Challenging construction of two huge shafts by diaphragm walls – new dimensions for Africa

Contestation de la construction de deux énormes puits par la paroi moulée - nouvelles dimensions pour l'Afrique

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ABSTRACT: The main cables of the new suspension bridge under construction in Maputo (MZ) are anchored inside a shaft built by diaphragm walls of 1.20 m thickness. With an outer diameter of 50 m and an excavation depth of 17.50 m and 37.50 m, these shafts are among the largest being constructed in the world in the last years. The structural design follows Chinese Standard, South African Standard as well as Eurocode design methods that is used for verification of the original design. The existing geology is characteristic for this coastal region with mainly medium-sized sands, soft mud stone underlying by sandstone. Soil improvement in the upper layers by mixed-in-place piles and underneath the tip of the panels by jet grouting have been required. The concrete with 40% of fly ash and a specially designed superplastizer retarder for a 16-hour retarding has been carefully selected and tested. One major part of the work onsite is the quality control and verification. For the diaphragm walls testing methods have been among others ultrasonic testing in the open trench, CSL testing after concreting and visual inspection of the wall after excavation. The excavation inside the two shafts gave a feedback of the records taken before.

RÉSUMÉ: Les câbles principaux du nouveau pont suspendu en construction à Maputo (MZ) sont ancrés à l'intérieur d'un arbre construit par des paroi moulée de 1,20 m d'épaisseur. Avec un diamètre extérieur de 50 m et une profondeur d'excavation de 17,50 m et 37,50 m, ces arbres sont parmi les plus grands construits dans le monde dans les dernières années. La conception structurelle suit la norme chinoise, sud-africaine ainsi que les méthodes de conception Eurocode qui est utilisé pour la vérification de la conception originale. La géologie actuelle est caractéristique de cette région côtière avec principalement des sables de taille moyenne, de la pierre de boue souple sous-jacente au grès. L'amélioration du sol dans les couches supérieures par des pieux mélangés sur place et en dessous de la pointe des panneaux par jet grouting ont été nécessaires. Le béton avec 40% de cendres volantes et un retardateur de superplastizer spécialement conçu pour un retard de 16 heures a été soigneusement sélectionné et testé. Une partie importante du travail sur place est le contrôle de la qualité et la vérification. Pour la paroi moulée, les méthodes d'essai ont été parmi d'autres essais à ultrasons dans la tranchée ouverte, essais CSL après le bétonnage et l'inspection visuelle du mur après l'excavation. L'excavation à l'intérieur des deux arbres a donné une rétroaction des enregistrements précédents.
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KEYWORDS: diaphragm walls, shaft, durable underwater concrete, CSL testing, quality assurance of foundation works.

1 INTRODUCTION

Among the 100 longest suspension bridges worldwide are more than 30% built by Chinese contractors mainly in their home country but also abroad like in Indonesia or Mozambique. China`s construction companies are leading in building these conventional suspension bridges. In Maputo, the capital of Mozambique, the new landmark will close an important infrastructure gap to the south and further to South Africa (Burhenne 2016).

The main bridge will be finished after 39 months at the end of 2017 with an open span of 680 m. The Government of Mozambique as Owner is represented by the Ministry of Public Works, Housing and Water Resources. They have awarded Empresa de Desenvolvimento de Maputo Sul (EDMS) as "The Employer". China Road and Bridge Corporation (CRBC) is the Main Contractor awarded through an EPC Contract of FIDIC. CRBC is a leading worldwide operating contractor and is present in more than 50 countries. GAUFF Engineering from Germany is the responsible consultant with an individual contract for verification of design, quality control and the complete site supervision.

2 DESIGN

The structural design for the foundations and the bridge follow Chinese Standard, Southern African Standards (SATCC) as well as Eurocode design methods which is used for the verification of the original design by Chinese Standard as this was a requirement by the Owner. There are only a few principal and comparable design studies between Chinese Standard and Eurocode. The general difference according to Chinese view is that their standards are developed coming from calculation and investigations whereas the Eurocode is more of theoretical nature. This view is reflected for the design in the Technical Specifications for Construction of Highway Bridges and Culverts (JTJ 041-2000) that are used for the project.

