THE MOSES MABHIDA STADIUM has been designed as a symbol of the unification of a nation with a passion for sport. This is epitomised by the 106 metre high central arch – spanning the length of the stadium. The 360 m long arch supports a web of interlocking galvanised steel cables totalling over 36 km in length which add form to the tensile roof. The 30-storey high arch weighs 2 600 tonnes and consists of 56 sections, each measuring 10 m in length.

The iconic arch has become a world first tourist attraction featuring a high-tech cable car designed to take visitors up to a viewing platform, where they can disembark to enjoy panoramic views of the city and the stadium. The two southern legs incorporate a guided adventure walk of some 550 stairs to reach the top of the arch.

The stadium was designed to be a multi-purpose facility and has proved to be very popular with local and international tourists, due to the attractions and shopping area. To date it has successfully hosted 15 bowl events since its opening at the end of November 2009 with a total of 275 000 spectators. In addition, over 100 conferences and corporate functions have been hosted, 100 000 people have been up the SkyCar, almost 3 000 have walked up the arch and 35 000 people have been on a stadium tour.

PROJECT OVERVIEW
Ibhola Lethu Consortium was awarded the design and project management of the new stadium in mid-2006. The major challenges and highlights of this unique project include:

- Stringent requirements for concrete quality, durability and aesthetics were specified and achieved
- Procurement of 57 contracts, 3 direct and 54 sub-contracts, to the main building contract
- Installation of 1 901 no of CFA piles, ranging from 450 – 700 mm in diameter, to an average depth of 20 m
- A world first in the design of the roof arch foundations, involving diaphragm walling to bedrock, massive cappings and springer plinths
- Innovative design and a South African first for pre-cast design and installation in stadiums
- Construction of saw-toothed raking beams to stringent tolerances for the support of pre-cast concrete seating panels

KEY PLAYERS

Client Strategic Projects Unit, Ethekwini Municipality
Professional Team Ibola Lethu Consortium (Pty) Ltd
Main Contractors Group 5, WBHO, PANDEV Joint Venture
Design, manufacture and erection of
1 832 pre-cast seating panels varying in
weight from 4.5 – 6.5 tonne
102 pre-cast façade columns in 25 pro-
gressively raked shapes weighing up to
60 tonne
16 Shear-cores providing lateral sta-
bility to both the bowl and roof struc-
tures
84 000m² of post-tensioned suspended
slabs
Construction of 800 m of reinforced
concrete retaining walls varying in
height between 4 m and 8 m
18 pre-cast ‘Tilt Up’ panels for archi-
tectural cladding of the arch’s springer
plinths
100 pre-cast U-shaped illumination
beams
Precision planning for the operation of
14 tower cranes with 60 – 70 m overlap-
ing jibs, 450 and 650 t crawler-crane
with 115 m jibs, as well as numerous
mobile-crane often working simulta-
neously
A workforce of over 2 800 on site at
peak time.

STADIUM DESIGN
The stadium bowl provides a structural
cement frame for the support of the spec-
tators seating arena and also acts together
with the arch foundations as support for
the roof structure. Normal seating capacity
is 56 000, which was extended to 70 000
for the FIFA World Cup with additional
seating installed on Level 6.

The main structural member of the
roof consists of a 106 m high arch span-
ing 360 m onto the arch foundations.
Fifty main ridge cables are supported
from the arch which defines the shape
for the 46 000 m² of roof coverage.
These ridge cables, as well as the valley
cables, are connected to the compres-
sion ring that in turn is supported on
steel façade columns

The roof cables are pre-manufactured
to exact lengths required for the precise
geometry of the cable net structure
that spans between the arch and the
compression ring. Any deviation from
the tight geometrical tolerances would
induce forces in the pre-stress cable
net that would potentially have serious
structural implications. This necessitated
very stringent specifications with respect
to the setting out tolerances for all sup-
port points at the interface between the
concrete and roof structure. In addition,
the stiffness of the concrete support
structure had to be precisely determined,
as accurate stiffness values at the inter-
face to the roof were required for the
structural analysis model of the roof.

The required stiffness parameters of
the concrete support structure were ob-
tained through Finite Element Modelling
(using Robobat software) of each seg-
ment (expansion joint to expansion joint)
of the bowl.

