Surveying on the Green Point Stadium

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Construction on Cape Town's Green Point Stadium got off to a somewhat controversial start, but is now well on the way towards its completion date at the end of 2009. The complexity of the stadium's design is providing some interesting and challenging work for the surveyors on the project.

As hosts of the 2010 FIFA World Cup, South Africa will see 64 football matches played in nine of its cities – Johannesburg, Cape Town, Durban, Port Elizabeth, Nelspruit, Polokwane, Bloemfontein, Rustenburg and Pretoria. For this purpose ten stadiums are being built or upgraded across South Africa. These stadiums are expected to seat more than 570 000 people during the World Cup.

The five stadiums under construction are located in the following areas – Cape Town (Green Point Stadium), Port Elizabeth (Nelson Mandela Bay Multi-purpose Sports Facility), Durban (Moses Mabhida Stadium), Nelspruit (Mataffin Stadium) and Polokwane (Peter Mokaba Stadium). The five stadiums undergoing upgrades are situated in Rustenburg (Royal Bafokeng Stadium), Bloemfontein (Vodacom Park Stadium), Pretoria (Loftus Versfeld Stadium) and Johannesburg (Soccer City Stadium and Ellis Park Stadium)[1].

Green Point Stadium

On completion the Green Point Stadium in Cape Town will be South Africa's second largest stadium. Situated between Signal Hill and the Atlantic Ocean, the multi-billion Rand stadium is being constructed on a portion of the Metropolitan Golf Course in Green Point. It replaces the 18 000-seater Green Point Stadium that was demolished in 2007 and will be surrounded by a 60 hectare urban park [2, 3]. The stadium is intended to have a capacity of 68 000 spectators and is scheduled to host five first-round matches, one second-round, one quarter-final and one-semi-final during the course of the 2010 FIFA World Cup.

Stadium design

The design of the Green Point Stadium is the most complex of all South Africa's world cup stadiums.

It will be 55 m at its highest point and the construction will involve 130 000 m^3 of concrete, 390 000 m^2 of formwork, 12 000 tons of reinforcing steel, 6-million bricks, a fabric façade and a unique steel cable tensioned glazed roof [4]. More than 1800 people are currently involved in its construction.

As the site where the stadium is being constructed is subject to high winds and has been labelled an area of potential seismic activity, the design has needed to accommodate high wind and seismic loading factors.

The stadium has a specific height restriction of 55 m stipulated in the environmental impact assessment (EIA) report and as a result it will not have the dome-shaped roof typically found on these structures. The need to accommodate the height restriction and to provide spectators with the best possible views of the pitch has added to the complexity of the roof design. To accommodate 68 000 spectators the height of the tiers has had to be maximised and, due to the

Fig. 1: An artist's impression of the completed Green Point stadium in its final form at night.

Fig. 2: Paul Edgecome, Dirk Wolters and Keith Lee of Edgeworks Surveys.

Fig. 3: Julian Gray of GNA Geomatics.

height restriction, the roof will have a complex, concave and super elevated roof structure.

The stadium structure itself comprises an external oval of 72 pylons which vary in height from 30 m to 50 m, and an internal network of radial concrete columns supporting 7 floors, lift shafts, and access stairways. Pitchside, the pylons, floors and columns support a series of raked beams creating 3 tiers on which more than 2000 pre-cast horizontal elements are mounted to carry the stadium seating. The 20 ton precast horizontal elements are manufactured off-site, delivered in the evenings and positioned on a daily basis using 250 ton and 450 ton Crawler Cranes.

The roof structure will primarily comprise a 1300 ton perimeter compression ring mounted on the pylons, an internal cable tension ring, steel trusses radiating inwards towards the pitch, and glass panels installed on top of the steel trusses.

The roof's construction will involve the compression ring, being placed on big box girder intersections that sit on top of all the 72 raked pylons. Seventy-two cable strands with the internal tension ring forming a doughnut, will then be strand-jacked into final position by huge hydraulic jacks. Secondary support in the form of steel trusses will then be hung all the way around and glass placed on top.

The roof's shape as well as the exterior fabric facade will reduce the noise level of the stadium by about six decibels, compared to the old Green Point Stadium. Unsightly structures such as flood lighting masts have been avoided by incorporating the flood lighting for the pitch in the hub [5].

This is the first time that a roof of this nature has been assembled in South Africa and it is scheduled to be installed by September 2009, ahead of FIFA's scheduled inspection at the end of October 2009 [5].

Contractors

Murray & Roberts in joint venture with WBHO are the contractors for the stadium. The project got underway in March 2007 and involves a 34-month programme from the date of handover to ensure completion in time for the 2010 Soccer World Cup [3]. The project managers are a consortium between BKS and MDA. The lead structural design consultants for the stadium are BKS. The lead architectural consortium is made up of GMP (the German architects responsible for the concept design) and Louis Karol Associates (the local architects of record). The work on the roof is being done by Birdair Pfeifer, a joint venture between US company Birdair and German firm Pfeifer. To date the net construction costs for the project stand at approximately R2,75-billion.