Figure 1. Southern shaft before installation of anchorage block inside

Gravity anchorage in the shafts is used for this bridge to resist the tensile force of the main cables. The depth of the panels and the level of the anchorage foundation follow the bearing capacity of the base layer and underlying formations. For the design analyses of the shaft a complex computer program was used for all stages of the excavation sequences. This resulted in maximum deformations of 36 mm. During all excavation steps survey was done and the deformation values varied between +50 mm to the inside and –41 mm to the outside. The shafts are located 260 m and 284 m away from the pylons. An overview of the southern shaft constructed to its final level is given in Figure 1.

3 SOIL CHARACTERISTICS

The geology is characteristic for this coastal region as there are: layer of imported fill of soil, medium-sized sands, soft mud stone, soft semi-rock and sandstone. A supplementary geological survey was carried out before the construction to evaluate the design values for the foundation in specific. The geological stratum revealed by the soil investigation is as following from top to bottom:

- Layer of imported fill of soil with a thickness up to 2.00 m
- Medium-sized sands; thickness below 10 m
- Mud stone - greyish brown, hypabyssal rock in mud texture, thin-medium thick, semi-rock semi-soil, extremely soft; thickness app. 11 m
- Arenaceous sand stone - greyish yellow, hypabyssal rock in fine particle structure, thin-medium thick, semi-rock semi-soil, extremely soft. This material at the upper section 21.50 m – 31.40 m easily falls apart, saturated by groundwater; thickness 28.5 m up to 46.50 m
- Argillaceous siltstone - grey, hypabyssal rock in mud texture, thin-medium thick, semi-rock semi-soil, extremely soft.

In all 12 separate borings have been set around each shaft. Due to the existing soil and together with the international experience of CRBC for comparable ground conditions at similar projects, the execution of a gravity anchorage system - founded in a shaft - has therefore been the preferred solution for Maputo Bridge. The standard method of execution of the diaphragm wall by using slurry was the favored solution.

3 CONSTRUCTION OF THE DIAPHRAM WALLS

Diaphragm walls for huge shafts have been always a challenging engineering task for foundation engineers as described in (Guettler and Seitz 1990; Seitz 1991). The construction for the panels of the wall started early 2015 and have been completed after 8 months. The single panels for both shafts are 56 m deep. The wall is divided into 44 sections following the construction of primary and secondary panels and considering the working sequence of day and nightshift. The construction of the panels follows the state-of-the-art.

The diaphragm wall was executed in the following sequence: soil improvement for guide wall construction (only south side), guide wall erection by cast in situ concrete, alternating panel element excavation, cleaning the slurry of the panel by airlift and removal of sand, testing of the open trench by ultrasonic equipment (“Koden”, see Fig. 2) for verticality and shape of the panel, reinforcement cage - up to 3 partial cages - placement together with permanent stop end for the interlocking section, casting of concrete, CSL testing of concrete quality after earliest 7 days with testing of panel body, panel intersections and at interlocking’s.

As the greater depth for the anchorage foundation of the southern shaft was more critical for the execution, the technical challenge for that shaft was higher. During the whole process of excavation the slurry was permanently recycled. The equipment used for the excavation allows the control of the verticality during perpendicular excavation.

To guarantee the stability of the soil during the excavation of the panels in the upper parts and also for the guarantee of the

Figure 2. Testing of the panels for verticality and shape after execution

verticality of the panel itself, cement stabilized “soil” piles of 12 m length were installed as a soil improvement before the erection of the guide wall.

A grout curtain was additionally injected underneath the panels in some parts as an additional sealing to increase the impermeability of the soil. These works have been executed only for the southern shaft with its extreme excavation depth against the existing high-level groundwater.

After the approval of the geometry of the trench and its profile, the reinforcement cage in several segments due to its length and weight. The cages have been outfitted with a special permanent steel plate construction of 12 mm thickness and H-shape between the panels for the interlocking section as seen in Figure 3.