These models incorporated all struc-
tural concrete components that contrib-
uted to the overall vertical and lateral
stiffness of the stadium bowl. The output
of the FEM modelling was also used for
the foundation and shear core design.
The shear cores provide lateral sta-
bility for each section of the stadium bowl
(expansion joint to expansion joint). The
thickness of the walls varies from 250 mm
to 300 mm. The main reason for this
variation in wall thickness is to obtain
compatible deflections in the concrete
structure at the interfaces with the roof
structure at Level 6.

The loads transferred from the steel
roof columns onto the concrete structure
at Level 6 vary vastly around the circum-
cference of the bowl. The concrete struc-
ture provides lateral support to the arch
at the north and south sides, whereas the
reactions on the east and west sides are
mainly axial loads.

The main forces transferred through
the arch onto the reinforced concrete
foundations are in excess of 100 MN ap-
plied at an inclination of approximately
38° to the horizontal. A number of
options were investigated to resist these astronomical forces, with the main challenge to limit lateral deflection of the arch foundations.

Options considered ranged from pile solutions, pile and anchor solutions, tie-back to the main bowl structure and diaphragm walls acting as shear walls. It was eventually determined that diaphragm walls were not only the most practical and least time consuming, but also the most cost-effective solution.

The foundations are elongated rectangular boxes with 800 mm thick reinforced concrete walls. The northern foundation is 44 m x 7 m in plan, and the two southern foundations are 30 m x 4 m in plan. The walls were excavated and cast under bentonite slurry (drilling mud) in panel lengths of up to 7 m to a depth of 20 m. Each wall panel is embedded at least 0,5 m into siltstone with a compressive strength of 2 MPa or stronger.

Only limited bond could be relied on between adjacent concreted panels since no transverse shear reinforcement is provided across the vertical joints due to the construction methods. In order for the wall panels to structurally act together, the individual wall panels were connected...
at the top with deep heavily reinforced capping beams (3 m on the south foundations, 5 m on the north).

In addition to vertical and horizontal reinforcement, each wall panel contains four or more vertical multi-strand post-tensioning cables. The vertical reinforcing is fully bonded into, and the strands extend through, the deep capping beams which are also post-tensioned. The high-strength post-tensioning cables were introduced not only to reduce the amount of conventional reinforcing in order to provide enough free space for the placing and compaction of the concrete, but also to enhance the stiffness of the foundation structure.

The structural design of the arch requires that the maximum initial horizontal deflection has to be limited to 25 mm while the maximum long-term deflection is limited to 50 mm. The load deflection behaviour of the foundations was analysed using PLAXIS 3D which applies Finite Element Elasto-Plastic techniques for the calculation of soil-structure interactions.

The connection of the arch to its foundation is facilitated through the introduction of a reinforced concrete springer plinth on top of the capping beam. The stringent geometrical tolerances with respect to the positioning of the arch, coupled with the transfer of the enormous forces onto the foundations, necessitated the introduction of a very complicated but precisely detailed steel cast-in element at the top of the concrete plinth.

The arch plinths have a trapezoidal shape similar to that of the arch and are in excess of 10 m high and 16 m long. A total of 275 m$^3$ of concrete was used in each of the southern plinths, and 420 m$^3$ in the northern plinth. Each of these plinths was constructed in a single pour, except for the top 1.2 m which contain the embedded cast-in elements. Appropriate additional measures were implemented to control the high heat of hydration to ensure optimal curing of these massive plinths. This was achieved through the introduction of 100 mm thick polystyrene cladding applied externally for temperature insulation.

The final architectural shapes of these plinths were achieved by the introduction of pre-cast cladding panels that were erected using tilt-up technology. These panels weigh up to 20 tonne each and are in excess of 12 m high.

**SUSTAINABLE MEASURES**

Several sustainable measures have been incorporated into the construction of the precinct. Masts, control gear, topsoil, pre-cast seating, steel (400 tons) and bricks (40 000) removed from the old Kings Park Stadium on the site were recycled and utilised for the new stadium, as well as for other projects in the city. Although the stadium has a huge visual impact, all the stadium lights are contained in a catwalk below the roof, so there are no light masts protruding above the stadium roof. Another sustainable measure has been the incorporation of a harvest tank which collects rainwater from the roof to irrigate landscaping in the precinct. Energy-saving light fittings and regulated water flow devices have also been incorporated, as well as double glazing and sun-control features on all windows.

Source: