Nelson Mandela Multi-Purpose Stadium

INTRODUCTION

The Nelson Mandela Multi-Purpose Stadium is located about 50 m from Port Elizabeth's North End Lake, and within 1 km from the sea, on a site that presented a number of challenging features, such as expansive soil, a high water table, and a pitch level 1 m below the overflow weir level of the lake. Various other challenges encountered during the execution of this project included late financial budget approval, a short project implementation period, an over-heated tender climate, a large number of consultants, and poor weather conditions.

Despite these challenges, and thanks to quality engineering and management, the 46 000 capacity, spectator-friendly stadium was completed on time and within budget, boasting a roof that is considered an engineering masterpiece, and excellent sight lines and limited distances from the pitch for all spectators.

PROJECT BACKGROUND

The initial design for estimating purposes was based on a 27 000 permanent seat facility and 18 000 temporary seats (FIFA required a capacity of 45 000 seats), and a single roof only for the western main stand. The Client, however, decided that it was imperative to design a facility which would be seen as an 'icon' – a unique design for the Nelson Mandela Bay (NMB) Metro. This resulted in a stadium designed with a full roof structure covering all the stands.

MANY CONSULTING FIRMS

The Client believed that it was important to broaden the knowledge base of the consultants within the NMB Metro by appointing 52 consulting firms of various disciplines to take the concept design into the detailed design stage, as well as the construction monitoring stage. A Project Management Plan was developed whereby each discipline had to be presented by a discipline leader reporting to the Principal Agent (BKS BTKM/PMSA Joint Venture). Design offices were made available on site to facilitate a closer working relationship between the various disciplines. This proved to be a challenge, as not all the disciplines were represented by the key designers in the design office. Notwithstanding the above, the exercise was considered successful in the transfer of specialist design skills related to a major sporting facility / industrial fast-track project.

LIMITED TIME

The exceptionally short time period, from the date when the project budget was approved (October 2006) to the anticipated inclusion as a Confederations Cup venue in June 2009, theoretically allowed a period of

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NELSON MANDELA MULTI-PURPOSE STADIUM

Technical Excellence category

KEY PLAYERS

Client Nelson Mandela Bay Municipality

Professional Team BKS BTKM-PMSA Joint Venture

Main contractor GLTAI (Grinaker-LTA Interbeton JV)

Major Subcontractors and Suppliers TMC (roof structure and membrane)

George Roofing (aluminium cladding)

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30 months, excluding the three Christmas periods. Within this time the consultants had to be formally appointed and briefed on the scope of work, detailed designs had to be carried out and procurement completed. The project was therefore split into preparatory work which consisted of the relocation of existing services, provision of bulk services, bulk earthworks and piling. The main contract included all works related to the stadium construction as a single project. The main contract commenced in March 2007 with practical completion close to the first week of June 2009 to allow the hosting of the first official match, albeit not a Confederations Cup match (explained later on in this article) on 16 June 2009 between the Southern Spears and British Lions teams.

SITE CONDITIONS

As mentioned above, the high water table, plus the close proximity of the North End Lake, posed specific challenges.

A specially designed crane pathway had to be constructed all around the stadium at very specific gradients and engineered levels. This entailed the excavation of expansive material and the importation of quality material to provide a stable base for the crane to lift the 55 t girder structures into position.

Due to the poor soil conditions the entire structure had to be founded on a set of 2 300 piles with pile lengths varying from 7,5 m to 12,5 m.

ASPECTS OF CONSTRUCTION

The concrete structure supporting the roof had high accuracy tolerances allowing minimal deviation, and the roof and its covering was a complex structure, difficult to erect in Port Elizabeth's notoriously strong winds.

The main critical path ran through the west stand, which had two additional levels housing the changing and hosting facilities. Whilst this area was started first, the volume and complexity of work was such that it was finished last.

The roof erection process started on the north stand, progressing clockwise until the west stand concrete works had been sufficiently completed to allow the erection of the roof there. Once the roof, including its coverings, had been erected on the west stand, the finishings in that area became the critical element, together with the external works which could not be started until the roof erection crane had been relocated to another area. The initial programming sequence required the roof to be erected in a clockwise direction only, but it became necessary to change this sequencing to 30% clockwise and 70% anti-clockwise, resulting in a time-saving of several months.

