Cape Town Stadium structural challenges

The new Cape Town Stadium, which hosted a number of FIFA 2010 World Cup matches, including a semi-final, provided the City of Cape Town with a unique opportunity to produce a top-class facility, located in one of the most recognisable vistas in the world. The Green Point Structural Engineers JV faced numerous challenges, both technical and non-technical, during their 40-month involvement in the project. They delivered an iconic, but functional structure, incorporating new materials and the latest principles in stadium design, using the existing strengths of the local industry

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CAPE TOWN STADIUM: STRUCTURAL CHALLENGES

Technical Excellence category

KEY PLAYERS

Client City of Cape Town
Professional Team Green Point Stadium Structural Engineers JV with BKS (Pty) Ltd as lead structural engineer, in association with ILISO Consulting, Goba Consulting, Henry Fagan & Partners, KFD Wilkinson, Arcus Gibb, and Schlaich Bergermann & Partner
Main Contractor Murray & Robberts / WBHO Joint Venture
Major Subcontractors and Suppliers Group 5, PPC, Freyssinet Posten Cape, Lafarge, RSC, Birdair/Pfeifer JV, Hightex/Mostostal JV, DSE, Union Structural, Mazor Steel, Cape Concrete, Concrete Units, Scheltema

INTRODUCTION AND BACKGROUND

After South Africa was awarded the 2010 Soccer World Cup, the City of Cape Town agreed to construct a new stadium in order to host a semi-final. Naturally, the cost and future viability were key concerns.

At a delicate point in the public discourse about the project, the City ordered two of the consortia which had shown interest in the design work, to merge virtually overnight and thus appointed the 'Green Point Stadium Structural Engineers JV' to perform the structural design and construction supervision of the new stadium.

The following milestones occurred during the 33-month construction phase:

13 December 2006	Construction tenders closed
5 January 2007	Provincial 'Record of Decision' issued, affecting location and various design parameters
26 March 2007	Contract awarded to the Murray & Roberts / WBHO Joint Venture
25 April 2007	First reinforced concrete foundation cast
25 September 2008	First roof compression ring element erected
18 September 2008	Last of 72 RC raking pylons completed
21 October 2008	Last of 2 600 pre-cast seating elements placed
26 February 2009	Tension ring lifted
2 September 2009	Roof construction completed
21 December 2009	Practical completion achieved
23 January 2010	First match played

During their 40-month involvement in the project, the structural engineers faced many diverse challenges, which they overcame by being adaptable and innovative and placing a high premium on coordination. The resulting mega-structure was successfully completed on time.

ENVIRONMENTAL CONSIDERATIONS

The early development of the stadium's form and layout focused on the site of the existing Green Point Stadium which had hosted various sporting and cultural events.

Among the bodies that had responsibility for, or a stake in, the project during this planning phase were not only National and Provincial Government and the FIFA Local Organising Committee, but also local residents, ratepayers, and

other concerned groups. The Client therefore commissioned a comprehensive Environmental Impact Assessment to inform decisions relating to the location, size, form and construction of the new stadium.

In October 2006, the EIA pointed towards a new site – the southern end of the existing golf club. Only limited geotechnical data was available at that stage.

The Record of Decision (RoD) was released some weeks after the construction tenders had closed. It was wide-ranging in its findings and conditions imposed on the new facility.

LOGISTICAL CHALLENGES

The Structural Design JV consisted of six local firms and one German sub-consultant. Having the core design office in Bellville, with satellite offices in Cape Town, Johannesburg, Durban and Stuttgart meant that design coordination, standardisation of details and drawing output control were challenging for the duration of the project.

Architectural responsibilities were also split between two main parties, resulting in a complex decision-making process. The Services Engineers JV also included several firms. The coordination of services within the stadium was only achieved well into the construction phase, many months after structural elements had been finalised, detailed and issued.

TECHNICAL CHALLENGES AND SOLUTIONS

Changes having significant structural impact were imposed late in the design process by the RoD findings and again when the tender results were received. There was no chance to change the stringent time constraints or delivery date.

The move to a new site affected foundations, height restrictions resulted in the lowering of the central bowl, and noise restrictions had significant influence on the roof design.

