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King Shaka International Airport

structural engineering and construction features

OVERVIEW

The King Shaka International Airport and the Dube Trade Port, located some 35 km north of the Durban City Centre, is a strategic and critical infrastructure development which will serve as a catalyst for economic growth in the KwaZulu-Natal region and South Africa.

Following an invited bid process to design and construct the airport, the Ilembe Consortium bid was accepted in November 2006 with construction commencing in September 2007.

The 2 000 ha site, with a runway length of 3 700 m (sufficient for the latest wide-bodied aircraft), and with runway and taxi areas of 400 000 sq m, can initially handle 7,5 million passengers with an extension provision to 45 million passengers per annum.

Besides the terminal of 100 000 sq m, other buildings include a 15 500 sq m cargo handling building for 150 000 tonnes of cargo per annum, a 60 m high control tower, a multi-storey parkade, and airport ancillary buildings. Access to the complex is principally by means of a new three-level interchange from the nearby N2.

The whole project, with a total value of around R8,4 billion, was completed in 32 months, being an outstanding achievement and setting a new benchmark for the South African construction industry. The project was awarded a Commendation in the Technical Excellence Category of the 2010 SAICE Awards, and was the joint winner in the Infrastructure Category of the SAISC 2010 Steel Awards.

Four structures, being unique features of the airport complex, are described here.

TERMINAL AND AIRSIDE CORRIDOR

The most significant building on site is the passenger terminal and associated airside corridor complex. The 100 000 sq m building comprises a basement, arrivals level, baggage handling, departures level, lounges and offices, and plant room block within the envelope. The airside corridor of some 560 m length, facing the apron, taxiways and runway feeds 14 fixed bridge links to the aircraft.

Foundations

The original geotechnical surveys, together with further boreholes and dynamic probes, indicated that the building was located over a filled valley arising from earlier earthworks. The engineered fill was satisfactory for surface beds, pavements and light buildings, but was not suitable to support large foundation loads. Soft to hard rock was anticipated at depths varying from 5 to 15 m below existing ground level. For the terminal, "Franki" proprietary 610 mm diameter pre-drilled cast *in situ* piles of 225 tonnes capacity were based above bedrock, in a cohesive fill or residual material comprising predominantly sandy clays.

1 Aerial view of terminal complex at the new King Shaka International Airport north of Durban

For the airside corridor, a similar but lighter solution using 90 tonne 410 mm diameter piles were used. Reinforced concrete pile caps, comprising pile groups up to 15 piles, support all structural column loads.

Basement

The 8 m deep basement was determined by plant clearance requirements and a service transfer zone located directly below the arrivals level slab.

The concrete surface beds were designed to accommodate loads on an imported subbase layer over the fill, being independent of the building shell. Specific air-conditioning plant machinery foundations were isolated. Although there is no water table as such, perched water could develop over impervious fill or rock. A basic subsoil drain system was therefore installed at surface bed level, discharging into a pumped tank system.

In certain storage rooms where condensation or minor weeping on the internal concrete face due to temperature differential could be a concern, an independent brick skin separated by an air gap was built internally, with associated drainage into the subsoil drain system.

Suspended slabs

The arrivals and departures suspended floors of over 60 000 sq m comprised the largest portion of the structure. Value engineering the optimum spans with available building systems, in conjunction with architectural building module requirements, indicated a 725 mm overall reinforced cast *in situ* concrete slab beam and coffer system supported on a 15 m by 15 m grid. This system utilised the proprietary and readily available quick strip coffer system on a 900 mm module, with 525 mm deep coffers and 200 mm slab over. The slab depth was sized to accommodate heavy plant and cranage wheel loads during construction.

This section of the structure remained on the critical path for a considerable period of the construction programme, leading to concrete pours of up to 1 100 cu m being achieved from the site batching plant.

In certain areas the public assembly loading was enhanced to provide support for a mezzanine office framework comprising a structural steel frame, 32 mm plyboard floors and drywall partitions. On the airside portion of the first level departures slab, the baggage handling system was hung from under the slab.

The levels of suspended slabs providing the arrivals and departures corridor links to the terminal, together with associated ramps, were constructed with a conventional reinforced concrete-framed structure. These structures comprise *in situ* reinforced concrete flat slabs, 250 mm thick at typically 7,5 metre support centres. This system was chosen to eliminate all downstand beams, in so doing facilitating rapid construction.

Roof structure

The architects' brief to express the primary elements of the roof support was developed into a system of ranking structural steel tubular struts springing from structural grid points, supporting deep tubular "toblerone" triangular girders as the primary featured system. Above this level, a convention structural steel lattice truss and purlin system provided the secondary roof cladding, service and ceiling support. The structural system is in essence a series of primary one-way continuous girders spanning up to 60 metres. The girders are spaced at 35 m centres, with a secondary orthogonal system supporting the purlins and roof fabric.

Due to the strategic nature of the roof structure, it was considered good practice to build a level of redundancy into the structural system using continuity over support points.

