This is not only a short term problem for the population but also an obstacle for potential investors and therefore a long term problem for the economic development of the country. The physical and economic dysfunction constrains the mobility of the labour market and prevents firms from reaping scale. Potential investors stay away fearing the lack of return on their investment (Lall et al 2017).

Maputo's chronic lack of space and the rising housing prices are the main drivers for the cities' uncontrolled expansion. A significant part of Maputo's population commute daily with an unreliable transportation system from the outskirts into the city. As a result the main access roads suffer frequent traffic collapses and the mobility is temporarily constrained.

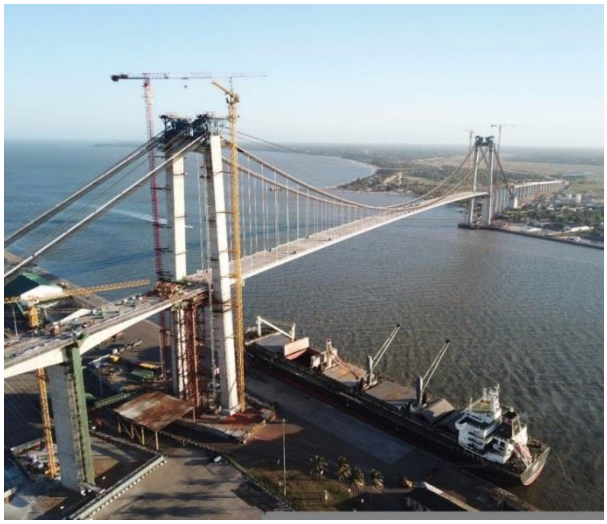

Figure 2: Maputo-Katembe Bridge out of the city to the south

The high fragmentation of the city's outskirts and the resulting variation of population density create a number of problems for sustainable

urbanization. Both the provision of public transport and the provision of basic infrastructure become economically unfeasible for the clustered outskirts. The transport among homes, job sites, and businesses is mostly privately organized and characterized by lengthy travel times and unsafe travel conditions.

Despite the availability of building land on the other side of Maputo Bay, where the rural municipality of Katembe is located, the city is constantly expanding further north-westwards towards the country side and along the coast. A narrow water channel of approx. 600 m works as a physical barrier and prevents an equal expansion southwards.

The idea of developing Katembe in order to prevent unsustainable urban development sets the cornerstones of the Maputo-Katembe Bridge Project.

The Maputo-Katembe Bridge and its infrastructure is part of the Katembe development master plan and will extend Maputo's area by approximately 10.000 hectares. The project promises the creation of sustainable urban development by improving the conditions of accessibility and the provision of a good functional infrastructure.

Figure 3: Katembe area and its future proposal for development

3 Building a new infrastructure in a historically grown city

The project's unique technical design is a result of a large number of limiting factors that are caused by the fact that a mega construction project has to be integrated into a historically grown city. The north approach bridge consists of a free cantilever bridge with spans of 119 m. Due to the large spans of the north approach bridge, a minimum number of piers and pile foundations are required. Thus the industrial area with different industries and the railway to the central station, which are located right under the new construction, are exposed to a minimum construction impact. No existing buildings had to be demolished or closed during the construction of the free cantilever bridge. Business owners and manufacturers could continue their activities as usual.

Figure 4: North pylon and free cantilever bridge

The planning of the south approach bridge on Katembe side was not affected by spacial constraints, due to the small amount of existing infrastructure, and could be designed in a generous way. Therefore it was executed as a precast T-Beam Bridge and the length of the prestressed T-beams varied from 30 m to 45 m.

Also the design of the main suspension bridge, which is the actual new landmark, was affected by a number of limiting factors. In order to keep the main bridge as short as possible, it connects two banks at the narrowest stretch of the channel and crosses the most important harbour of Mozambique. As a consequence the bridge's two main pylons are placed in the approach path of Maputo's international airport. A previously planned cable stayed bridge design was therefore discarded since the pylons would have reached the maximum permissible height and therefore the flight line of the airport's air traffic. A multi span solution had been discarded too, because that would have resulted in one of the Pylons being constructed in the channel. The risk of collusions with the deep sea vessels would have been too high.

The only solution to keep the bridge inside these parameters was a suspension bridge design. Therefore Africa's biggest suspension bridge is now being built in Maputo. Suspension bridges are one of the oldest types of bridges made by man. 30% of the 100 longest suspension bridges worldwide are built by Chinese contractors. Since most of them are built in China, overseas projects by Chinese contractors in counties like Mozambique or Indonesia are an exception.

China`s building industry is leading in the construction of these conventional bridges and that was one of the reasons for their appointment (Burhenne 2016).

4 Katembe District Urbanisation Project

Despite its proximity to the capital city of Maputo, the district of Katembe has remained a largely undeveloped area. This is about to change, when the new bridge construction connects Maputo's North bank with Katembe's South bank and its untapped potential. Spotting this tremendous opportunity, private companies in partnership with the government developed a master plan for the sustainable urbanisation of the district of Katembe.

The Katembe Urbanisation Masterplan consists in the creation of 13 separate units divided into residential, commercial, industrial, logistical, touristic and green areas. The new urbanized area of over 10,000 ha will create a modern, sustainable and comprehensive city structure and relieve Maputo from the symptoms of overpopulation and uncontrolled urban growth.

Figure 5: View from the suspension bridge to the harbour and into the city of Maputo

The city will be built in phases over a period of 30 years and will be home to 400,000 inhabitants. Priority will be given to the construction of two main residential areas followed by touristic and industrial areas, which will be developed simultaneously. The development of the remaining areas will advance in line with the population and urban growth in the region.

5 Achievement of a low carbon footprint

Achieving a low environmental impact was particularly important for a landmark project of such importance for Mozambique. Therefore a special concrete mix design was developed to keep the carbon footprint low. Up to 40% of the cement was replaced by FA.

The project's cement of CEM II 42.5 A-LN is a Portland Limestone Cement comprising of 80-94 % clinker and 6-20% limestone. It has the ability to reach between 42.5 MPa and 62.5 MPa of concrete strength. While the cement is supplied from *Cimentos de Mocambique*, the FA comes from South Africa and is a by-product of energy production (Swanepoel, Seitz and Bai, 2016).

Other advantages of the addition of FA in a range of 25-40% of total cementitious materials lies in the improvement of workability, the reduced water requirement and the slight retards in settling time.

Producing sustainable concrete was particularly important for this project since the Chinese contractor is aiming to balance the social, environmental and economic impacts of its activities. Following the "Triple Bottom Line" under reference to the concept mentioned in the "The Brundtland Report", CRBC as main contractor was requested to produce a sustainable structure that lasts more than 100 years. The improvement of the CO_2 footprint by

reducing the CO_{2e} emissions is part of their mix design philosophy. The use of FA as an extender intensely lowered the cementitious CO_{2e} emissions of the selected mix design, called PHB C40-4 concrete, from an estimated 352.5 kg CO_{2e}/ton to 229.5 kg CO_{2e}/ton, a total reduction of 35%. Therefor the main advantage remains a massive decrease in the CO_{2e} emissions. The development of this exceptional concrete leads to a commendation for the FULTON Award in 2017 in South Africa. This honour is linked to new developments in the construction industry in the Sub-Saharan area of Africa.

6 Link Roads and infrastructure

In addition to the construction of the bridge, the project also includes the construction of two main roads. The first road, with a length of 120 km, will link Katembe to Ponta do Ouro, a popular holiday destination near the South African border. The second road, measuring 65 km, will link Bela Vista, located halfway between Katembe and Ponta do Ouro, and Boane in the West of the country. Five existing bridges, crossing the rivers Tembe, Changane, Mahubo, Boane and Umbeluzi, will be rehabilitated as part of the project.

Figure 6: Rural Katembe – view from the Pylon (June 2017)

This new road infrastructure will link the North to the South and the East to the West of the country and create a connection with Swaziland and South Africa. It will play a key role in the planned urbanisation of the Katembe district and give a boost to the national and international trade.

The development of new areas for the tourism industry such as the Katembe special reserve and the Ponta do Ouro area creates employment and contributes to the socio economic growth of the country.

7 Conclusion

The construction of the Maputo-Katembe Suspension Bridge is in many ways unique of its kind. It will not only be Mozambique's new national landmark, but also Africa's longest suspension bridge. The new connection from Maputo to the underdeveloped Katembe district will release the effects of uncontrolled urbanization. At the same time a reliable over land connection will be created between Mozambique's capital Maputo and the neighbouring countries of South Africa and Swaziland. This connection means a significant boost for Mozambique's economy and will create further development opportunities.

Another evidence of the project's sustainable approach is the use of innovative construction materials. A special mix design, which is based on local and South African materials, was developed for the concreting of the structural elements. It guarantees high workability capacity, strength and exceptional durability. The replacement of cement by FA produced cost savings and a significant CO_{2e} emission reduction. As a result quality assurance is of paramount importance and forms a major part of the Quality Management Plan for this special project.

The key success factor of the project is integration.

The integration of a new construction into a historically built city, the integration of new components into conventional building materials and the integration of experience of three different cultures into one megaproject, forms the foundation of a modern engineering solution for the decongestion of Maputo.

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