Surveying teams

Paul Edgecome of Edgeworks Surveys has been contracted to undertake the surveying work on the Green Point Stadium. Keith Lee and Dirk Wolters, along with six surveying assistants, are assisting Edgecome with all the setting out for the Murray & Roberts/ WBHO joint venture (see Fig. 2). The Edgeworks engineering surveying team also takes measurements for planning purposes and checks the volumes calculated by Martin & East, the subcontractors responsible for the earthworks, roads and services construction. Thaaniyah Abrahams is the surveyor for Martin & East.

A number of other surveyors acting for and on behalf of various contractors work on the project, all of whom look to the Edgeworks Surveys team for primary survey control and to ensure conformality between all surveys done on site.

High precision specialist Julian A Gray of GNA Geomatics, an MRICS registered geomatics engineer, has been contracted by the project management team to act as the quality assurance surveyor (see Fig. 3). Acting on behalf of the client, he is managing the various coordinate systems used by the various consultants and relating these to the project survey system as well as undertaking audit and 3D verification surveys of all primary and critical elements during the construction period.

Fig. 4: The 16 m tower that has been erected in the centre of the future pitch.

Fig. 5: Construction of the pylons is being done in lifts of 3,8 m. For each lift the formwork has to be positioned correctly.

Surveying operations

Surveying work on the Green Point Stadium involves the setting out of everything. This includes setting out the bases and columns, raked beams and pylons as well as the grid lines on the concrete slabs. Basically from the start of the job, this involves advising the construction team as to where to dig holes for the bases in the ground, and providing reference lines (grid lines) on blinding (the working surface inside a hole) to enable the construction team to position formwork and reinforcing steel required for the base. In the early stages of construction the survey work was quite difficult with the team surveying into holes 4 m deep that were surrounded by safety barricading.

Town survey marks (TSM) were handed over to Edgeworks Surveys by the client as the control points. (The TSM points are maintained by the City of Cape Town and are on the WG Lo19 coordinate system.) Although the TSMs were around the perimeter of the golf course, only two were used in order to establish the site control. The site datum for the project is mean sea level and was established from the TSM provided by the consultants. Planners for the Murray & Robert / WBHO Joint Venture initially used a base map provided by the consultants.

Initially based on the national grid system, a local system was created for the project, thereby removing all effects of scale correction applicable to any survey observations. As the construction progresses, additional control is installed as required.

At first eight 1,5 m high concrete pillar beacons with forced centring were constructed around the perimeter of the site and, once the initial stadium excavations had been completed, two further pillars were constructed on the future pitch of the stadium. The two pillars on the pitch were 4 m high, in order for them to be visible over obstacles.

Well into the project, John Trangos, the chief surveyor at Murray & Roberts came up with an innovative idea involving the erection of a 16 m high tower in the centre of the pitch. A Leica robotic total station was then mounted on top of this tower to assist with the setting out in general as well as the setting out for the embedded mounting plates for the roof structure. Management accepted the proposal and the tower was erected in January 2008 (see Fig. 4). It has proved to be a great success with good visibility from the tower enabling setting out to be done of all the various decks, slabs, raked beams and the pylons relative to one point.

An additional high precision control comprising a network of permanent prisms mounted on columns surrounding the pitch, has been established by GNA Geomatics using a Trimble S8 robotic total station to enable the positions of the embedded plates on the pylon tops, (upon which the roof structure is to be mounted), to be fixed to a high level of accuracy. As the 16 m central tower is subject to movement of up to 10 mm per day, it is necessary to fix its position regularly to ensure that the high levels of accuracy required for the setting out of critical elements is maintained.

Site surveyors are using free positioning techniques to locate their total stations in positions suitable for the setting out of bases, columns, raked beams and pylons and grid lines on the concrete slabs. A particularly challenging aspect has been the setting out of formwork in three dimensions, high above the ground under congested and very difficult conditions. The rodmen make extensive use of man cages to access high points, wearing safety harnesses to ensure their safety on high and exposed positions.

Tolerances

Although the setting out works undertaken by Edgeworks Surveys is expected to achieve an accuracy of 5 mm, their teams strive to achieve a standard error (SE) of 2 mm on all their surveys. Their field practises and procedures are designed to achieve this accuracy while faced with the difficulty of positioning flexible formwork, metres in size, weighing many hundreds of kilogrammes apiece. There is much inter-dependency between the setting out surveyors and the formwork positioning teams to enable the required accuracies to be met.