Figure 3. Installation of reinforcement cage with special steel joint

4 TREMIE CONCRETE

The concrete has been carefully selected and tested before its use as there was no comparable project in the past in

Mozambique; details are described in (Seitz, Swanepoel and Bai 2016). Criteria like chemical aggressivity of environment and service life of >100 years of the structure had to be considered. Design of the concrete mix design followed Chinese Standard, Southern African Standards (SATCC) as well as Eurocode design methods. A high percentage of fly ash - up to 40% - and a specially developed superplastizer retarder had to guarantee at least 16-hour retarding time that has been needed for the concreting of one complete panel; concreting procedure see Figure 4.

Figure 4. Concreting one panel by tremie method

As an American-European Task Group for tremie concrete has verbalized the consequences of problems with tremie concrete for foundations, the project for Maputo Bridge considered their recommendations seriously (EFFC/DFI 2016). The requirements for concrete placed underwater in and around reinforcement are generally different from its use in conventional construction. The fresh concrete is poured through a tremie pipe and displaces the slurry by gravity alone upwards. Certain and in its origin different conditions during placement and curing in soil with groundwater will materially affect its properties.

The concrete used for diaphragm walls is self-levelling and self-compacting. A gravity-fed tremie with a diameter of 28.5 cm is used for the concreting. This is fed directly from a ready mix truck. The tremie is watertight to prevent inflow of slurry during concrete placement. With slurry in the pipe, the concrete flow from the tremie must be initiated so that there is a minimum of contamination of the concrete. The open tremie was installed and a travelling plug was used. This acts as separator between slurry and fluid concrete and prevents mixing as the concrete travels down the tremie pipe.

The management of the tremie during the first few meters of rising concrete during placement is important for the successful operation. The concrete delivery came in continuously and guaranteed a homogenous quality. Concrete placement was carefully planned during day and nightshift for the construction of the panels and around 10.000 m^3 concrete has been cast per shaft for the diaphragm walls.

One of the most important parameters is the workability of the concrete and it must be retained beyond the duration of the concrete placement operations. If the slump of the concrete is too low, arching of the material will occur when moving upwards in the trench. It will create a gap. The concrete used must have good flow characteristics in order to move easily through the reinforcement to fill the space between reinforcement and excavated soil surface and displace any slurry around the reinforcement from the bottom up. The good quality of the casted concrete at deeper levels was visible and also inspected during the excavation for the anchorage.

All concrete placed had strict temperature control methods as the SATCC state that a maximum temperature of 30° Celsius is allowed; tests have shown the compressive strength of the concrete reaches the high value of 78,5 Mpa after 365 days.

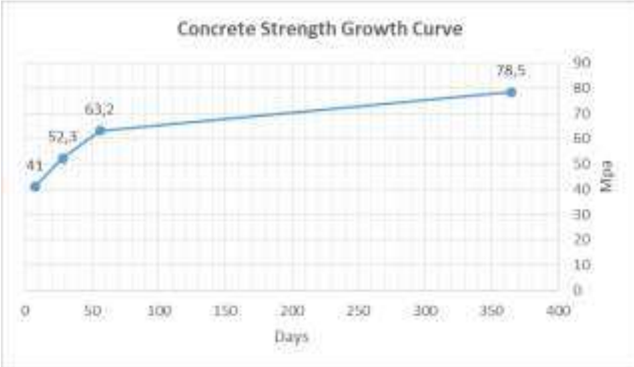

Figure 5. Concrete strength development until 365 days

5 ACTIVITIES TO GUARANTEE QUALITY

5.1 *Measurements*

For the diaphragm wall direct, indirect and supporting testing methods like ultrasonic testing in the open trench (verticality and shape), measurement and comparison of casted concrete quantities, CSL testing (see Figure 6), concrete testing before, during and after casting, visual inspection of the wall after excavation and evaluations of results therefrom have been performed.

The excavation inside the two shafts gave a unique feedback of the records taken and allowed statistical analysis for future projects and the quality management plans. Groundwater level, amount of groundwater pumped, settlement of surrounding area, inclination and deformation of the exposed walls, shape of shaft - all these measurements supplemented the execution and quality management procedures.

Figure 6. CSL – tubes at head of diaphragm walls for testing

5.2 *Dewatering*

Theoretical studies and groundwater pumping tests have been completed before the commencement of the works. There are two different types of groundwater: unconsolidated quaternary rock pore water and bedrock fissure water. As there is an existing railway near the northern anchorage this has to be encountered during the phase of dewatering by a different study and various settlements measurements.

