Soccer City Stadium

Supporting the 2010 World Cup

Being involved with the design and construction of the Soccer City Stadium would seem at first to be like most large-scale construction projects. It is only as the excitement and anticipation builds approaching the 2010 FIFA World Cup that the realisation dawns as to the great privilege it is being part of this amazing project

Courtesy of Boogertman Urban Edge & Partners

THE SOCCER CITY STADIUM in Johannesburg, formerly known as the FNB Stadium, is at present being upgraded at a cost of R1,5 billion.

The stadium is earmarked to host five first-round matches (including the opening match), one second-round match, a quarter final and the final of the 2010 FIFA World Cup. The new stadium will have an official capacity of 94 700, making it the biggest stadium ever to be used in a FIFA World Cup.

Aside from completely renovating the existing stadium, the boxes and upper seating, which were previously only on the western side of the stadium, are being extended around the entire perimeter. A circular steel roof is to be added, giving the stadium the distinctive calabash shape envisioned by the architects. Owing to the round shape of the roof, it will be largely independent of the stadium structure and supported by twelve reinforced concrete 'shafts'. These shafts and the loads generated by the roof have resulted in exceptionally high loads being transferred to the foundations, with the design and construction of some of the most extreme piles ever installed in South Africa.

Once the piling is completed, 1 325 piles will have been installed, along with lateral support for three cut-and-cover tunnels that are at present being constructed through both existing and new portions of the stadium.

To provide some idea of the scale of the project, it is worth considering that over 20 km (20 317 m, to be exact) of pile shaft has already been installed by GEL, the specialist geotechnical division of Grinaker-LTA, who has completed the geotechnical construction work over the past 14 months. This has required the placing of 13 000 m^3 of 40 MPa concrete for the piled foundations alone, as well as 1 132 tonnes of high-tensile steel.

TENSION PILES AND SHAFT FOUNDATIONS

While many of the piles carry large compressive loads, perhaps the most daunting aspect of the pile design has been the exceptionally high-tension loads. The calabash-shaped façade transfers all the load from the roof down twelve reinforced concrete shafts and 120 backward sloping façade columns constructed around the perimeter of the stadium.

By way of an example, a single shaft foundation is required to carry up to 13 000 kN of tension, combined with 6 000 kN of shear and 125 000 kNm of moment. Given the limited space, it was only possible to install a maximum of 12 piles per shaft foundation with the result that some piles were expected to carry up to 5 800 kN of tension.

Unfortunately the rock strength and depth across the site is highly variable, and therefore only limited capacity can be safely generated in the rock socket.

In order to accommodate these massive loads, it was decided to anchor the piles into the sandstone bedrock using dowel bars installed through the base of the pile. Between four and eight 100 mm steel tubes, similar to those used for cross-hole sonic logging tests, were cast into the pile to a depth of 300 mm above the pile/rock interface. Once the concrete had reached sufficient strength, these holes were extended using percussion drilling into the rock below. The 10 m long Y40 Threadbar 600 dowel bars were then grouted 6 m into the rock, with 4 m projecting into the pile. Just over 700 of these Threadbar 600 dowels have been installed.

Given the massive loads required, the huge financial cost, and programming and access constraints, conducting a full-scale load test for one of the 1 200 mm or 1 500 mm diameter shaft piles was not a viable option. Instead it was decided to simulate the behaviour of the shaft piles by load testing a 600 mm diameter test pile with a single dowel bar. The results of the test could then be extrapolated, allowing the reduction of the test to a more manageable scale.

The tension test is being conducted by Dr Irvin Luker of the University of the Witwatersrand's Civil Engineering Department. Strain gauges are affixed at salient points along the length of the reinforcing and the dowel bar and are connected to a data acquisition unit which will collate all the information during testing. The pile will be tested to a maximum tensile load of 2 000 kN, by jacking against two compression piles.

LATERAL SUPPORT

To allow access into the completed stadium, three cut-and-cover tunnels are being constructed. The Western Tunnel runs below the existing stadium and has permanent support with a maximum vertical height of up to 10 m. The restricted nature of this lateral support proved challenging, with a fairly conservative approach taken to the design given the potential consequences of a collapse to the stadium structure above.