Several techniques are used when setting the tolerances. These include:

- Using forced centring on all the beacons.
- Using free positioning in order to fix the centre tower instrument position which minimises an error setting up over a peg.
- Using support poles to stabilise the prism pole when setting out.

High tolerances are required due to the seating being made up of precast concrete units which need to sit on top of the raked beams. If the raked beams are not built in the correct position, the precast units won't fit.

Being responsible for quality assurance, GNA Geomatics is required to guarantee results to an accuracy of 3 mm with 99% confidence, and therefore works to a SE of 1 mm for their survey operations. This is achieved through the use of specialist equipment and field procedures, and extensive numeric filtering and statistical checking of field observations prior to processing.

Precast seating

The precast seating is measured by the manufacturers and delivered to the site. The manufacturer has a surveyor on site checking the placing position of the precast seats (see Fig. 6). The precast manufacturer is a joint venture between Concrete Units and Cape Concrete.

Fig. 6: Checking the placing position of the precast seating elements from a 4 m high pillar on the future pitch.

Equipment

Edgeworks Surveys is using a Leica TCRP1201+R400 Robotic Total Station which is mounted on the centre tower and controlled by a RX1250Tc WinCE System 1200 Controller. They are also using a Leica TCRP 1203 R100 and a Leica TC 1000. Software packages being used include Leica Geo Office, Surpac, Model Maker and AutoCad.

GNA Geomatics is using the recently developed Trimble S8 high precision robotic total station , controlled by the Trimble TSC2 controller, and combined with a range of imported and customised high precision accessories. GPS work where applicable is done using the Trimble R8 GPS system, while sub-millimetre levelling is done using Leica levels with invar staves. Network and GPS processing is done using Trimble's TGO, and the 3D analysis of the structure scans is done using System Euclyd, a specialist 3D analysis software package developed by GNA Geomatics.

As the S8 has only just been released worldwide, this is one of the first high precision projects on which the instrument is being used. There is very close cooperation between GNA Geomatics and the S8 development team (Sweden), the Trimble TGO development team (USA), and the local Trimble suppliers (Optron, Cape Town). Other software being used includes Civil Designer, AutoCad and various other proprietary CAD packages.

Challenges

Construction of the Green Point Stadium has provided the survey teams with some interesting challenges.

Shape of the stadium

A major surveying challenge has been provided by the oval shape of the stadium. Basically each row of columns is in no relation to the adjacent column. The professional consultants are using an elliptical and radial grid system to reference the internal elements of the stadium. There are further grid systems defined for the external works and for the roof structure. These systems need to be combined and converted into the survey system used by the field teams. GNA Geomatics is tasked with overseeing this operation in collaboration with the architects who manage the drawing database for the stadium development, to ensure that the integration and conversion of the various systems is successfully executed.

Complexity of the site

The site itself is highly congested. The primary construction area is approximately 300 m^2, with over 14 tower cranes, mobile cranes, telescopic handlers, articulated dump trucks, excavators of various sorts and sizes, ready-mix concrete trucks, mobile concrete pumping units, delivery vehicles, tractor trailer combinations, and fork lifts amongst others, operating within this confined space, which also contains the stadium itself, secondary steel yards, rebar preparation areas, a berm and haul road and various office complexes. There are also over 1800 workers on the site. The survey teams do not have the luxury of ideal locations for their instruments and need to operate quickly and accurately within this extremely busy location.

Pegs cannot be knocked into the ground and be expected to remain in position especially when such high tolerances are required. With vehicles and materials being moved around the pegs are often damaged. To compensate for this the surveyors have kept the required information onboard the total stations, then basically fixed the position of their instruments and set the required marks where the construction employees are working.

Pylons

Construction of the stadium's 72 pylons is the biggest surveying challenge on the project so far (see Fig. 5) . To accommodate the roof design, the pylons vary in height by 11 m with the tallest pylon being 50 m high and the shortest 39 m.

Fig. 7: Raked beams on which the 20 ton precast seating elements will rest.

A pylon is 800 mm wide, 3 m long and is constructed at an angle of 17,35°. The construction on the pylons is being done in lifts of 3,8 m and a pylon may consist of anywhere between seven and ten lifts. For each lift the formwork has to be positioned correctly.

Finding a practical solution to setting the pylons was the first challenge. One could calculate the position of each corner of the pylon at the elevation of each pour, but this would mean that the formwork had to be positioned to an exact elevation. Practically this wasn't going to be achieved. If any movement occurred, new coordinates would have to be calculated.

Edgeworks Surveys decided to calculate a coordinate for the top outside centre and the bottom outside centre of the pylon. These two coordinates established the orientation as well as the slope or rake of the pylon. By using the reference line program on the instruments it was possible to adjust the formworks verticality or rake at any elevation. Once this method was settled on, the actual site work was relatively easy.