5.3 *Inner Lining*

In order to meet the stress requirements of the diaphragm wall, especially during the excavation stages, a circular rigid concrete lining was placed inside the circular wall as an elastic support. The stresses of the lining thickness along with the vertical extension are set up by adopting segmented thickening approach. The thickness of the inner lining until 6 m below the surface is 1,50 m, between 6 m and 21 m up to 2,00 m and below 21 m of excavation depth until the base it reaches 2,50 m. The height of one ring of the inner lining is 3,00 m.

5.4 *Stress measurements of the shaft*

In order to ensure engineering safety, additional construction monitoring was performed of the stress development inside the lining. After each step of excavation of 3 m the soil displacement at 4 different locations outside of the shaft has been measured by inclinometers together with a survey at the inside of the lining at different levels.

5.5 *Soil improvement south side anchorage at the bottom*

During excavation it was recognized that the soil characteristics changed widely for the southern shaft. When reaching the final foundation level for the anchorage of -32,50 m approx. 2/3 of the soil indicated a reduced bearing capacity as tested by plate load bearing tests of 600 mm diameter and CPT`s. The foundation level for the anchorage block had therefor to be lowered to -37,50 m. Still at that level the soil underneath needed to be improved up to the bearing capacity acc. to the design requirements that asked for a value of 42,50 kN/m^2.

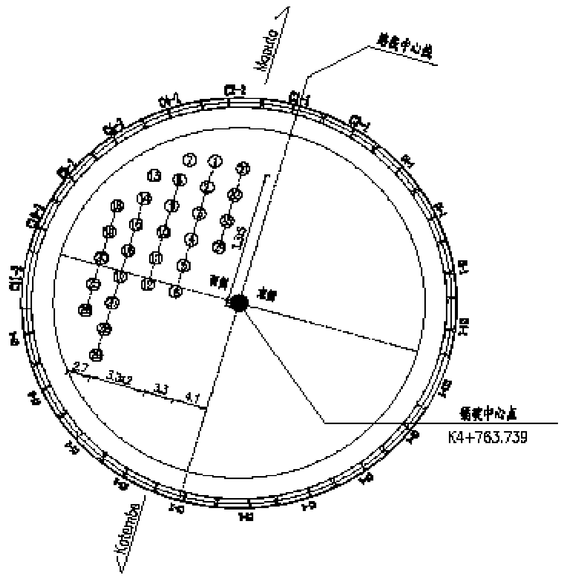

Figure 7. Concrete columns for soil improvement of the southern shaft

The soil improvement was performed that 1/3 of the foundation area remained as originally; for another 1/3 of the area 1,50 m of the soil was exchanged against "weak" concrete C20. For the final 1/3 unreinforced piles (diameter of 1,50 m, length of 12 m) have been executed. The weight of the anchorage block on the south side reaches finally approx. 170.000 to; the block is placed on a special concrete cushion that was casted on the soil.

6 QUALITY CONTROL

One major part of the work of the consultant GAUFF Engineering is the verification of the design, the quality control in general, supervision and the verification of work on site. As elements of foundation suffer from not being visually inspected directly, several indirect methods have been set up as international standards and are being used throughout; one method is the CSL (ASTM D6760-14) earliest after 7 days. For the project furthermore measures like ultrasonic testing of the open trench, concrete quantities delivered and their distribution over the height of the trench together with a visual inspection of the wall down to -37,50 m have been set up strategically.

Over the years these methods have been recognized as internationally documented procedures to guarantee highest quality for diaphragm walls for different purposes. The data will be used as input into the Chinese and European Standards for confirmation together with the relevant calculation methods and programs.

7 CONCLUSION

Africa`s largest suspension bridge is being built in Maputo (Mozambique). For the gravity anchorages - located in shafts using diaphragm walls as their supporting system - a permanent quality control and supervision was in place to guarantee the international standard for the bridge as being number 60 in the world. The quality assurance on the site covers additional methods before, during and after excavation and concreting and during the whole process of operations as for the concrete quality control for example this is one of the paramount key parts for the lifetime operation of 100 years of the bridge. It forms a major part of the Quality Management Plan for this special project.

8 ACKNOWLEDEMENT

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