The South-west Tunnel and North-east Tunnel are being constructed through new portions of the stadium, but owing to programming constraints it was decided to adopt a similar system of permanent lateral support comprising soil nails, shotcrete and mesh. As a result of the construction of deep pile caps at the base of the North-east Tunnel, vertical lateral support heights of up to 13 m will be required. Continuous movement monitoring has been implemented to ensure the safety of the workers during construction.

ROOF ERECTION

The distinctive calabash shape of the stadium utilises cantilevered steel trusses for the roof. Erection of these trusses will be done using a 600 t Terex Demag 2800 crane. This massive piece of equipment has two tracks, each with a footprint of 10 m x 2m and imposes ground pressures equivalent to a medium-size office building (that is, up to 550 kPa while in operation). These high stresses were a major concern, given the typically poor strength of the soil near ground level and the consequences of a bearing capacity failure. One engineer on site jokingly stated that if the crane were to collapse, we 'better make damn sure it doesn't land on the stadium'. To avoid this scenario altogether, an evaluation was undertaken to assess the bearing capacity of the soil and the requirements for any remedial action.

Investigation

The stiffness of the substrata was assessed by performing some 50 No 2 m deep dynamic cone penetrometer (DCP) tests. The DCP profiles generally revealed very similar results. The most conservative test was found to indicate that the in-situ materials to 2 m depth, exhibited California bearing ratio (CBR) values in the range 15–20.

This would indicate that the in-situ Young's modulus would be given by:

$E \approx 100$ MPa

The design shear strength parameters for this material are therefore likely to be in the order of:

$c = 15$ kPa

$\phi = 35°$

$\gamma = 20$ kN/m^3

Using bearing capacity formulations for the crane track placed at the shoulder break point of an embankment, factors of safety were calculated in the range 0,65 to 1,75 for slope angles of 1:1.5 to 1:2.0. Thus small changes in the slope angle lead to very pronounced changes to the calculated safety. The factor of safety (FOS) drops below the critical FOS = 1 value when the slope angle exceeded about 1:1.7.

A more advanced finite element model was used to accurately depict the situation which would occur in practice. Here the 250 kPa stress exerted by the track in the transport mode over a 2 m wide area, 2 m from the edge of the embankment, was modelled. This analysis yielded factors of safety of 1,53 for the 1:1.5 slope to 1,75 for the 1:2.0 slope.

From these results it is obvious that in moving the load from the edge of the slope to 2 m from the edge has a highly beneficial effect. Not only are generally higher safety factors predicted, but the range of these values is much lower.

DISCUSSION

While the above FEM analysis may generate the idea that the ramp area that will be traversed by the crane in the lower bearing stress mode is safe, the bearing capacity formulations indicate that extreme caution is necessary when the load moves towards the outside of the embankment.

Owing to the extreme sensitivity of the situation, it was felt that a very cautious approach should be adopted and the recommendations included limiting ramp side slopes to shallower than 1:1.75, making the ramp sufficiently wide to ensure 3 m of space between outer edge of track and shoulder breakpoint of the fill is maintained.

In order that horizontal tensions exerted by the crane were not transferred to the fill substrata, a layer of high-strength geosynthetic has been specified over the top of the fill prior to a wearing course being placed. A wearing surface comprising a 300 mm thick layer of G5 gravel, compacted to 93 % Mod AASHTO, has been specified.

CONCLUSION

The stadium is currently progressing well, with some areas actually slightly ahead of programme. That said, there remains some big challenges ahead, particularly in the complex erection of the steel roof structure.

There is no doubt that the professional and construction team will continue with their present commitment, looking forward to completing this iconic structure which will be viewed by billions of people in only a couple of years' time.

1 Cantilevered steel trusses are used for the roof
2 Construction well advanced on the southern side
3 The Western Tunnel mid-way through excavation
4 Construction of North-east Tunnel lateral support

Source:
http://www.saice.org.za/downloads/monthly_publications/2008/CivilApri08/#/0