1 The completed Cape Town Stadium at night (Photo: Terry February)
2 Inclined pylon construction (Photo: Terry February)
3 Pre-cast seating beam installation (Photo: Gerrit Bastiaanse)
4 Pre-cast seating beams and their supporting raking beams (Photo: Gerrit Bastiaanse)


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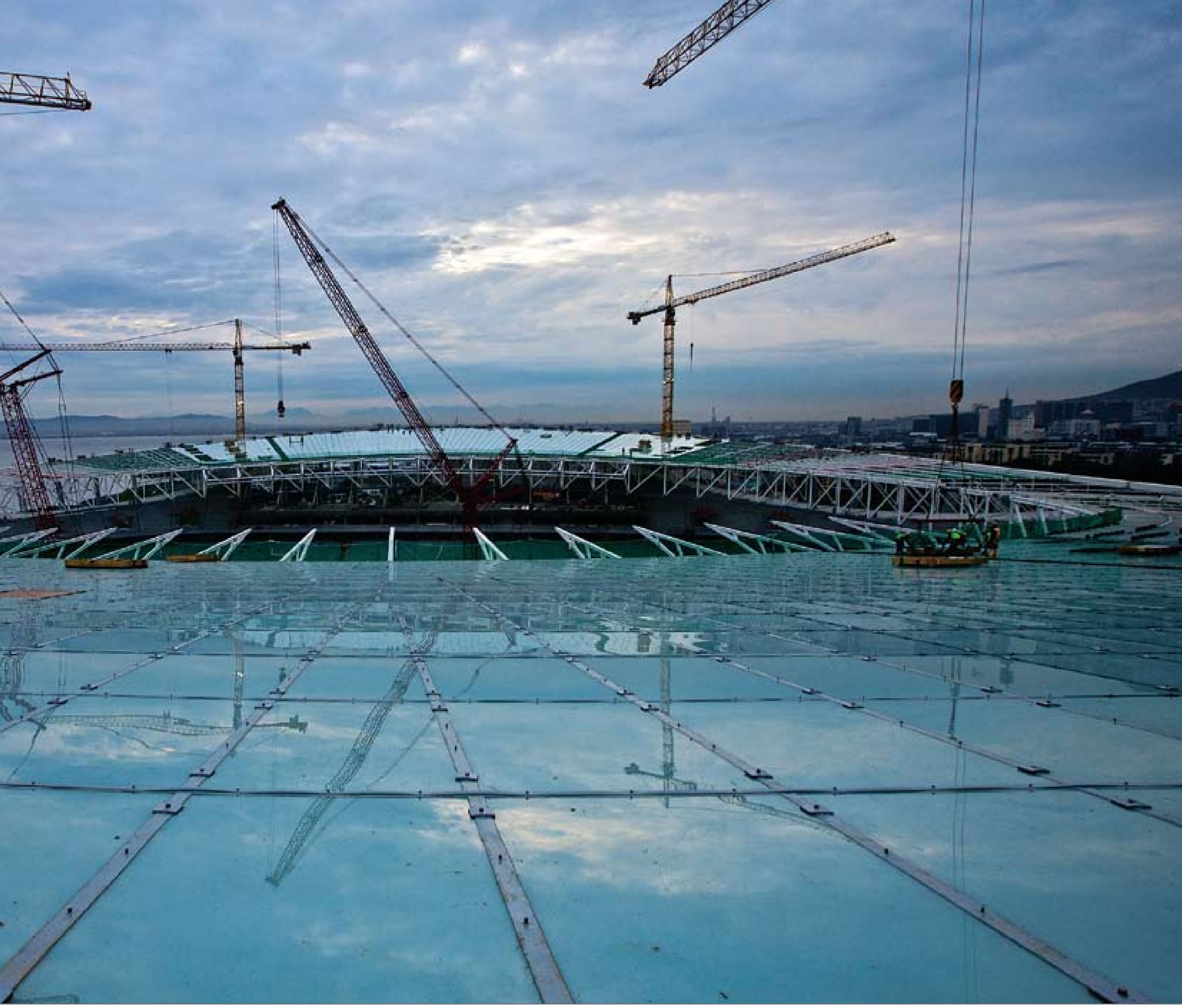
The higher-than-expected tender prices prompted a cost-cutting exercise, resulting in the reduction of the width of the bowl around the pitch, making the 72 radial frames less stiff. The inclined pylon columns supporting the roof were revised in cross-section from 6 m x 1 m to 3 m x 0,8 m, severely reducing bending capacity and stiffness.

As a direct consequence of these two changes, extensive RC elements were added to cater for in-plane forces in the radial planes, especially under seismic loading. More critical from a programming point of view, the pylons could no longer be constructed freely ahead of the rest of the structure (see photo 2).

While the architects tackled the re-design, the contractor was ordered to move onto site and commence earthworks. At that stage, not even the foundation design was complete.



Further challenges, resolved under extreme time pressures, provided opportunities for innovation and creativity as described below:

- Excavations revealed that the foundation conditions varied widely. The levels of the desired load-bearing strata sometimes differed by more than 3 m between adjacent bases. To speed up construction, extensive use was made of mass concrete fill to obtain some uniformity in base depths and sizes. Rebar cages could thus be standardised.
- To advance the vertical elements as quickly as possible, extensive use was made of rebar couplers, which increased detailing effort. They had to be provided for and cast in, often before the adjoining elements had even been designed.
- The critical path hinged on the completion of the pylons to enable the roof construction. The pylons had to be constructed ahead of the rest of the main structure. We thus had to analyse each 'stage' of each of the 72 radial frames, with the consequent introduction of new radial downstand beams on certain levels.
- Shrinkage, creep and self-weight deflections of the 50 m high raking pylons had to be taken into consideration so that the cast-in adaptor plates for the roof bearings would be in the right position, and that with the roof complete and under 'still' conditions, the pylons would be in their 'neutral' positions.
- The SANS Standard 10160 Part 4, was followed in full regarding seismic loading considerations in both design and reinforcement detailing.
- The seating tiers consist of pre-cast beams spanning up to 12 m between the raking beams of the 72 radial frames. The efficient design and coordination of these elements contributed significantly to the success of the project.
- Finite element analysis was used to check the natural frequencies of the PC seating beams, which as a result were cast in 3-stepped Z-shaped sections, increasing their stiffness (see photo 3).
- Being supported on in-situ concrete raking beams, construction tolerance was built into the plan arrangement by incorporating a 200 mm strip of in-situ concrete between the PC seating panels. This provided moment continuity under live loads and assisted in stiffening the structure, improving both seismic resistance and frequency response (see photo 4).

5 Tier front edge (Photo: Schalk Marais)
6 Steel balustrade beam (Photo: Schalk Marais)
7 Perimeter escape stairs (Photo: Terry February)
8 Steel and glass roof construction (Photo: Terry February)

- Considerable attention was given to the highly visible front tier edges. Unlike the segmented seat panels, they follow various radii to create the continuous curved front edge. These front edges are not supported directly on the raking beams, but cantilever beyond, providing an elegant edge to the concrete tiers (see photo 5).
- The intersection of the pylons' envelope with the stepped horizontal lines of the top-most seating units creates the pleasing 'wave' shape of the top perimeter of the grandstands. Forming this edge posed a complex challenge, because of all the inclinations and angles involved. Eventually a way was found to use segmented, straight steel beams between the pylons (see photo 6).
- The large external escape staircases are cantilevered from the main floor structures, completely free of the pylons. These consist of pre-cast flights, stitched together with in-situ landings (see photo 7).
- The 37 000 m^2 hanging steel and glass roof is the largest of its kind in the world. Wind-tunnel testing revealed unbalanced loadings in certain circumstances. Circumferential stiffening girder trusses were thus introduced (see photo 8).

SITE AND COORDINATION ISSUES

A fast-paced mega-project normally poses many site and coordination challenges to the design team. This was no exception:

- The Contractor divided the 'bowl' into four quadrants, allowing four teams to work concurrently. This meant that there were four 'learning curves'.
- The construction of the 13 000 m^2 double-storey podium structure around the bowl had to be carefully managed to ensure continued access for construction traffic and the mobile cranes used for the installation of the roof and the PC elements.
- Coordination of production, delivery and installation of the pre-cast seating units was critical, since they were stitched together horizontally on site and also inter-linked vertically.
- The installation of the roof, a column-free steel structure, onto precision bearings already cast into concrete pylons some 50 m in the air, required great accuracy. Extensive measuring and checking procedures were put into place.

AESTHETIC CONSIDERATIONS

The structural engineers had little say in the overall form of the stadium, but did make positive contributions to its appearance. These include:

- The curved, rather than facetted, PC concrete tier edge beams which echo the lines of the moat and the roof opening.
- The roof's lower fabric membrane which hides all the main structural members.
- The glass roof sheeting which not only provides weight against uplift forces, but also contributes significantly to the noise suppression required by the RoD.

CONCLUCION

Through perseverance and teamwork, the stadium was completed on time and has met with universal acclaim. □

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