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Civil Engineering

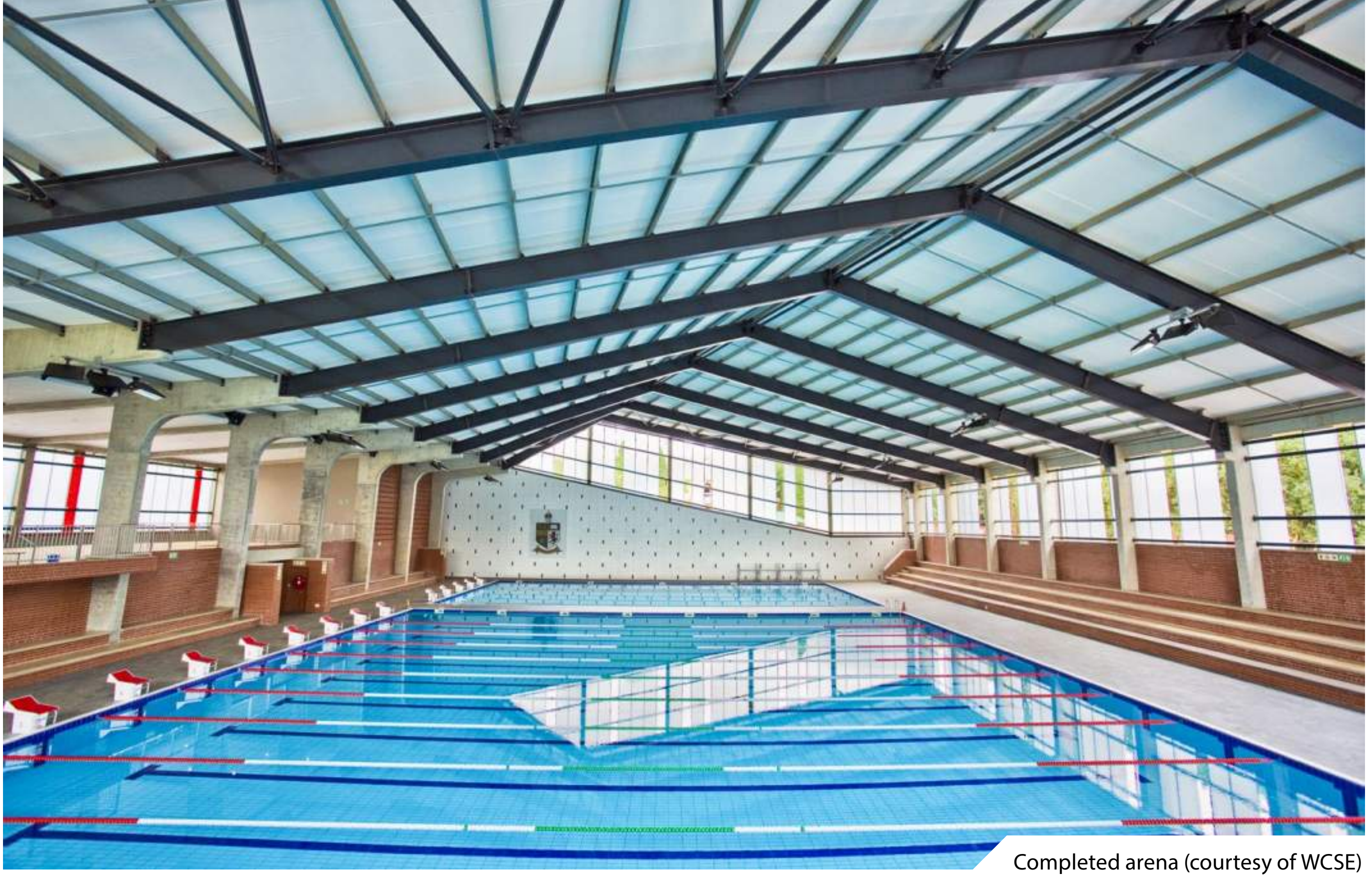
Sivili Enjeneereng

THINKING LIKE AN ETHICAL ENGINEER IN CHALLENGING TIMES

NO STEEL, POOR SOIL: NO PROBLEM FOR PRESS PLANT CONSTRUCTION

WATER WEEK – MOVING PAST PROMISES AND RHETORIC

TRM PILING



Completed arena (courtesy of WCSE)

KES Aquatic Centre – a structural engineering feat

The King Edward VII School (KES) Aquatic Centre, located in Houghton Johannesburg, comprises the redevelopment of the previous uncovered aging school swimming pool into a world class aquatic centre to be used for swimming and waterpolo by both the junior and high schools.