The concrete structure was constructed in eight segments by different construction teams, all segments topping out at a highly reinforced ring slab/beam containing the precisely positioned securing bolts for the structural steel roof. The positioning of these bolts and the casting in of these into the columns was critical, as the roof trusses were of a predetermined size that could not be altered. In addition, it was imperative that not only were they dimensionally accurately positioned, but they needed to have the necessary cast in-situ bond to the concrete structure to ensure that the loads carried by the roof, both as dead and live loads during high winds, were effectively transferred into the structure and into the foundations.

The roof structure and coverings were designed by specialist roof design engineers based in Germany who ensured that the weight of the roof structure was minimised by designing a space frame tubular truss which kept the mass of each of the 36 trusses at 55 tonnes each.

Monitoring the production of the structural steel roof and its delivery and erection, proved to be a considerable challenge due to the distant location of the manufacturing facility. Each truss type had to be pre-assembled in Kuwait to check the geometric correctness of the curves and any deflection at the front tip of the truss. Once the pre-assembly had been verified, the trusses had to be deassembled prior to shipping. The manufacturing process took eight months, three months longer than had been programmed. Much of the delay was caused by the non-availability of certain sections of steel, together with the complexity of the roof geometry impacting on the production of the roof purlins. This, together with delays experienced in shipping the trusses, resulted in substantial delays.

The roof trusses were shipped in three major consignments from Kuwait to Port Elizabeth, then transported to site for assembly. Massive steel frame jigs were set up on site for the assembly of each of the 46 m long trusses. The first truss components arrived on 27 August 2008, and were assembled over a two-month period before being erected. The last truss was erected on 12 March 2009.

2 and 3 and 4 The roof girders were installed entirely from the outside of the stadium. The window of operation for the 500 t caterpillar crane was limited by the notorious Port Elizabeth winds, resulting in the erection of the girders occurring mostly in the morning
5 The initial programming sequence required the roof to be erected in a clockwise direction only, but it became necessary to change this sequencing to 30% clockwise and 70% anti-clockwise, resulting in a time-saving of several months
6 The roof acquires its remarkable form from the alternating arrangement of the girders and the membrane surfaces spanned in-between

The girder ring connecting the cantilevered end of all 36 trusses was sequentially erected with the trusses some 40 m above the playing surface. A restrictive requirement of the structural engineers was that at least five completed trusses had to be erected before any roof sheeting or cladding could be installed, and that this requirement be maintained until the whole of the girder ring had been completed.

Despite these challenges it is worth recording that the sequencing and programming of the work was sufficiently precise to require only minimal adjustment to the last truss to complete the installation.

The fabric roof cladding spanning between the trusses was erected by specialised erectors. The roof sheeting also required specialist installation teams who had received training in erection and abseiling techniques. These teams had been recruited from locally-based labour and, through this project, they acquired specialist abseiling and other skills which they could use elsewhere in the industry.

Due to the many complexities, practical completion was achieved some six months later than had originally been planned. The stadium lost its right to host the Confederation Cup in 2009, not because the stadium was incomplete, but rather because of the risk of being late and the need to consolidate all the matches to be within a reasonable commuting distance. However, the British Lions tour of South Africa in June/July 2009 included a match played against the Southern Kings at the NMB Stadium.

BULK EARTHWORKS

In May 2006 the joint venture between consulting engineering firms Goba, Izizwe and Iliso was appointed to complete the design and implementation of Work Package 5. Work Package 5 entailed the planning of (a) the bulk earthworks, (b) the demolishing or relocation of existing structures, and (c) the diversion and relocation of the existing box storm water culvert that drained the North End Lake.

The earthworks related to the excavation of the stadium bowl and the construction of the stand platforms. A total of 122 203 m^3 of cut material was taken away to spoil, with 103 210 m^3 of imported fill material placed and compacted to form the north, east and south stands. Of note is the fact that the spoil site was located at the quarry where the quartzitic fill material was sourced, resulting in trucks travelling fully laden in both directions.

NORTH END LAKE

The influence of the North End Lake on the construction was significant. The pitch level of the stadium would be constructed below the level of the lake, and therefore certain mitigation measures, such as determining flood paths and overland storm water routing, had to be taken to ensure that the excavations were not flooded during an extreme storm event.

The lake had to be lowered by approximately 1,2 m to enable critical storm water components to be removed and new storm water infrastructure to be constructed. All stakeholders and organisations that use the lake for recreational purposes had to be consulted before the water level could be lowered. The process of lowering the lake and returning it to its normal operating level was done in a shorter period of time than had been anticipated.