The surveyors are responsible for positioning the formwork correctly before the concrete is poured and for rechecking and adjusting the position after the concrete has been poured. The wet concrete weighs about 18 tons and the formwork about 3 tons, making it a huge weight to try and push around. This is sometimes tedious and frustrating work. It is essential therefore that the formwork be in the precise position and to secure the formwork, in order to minimise the movement. Fortunately, the control has been very stable and this has enabled the surveying team to work as accurately as possible.

While the Edgeworks Surveys team devised a successful method for positioning the formwork, GNA Geomatics developed a scanning and analysis procedure which takes into consideration the deviations of each of the lifts while extrapolating the readings to determine the accuracy to which the pylon should achieve its final location in space, in order to accurately accept the embedded plate upon which the roof elements will be mounted. Between the two teams, the pylons that have reached their final lift have done this successfully to date.

Roof construction

Surveying work for the stadium roof is quite tricky. The design information provided by the consultants was on a different grid system and was only for a quarter of the stadium. It then had to be related to the project's coordinate system.

Surveying work on the roof structure has recently started with the assembly of the first two embedded plates. This involves adjusting the formwork that is going to hold the concrete for the last section of the pylon and then positioning the embedded mounting plate. Once the embedded mounting plates in the roof are positioned the engineers need to ensure that the pylons do not move when the actual weight of the roof is placed on these plates during the assembly of the roof structure. The engineers intend allowing for this movement by adjusting the plates slightly.

As part of this process GNA Geomatics provides the results of the extrapolation data to the design engineers who use this information to adjust the design location of the embedded plates for construction deviations and the anticipated deflections in the pylon due to the weight of the roof structure and concrete shrinkage and creep after pouring.

Using a specially manufactured jig, the embedded plates are mounted in three dimensions on the adjusted location with the use of the central control pillar by the Edgeworks Surveys team. Once the plate has been cast and the pylons settled into their final positions, their final locations are surveyed in three dimensions and radial orientation, to millimetre accuracy, using a specially manufactured prism mount by GNA Geomatics from independent control. This information is then used to confirm the final location of the plate and to verify that the roof structures will mount correctly on the plates.

When the installation of the roof structures are started, it is anticipated that both survey teams will be extremely busy with the setting out and checking procedures, while the roofing contractor will also make use of his own survey team. The high precision total stations will come in handy with this element of the work. It is also anticipated that use will be made of terrestrial scanners to capture and analyse mass data of the structures during the erection process.

While the survey teams understand the complex three dimension vagaries of the survey systems, the management teams are not trained surveyors, challenging the manner of presentation of results. Extensive use is made of simple graphics and clear, uncomplicated spreadsheets. Although GNA Geomatics uses 3D graphic imaging and displacement vectors for the analysis of the results, this has proven too complex for the client's decision-making process, and much time and effort was needed by both survey firms to produce simple and clear reports on which critical decisions could be easily and reliably made by the management teams.

As-built surveys

A large amount of the Edgeworks Surveys team's time is spent doing as-built surveys. This entails surveying concrete structures using the reflectorless feature on the Leica TC 1200s, then comparing the as-built position to the design position. Monthly reports are then submitted to the consultants.

The greatest challenge here was presenting understandable as-builts of the pylons. Each pour of 3,8 m had to be checked and a comparison done to the design. This involved surveying four points on each pylon at each lift. Considering that there are 72 pylons, this amounts to a lot of observations.

The surveyed points were then dumped into a CAD drawing and the vertical sides of the pylon could simply be dimensioned from the gridlines. The raked sides were more difficult. The team needed to be able to compare the as-built position with the design's position anywhere along the sloping surface. This required that the pylon be drawn in 3D. A dimension could then be taken from the surveyed point to the design surface. This provided the information, but looked very confusing in plan view. The data could then be tabulated but still required a clear head to interpret.

Quality assurance surveys

Extensive use is made of the quality assurance surveys undertaken by GNA Geomatics by the project management team to independently monitor the accuracy and progress of the project. In accordance with the "Team Green Point" attitude of all involved with the project, there is close cooperation between Edgeworks Surveys representing the contractor, and GNA Geomatics representing the client. Information and data is freely passed between both teams, all the while preserving the independence of the checking procedures. Both parties have one goal in mind – to construct the stadium to the accuracies required – and through joint co-operation this has been successfully achieved to date. Edgeworks Surveys present their reports to the contractor, while GNA Geomatics presents their reports to the project management team.

Conclusion

Construction of the Green Point Stadium is proving highly challenging to the surveyors working on the project and this has been compounded by the need to meet tight time schedules. Much lateral thinking has been required to solve the unique and unusual survey problems and the survey teams are proving themselves up to the task. Overall "Team Green Point" is satisfied that the stadium will be constructed "on time and within specification" for handover to FIFA by 15 December 2009, and this certainly seems to be the case.

Acknowledgements

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