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The architectural design maximised the existing swimming pool site to encompass a 2 750 m^2 covered, yet naturally ventilated aquatic centre that includes two large new pools and a learn-to-swim facility. Within the covered area, a new double storey adjoining structure houses the changing rooms, upper viewing platform and plant rooms, while keeping and upgrading the original 1920s northern entrance to the pool area and stand – a structure with significant heritage value to the school.

A focal point of the development is the intricate feature roof with clear spans over the pools and an intriguing, stepped apex creating an unusual form and space.

PROJECT INCEPTION

The existing swimming and waterpolo facility at KES comprised two pools – a large 25 × 25 × 2 m deep pool and a small learn-to-swim pool. These pools and the paved eastern section of the facility were additions and upgrades done in the mid-1990s, while the far older entrance and stand to the north, seating to the west, and changing block to the south, were constructed in 1927 as the original swimming bath.

Other than general aging of the surrounding structures, the learners were missing out on many hours of training and galas due to lightening over the course of a typical Highveld summer season. In addition, the large pool was too short and slightly too shallow for first class junior waterpolo.

Thanks to an exceptional donation from an alumnus of the school, the pool facility could be fully upgraded to enable top level competition and training over an extended period, under cover.

KES invited selected architects to provide a design solution in early 2018 and Shed Architecture + Design was selected. The remaining core professional team – comprising WCSE as the structural and civil engineers and Jan Pienaar & Associates as the quantity surveyors – was appointed to take the winning architectural concept through a preliminary design stage to confirm budget costs.

DESIGN DEVELOPMENT

The design called for new swimming pools, and pool specialist Water Dimension International (WDI) was subsequently appointed. Following a lengthily consultation with the school, the following new pools were confirmed:

The existing pool site showing the original 1927 north entrance (courtesy of WCSE)

1. Main waterpolo swimming pool
   - 28 × 25 × 2.3 m deep tiled heated pool
   - 25 m pool with first class school waterpolo capabilities
   - 10 swimming lanes built to FINA specifications
   - Extended heating (allowing for six weeks extended use either side of summer).
2. Swimming, waterpolo training, and learn-to-swim pool
   - 12 × 25 × 2.3 m deep tiled heated pool with 3 m wide learn-to-swim lane of varying depth between 0.5 and 1 m
   - 25 m pool with waterpolo training capabilities
   - Five swimming lanes built to FINA specifications
   - Double safety lane and full depth tensioned safety net between learn-to-swim lane and standard pool
   - Year-round heating.

WCSE undertook to design a fully reinforced concrete (RC) shell for both pools to provide a robust and durable structure to which WDI would apply all the necessary finishing and filtration requirements. Upfront design co-ordination and discussion on the aggressive corrosive nature of the treated pool water was debated, as well as the best waterproofing methods to be used for such large, tiled pools. This resulted in the following design solution:

- High strength 40 MPa concrete for durability with Penetron waterproofing additive.
- Increased concrete cover at the pool face of 60 mm.
- Design the 250 mm thick RC shell to a maximum crack width of 0.30 mm to BS 8007 using closely spaced small diameter bars.

Large pool base reinforcement and first western roof column cast (courtesy of WCSE)

- Cast the inner pool surfaces to a high degree of accuracy to ensure the stringent final pool dimensions.
- Allow for and co-ordinate the filtration system box-outs in the initial casts that could be treated with Penetron joint details and infill requirements to ensure watertightness.

Large, modern pools such as these are costly due to the high quality imported tiled finish, the high accuracy of the works, and the integrated complex automated filtration, chemical dosing, and cleaning systems. A waterproof concrete shell complimented this technology to ensure that the core of the facility was an integrated and appropriate design solution that would provide may years of service.

FEATURE ROOF

The architect envisaged a feature roof that would span 38 m over the pools and connect the new eastern double storey block to the original northern entrance and seating area. The concept called for the stepped apex, of consistent height above the pools, to slide on plan by 20 m over the 56 m length of the roof, or 360 mm shift per metre length. The architectural intent of the space required a slim neat structural solution to enhance the arena. Through several conceptual iterations, the design for the feature roof was chosen as a complimentary combination of structural steelwork and reinforced concrete elements.

The long-span steel rafters required a high strength-to-weight ratio and fabrication versatility due to the stepping apex line. The roof was to be a focal point and the desire was for a sleek elegant solution that did not resemble a trussed "busy" roofscape. To provide this, portalised structural steel plate girders (720 × 300 × 137 kg/m I-sections) were chosen for the non-identical rafters.

Through collaborative verification design between WCSE and The Structural Workshop, the steel design of the roof was finalised. This included circular hollow section braced bays and the sheeting support criteria for the double-curved sheeted surface. The cold rolled purlins were set out to enable the use of standard concealed fixed sheeting – Zip-Tek 420 sheeting by GRS. The converging layout of these purlins was left exposed to create intriguing lines to the internal surface of the roof together with the underside of the white Lambdaboard insulation.

The new eastern block, housing the changing rooms, filtration, and dosing plant room at ground level and a viewing area and heat-pump plant room on the first floor, provided a solid element from which to support the long span roof from this side. The block was regular along the length of the building, making it an ideal element to provide east-west stability to the roof.

To create a unique and contrasting feature to the lighter and slimmer long span roof, a feature "diving" architecturally exposed RC column and cantilevering beam was proposed for the internal support of the roof rafters. Behind these, and over the eastern block, standard high quality RC beams and external columns completed the eastern portalised support frames. These frame elements were repeated along the length of the building on a grid at a typical spacing of 6 m. Each eastern frame consisted of:

- 400 mm wide special smooth portal frames of 50 MPa concrete with a height above ground floor of 8 m to 9.245 m.
- Feature "diving" column varying in width from 1 000 mm to 1 200 mm with a 5.195 m long cantilevering beam over the eastern edge of the pools with a 600 mm long end seat for the plate girder rafter vertical shear load.

Stripped eastern feature cantilever beam (courtesy of WCSE)

- Back span of 600 mm deep RC beams to the external face of the building spanning 9.335 m onto the external 400 × 600 mm column.

The western support of the long-span roof was chosen as a set of nine bold, reinforced 1 200 × 400 mm by 8 m high special smooth finish concrete columns cast with 50 MPa concrete with a 300 mm long corbel for the plate girder rafter vertical shear load.

On the eastern and western facades between the feature RC frames and columns, a set of concrete eaves beams were added.

The structural design of the feature roof had reached a point where the material selection had been done on appropriateness of function, form, and constructability in using both reinforced concrete and structural steelwork to their individual strengths. But the union of the two materials required an innovative solution.

At the junction of the plate girder steel rafters and the supporting stabilising reinforced concrete elements, a robust yet elegant connection was required that would be visible from within the arena. To limit the depth of the roof structure, the structural system chosen was a double portal frame, namely the 38 m span portal over the pools and the shorter 9.335 m span portal over the eastern block. As a result, there are significant moments to transfer at the two concrete to structural steel connections.

Initially, a custom cast-in steel plated and shear studded element was considered, but due to the condensed reinforcement required in the concrete elements in these zones this was problematic and would have resulted in a larger concrete section at this junction. A more suitable and refined solution would be a cast-in anchor with coupler, but the loads developed in tension were over 300 kN each in areas; higher than typical anchors' capacities on the local market.

WCSE investigated whether Peikko SA's high-strength COPRA anchor and coupler system, typically used in precast concrete connections in Europe, could be adapted for this purpose. Following a rigorous suitability exercise, including the full design of the COPRA anchors to the Eurocodes and ETAG 001 anchor requirements by Peikko Europe, the following was approved for the critical connections:

1. Eastern connection:
   - Moment capacity of 544 kNm required at junction of plate girder and RC beam.
   - Six no. COPRA 39H-P anchors required, each with a coupler for a M39 bolt on the steel side and high strength 40 mm diameter reinforcement bar on the concrete side.
   - Anchors' reinforcement custom bent to suit connection and concrete form requirements in Europe by Peikko prior to importing.
2. Western connection:
   - Moment capacity of 848 kNm required at junction of plate girder and RC column.
   - Eight no. COPRA 39H-P anchors required, each with a coupler for a M39 bolt on the steel side and high strength 40 mm diameter reinforcement bar on the concrete side.
   - Anchors' reinforcement custom bent to connection and concrete form requirements in Europe by Peikko prior to importing.

The use of these Peikko COPRA anchors in such a way to create significant moment transfer at a concrete and structural steel interface of a long span roof is a first in Africa, and one the project team is particularly proud of. In fact, the use of the COPRA range of anchors had not been done in Africa before, creating excitement both locally and within Peikko's European base.

SUSPENDED FLOOR

The final element of the superstructure was the suspended first floor of the eastern block.

To eliminate vertical supports in the plant room and enable flexibility in the changing room design, a flooring solution capable of carrying the 650 kg/m^2 imposed loading over the 9 m clear span was required. To provide this one-way spanning solution, a precast prestressed concrete hollowcore plank and in situ structural topping system was proposed. These planks were supported on either loadbearing brick walls or on in situ RC beams where openings were required at ground level. This provided a prefabricated solution that was lighter than an in situ solution and

Aerial progress photo prior to the Covid-19 lockdown (courtesy of The Structural Workshop)

faster to construct with an optimal load capacity to weight ratio for a concrete slab solution over this span.

Below the superstructure, a standard concrete surface bed with typical joints on compacted fill was designed for all ground floor slabs. The superstructure was supported off deep piled foundations – cast in situ reinforced concrete augured piles with reinforced pile caps and ground beams. The RC ground beams along the eastern and western façade between supporting piles on grid acted both as the vertical support of the façade brickwork and the horizontal restraint via passive earth pressure to resist the base horizontal thrust of the roof. The pile sizes ranged from 450 mm to 600 mm in diameter.

CONSTRUCTION

The piling work was carried out by Pilecon using 25 MPa ready-mix concrete supplied by Metier Mixed Concrete. The piles ranged in depth from 4 m to over 15 m, and the 40 piles were cast in eight days during August 2019.

The waterproof reinforced concrete shells for the two swimming pools were constructed by the main contractor Akhane Construction using an approved Penetron joint applicator between October 2019 and August 2020. The extended construction period was due to two factors: the forced Covid-19 lockdown period and staggered construction times to allow for other critical construction works within the confined site. WDI completed the finishing on the pools, including all filtration and cleaning systems, by November 2020 and the pools were filled and commissioned in December 2020.

The eastern portal frame and western columns supporting the feature roof were workshopped and Akhane Construction proposed that each set of east and west elements be cast together and in one lift each. The western column was a standard lift of 8 m, but the eastern portal required both columns, the roof beam, and the extending cantilever beam to be cast in one. Both east and west elements required the fixing and accurate setting of the Peikko cast-in anchors to allow for the port structural steelwork erection.

Form-Scaff was appointed as the specialist formwork supplier for these elements and produced customed-made steel shutters in accordance with the project requirements. The formwork allowed for accurate setting out and fixing of the Peikko anchors with pre-drilled end plates which enabled the anchors to be set in position and bolted to the plate. In addition, the formwork at eaves beam level had openings to allow for the transverse portal beam cast-in reinforcement to protrude and be cast with the associated element.

The concrete mix design was altered slightly to be a 13 mm aggregate 50 MPa mix. The reduction in aggregate size was done to assist with the highly congested reinforced zones and in producing a high quality special smooth finish. Compaction was done via two extended length poker vibrators using a controlled pour rate.

The first set of feature roof supporting elements was cast in October 2019, with the ninth and final set cast successfully in December 2019. This allowed sufficient time for the planned plate girder installation to occur over two days in mid-January 2020.

The hollowcore planks for the first floor of the eastern block were delivered and erected on site over two days in early February 2020. The planks supplied by Concrete Slab Supplies (CSS) for the project were:

- 250 mm FabPanel sections.
- 50 MPa concrete mix.
- 8 × 12.7 mm bottom and 2 × 9.53 mm top prestressing stands.
- Panels cast in their slipformer imported from Brazil, with strands tensioned to 70% GUTS of 1 860 MPa, and de-tensioned at 35 MPa concrete strength.

Some time after the project commencement, KES decided to renovate and add onto the entertainment area within the original northern entrance building. Part of this work involved the removal of a sheeted roof and addition of a flat concrete roof. To limit the additional load on the original brick walls and foundations, and to aid construction time, CSS supplied a 50 m² rib and block slab using their S150 block and 50 mm thick topping. The rib and blocks were installed in March 2020 prior to the Covid-19 lockdown and the topping was cast in May 2020 once the site had been cleared for construction to re-commence.

All other concrete works were constructed by Akhane Construction, including the main entrance special smooth double storey frame and exposed aggregate arena seating.

The project was completed in December 2020 and is due to be officially opened by the school in early 2021.

IN CONCLUSION

The KES Aquatic Centre proved that upfront collaborative design engagement can result in a combined architectural and structural engineering solution that not only compliments the original intent of the architect's design but enhances it. The early-stage emphasis on thorough design enabled the main contractor to price the works accurately and plan the critical tasks together with the design team to ensure that the design could be constructed as envisaged to the required level of accuracy and quality.

The project required a true team effort – fitting for a facility that will foster teamwork and excellence in swimming and waterpolo, and perhaps inspire some to consider a career within the built environment. ◻

PROJECT TEAM	
Client	King Edward VII School
Project manager & architect	Shed Design + Architecture
Civil & structural engineer	WCSE, in collaboration with The Structural Workshop
Quantity surveyor	Jan Pienaar & Associates
Pool specialists	Water Dimensions International
Main contractor	Akhane Construction
Ready-mix supplier	Metier Mixed Concrete
Piling subcontractor	Pilecon
Specialist formwork	Form-Scaff
Heavy duty anchor supplier	Peikko South Africa
Precast and rib & block supplier	Concrete Slab Supplies
Waterproofing additive	Penetron SA
Steel fabricator	Tass Engineering
Sheeting supplier	GRS