A full drainage analysis of the stadium was undertaken by a

7 The backlit membrane surfaces of the roof make the stadium widely visible at night

specialist geotechnical engineer on behalf of BKS (the Principal Agent). PD Naidoo & Associates were then called upon to design a subsurface drainage system below the entire west stand of the stadium to relieve the area of surplus water.

PILING

A Joint Venture comprising Iliso Consulting, ARQ and Arcus Gibb was appointed by the NMB Metro to undertake the design and construction monitoring of the foundation phase for the stadium.

The geotechnical experts recommended that cast in-situ augured piles with enlarged bases be founded on very stiff clay / very soft mud rock of the Kirkwood formation. A total of 2 300 piles were installed in pile groups of up to 48 piles per pile cap. The pile sizes ranged from 355 mm to 610 mm in diameter. The piles were cast in-situ concrete piles with reinforcement of up to 8 Y32 per cage. The majority of the piles were designed to resist vertical compressive forces ranging from 3 500 kN to 10 500 kN. Other piles were also designed to resist tensile forces of up to 10 500 kN.

ROOF

The silhouette of the stadium is marked by the structure of the girders, which are arranged to point towards the center of the stadium. The girders taper towards the bottom where they 'grow onto' the columns of the multi-storied colonnade that wraps around the entire stadium.

The structural roof elements (girders) were all pre-assembled in a jig at ground level, surveyed for tolerance compliance and then installed. The 55 t mass elements were manufactured to very high tolerances to enable the structure to be erected in this manner.

The roof cladding terminates before the façade to provide a wind-tight connection of the roof to the façade, without requiring additional provisions. The roof acquires its remarkable form from the alternating arrangement of the girders and the membrane surfaces spanned in-between.

Port Elizabeth is known as the 'Windy City'. Therefore, besides rain protection, much value was placed on perfect wind protection. A high roof edge, as well as the reduced roof depth, mirrors these requirements. The effectiveness of the derived geometry was tested using a wind tunnel and evaluated according to a comfort study.

In order to not interfere with the work on and around the playing field, the pre-fabricated girders had to be installed entirely from the outside of the stadium. The pre-fabrication of the girders was performed on scaffolding, which was equipped with individually adjustable clamping saddles to accommodate the different girder geometries. After the calibration of the scaffolding, mobile cranes lifted the pre-fabricated units into place, where they were bolted. The tip of the girder was set in place as a single unit at the end. To compensate for the tolerances from fabrication and the bolt-hole clearance of the connections, the girder tips were initially set in the specified position on the work-shop geometry and then connected with the rest of the girder. Connection plates with slightly varied hole patterns were implemented to accomplish this. After the calibration of the girder and the pre-stressing of the bolted connections the support of the girder tip was lowered and the deformation at the girder tip was checked. At the same time the secondary structure of curved tubes was assembled and calibrated for the aluminium cladding. With the help of taut lines the relative height between the purlins was measured to limit the unevenness of the cladding. The Y-columns were also bolted before being lifted into place.

The window of operation for the 500 t caterpillar crane was limited by the maximum wind speed of 10 m/s. As such wind speeds occur daily in Port Elizabeth, often already before noon, the erection of the girders occurred mostly in the early hours of the morning. The installation of the aluminum cladding proved equally challenging in these windy conditions.

Calm weather conditions were also required for the unrolling of the membrane to the preliminary anchorages. The membrane bales were rolled out on a temporary net of tension straps and secured with over-laying straps to prevent lift-off until it had been sufficiently anchored.

ENVIRONMENTAL CONDITIONS

Situated on the coast of the Indian Ocean, Port Elizabeth belongs to a group of places that has some of the highest recorded normative exposure to corrosion in the world. High temperatures, in combination with humidity and prevalent coastal parallel winds, which carry salt from the coast-line ocean spray across long distances, result in steel corrosion rates of 100 to 300 µm/a. These conditions set the highest requirements for corrosion protection.

For corrosion protection, high grade and very UV-resistant Polysyloxane were employed. Movable parts were dual-layer coated. In construction all gaps and areas difficult to reach were minimised and single shear-plane bolted connections were favoured.

CONCLUSION

The succsssful completion of the Nelson Mandela Stadium, despite considerable challenges, represents a significant contribution to modern stadium architecture. □

Source:
http://www.saice.org.za/downloads/monthly_publications/2010/2010-Civil-Engineering-dec/#/0