The office block is located at approximately one third of the building length, which laterally braces the roof, with the

main girders being tied into the upper plant room level as continuous elements. All in-service longitudinal movement was then controlled by sliding teflon pad bearings at the peripheral support points.

Fabrication of the girders into large elements that were erected from the slab levels, facilitated a rapid and cost-effective erection process.

An elevated roof light monitor structural portal frame beam structure was located above the roof line centrally between the main girder axis grids of the building.

The glass façades are typically supported by an independent structural steel mullion system, at 6 m centres, to tie in with the roof module. Due to their overall length at the air and landside, careful consideration of the building movement was required. The landside departures façade is the entrance feature into the departures hall utilising glass and steel integrated with the main roof girders.

All fabricated structural steelwork, other than purlins, was Grade 300 W hot-rolled, including the tubes (large diameter tubes imported from the United Kingdom). The purlins were fabricated from cold-rolled sections and galvanised.

Quality control of the welded site-assembled connections was strictly enforced, using X-rays and ultra-sound testing non-destructive techniques. All steelwork was sand-blasted, primed with organic zinc primer, a barrier intermediate coat and finished with polyurethane enamel.

A careful evaluation of the suitable roof materials available, considering the long run-off length, low roof pitch and long-term durability, led to the selection of colour-coated aluminium sheet, roll-formed on site, clip-fixed without penetration to the purlins. The sheet is laid over an acoustic layer comprising two layers of gypsum board and mineral wool to attenuate sound penetration.

CARGO HANDLING BUILDING

This 15 500 sq m facility provides the transfer point of the Dube Trade Port with storage direct to the apron of 150 000 tons per year at this stage.

2 Departures hall
3 South view of terminal complex
4 Cargo handling hall during construction

Foundation

Evaluation of the original geotechnical surveys, together with recent dynamic probes, indicated that the building was located within a zone of deep fill material, placed during the original site development. The boreholes indicated consolidated granular but varying fill material, to a depth of up to 40 metres over natural ground.

It was not economically feasible to pile to that depth, considering the relatively light magnitude of loading. An engineered fill layer of G5 material of 1 m thick provided a stable founding system with acceptable small differential settlement. This had particular relevance to the structural surface bed supporting the cargo handling systems.

For founding of the heavier office block section and relatively light loading of the building structural frame, the predominant loading being due to wind stability, pad footings founded into the engineered fill material with a bearing pressure of 100 kpa were utilised. Small order differential settlements along the length of the building, due to the varying nature of the existing soils, were within the limit of normal building tolerances.

The degree of consolidation evident from *in situ* testing undertaken, indicated that the founding material was suitable for the support of the cargo storage rack loads, being transferred through unreinforced concrete pavements.

Surface beds

Significant specified loading conditions are applied to this area, due to the storage racking and fork lift wheel load applications. The independent "floating" slab system comprised unreinforced concrete *in situ* slabs, with jointed panels, cast over the 1 m thick imported G5 material on a 150 mm G4 layer compacted to 98% mod AASHTO density subgrade layer. Three cases of loading were applicable:

1. *ETV rail area*
   The movement of the storage modules within the racks was by means of an electronically controlled rail-supported transfer vehicle with a 680 KN dynamic load on each wheel at 8,64 mm centres using two wheels on mono rail.
   ULD racking post loads of 230 KN per post at 3,4 m by 3 m centres were designed for. Vertical deformation under load became the major design consideration, due to local slope deformation being limited to 0,5 mm per 1 000 mm or 1 in 2 000.
   Global settlement of the building was anticipated to be in the order of 120 mm, but uniform, and was ignored. However, due to the surcharge loading of the ETV area, a differential settlement of 23 mm was estimated along the 180 m length of the rail.
   The design of the founding for the ETV rail was typical stiffened cellular raft configuration with a bending deformation in the order of 12 mm, resulting in a total deformation under load in the amount of 35 mm (i.e. 23 + 12 mm) which is less than the acceptable 54 mm over the 108 m length.
2. *Static high bay racking area*
   The post load of 100 KN per post at 3,7 m by 1,05 centres was designed for. The forklift tyre load assumed a forklift load of 38,7 KN per wheel. Slab thickness utilised varied from 420 mm of 30 MPa concrete.
3. *General floor storage area*
   The forklift tyre load assumed a forklift load of 38,7 KN per wheel. Slab thickness utilised was 235 mm, of 30 MPa concrete.

Building structure

The framework to support the enclosure of this large building comprises in effect two systems – a reinforced concrete beam and coffer slab system for the landside office section, and a structural steel framed lattice truss and girder system over the cargo handling area. The structural module of 6 m and the large clear span layout of 34 m were driven by the cargo handling operation.

The use of deep structural steel lattice trusses and girders gave the opportunity to provide large clear spans over the racking section, with major internal columns at 24 m spacing.

All steelwork was sand-blasted, primed with organic zinc primer, a barrier intermediate coat and finished with polyurethane enamel.

In keeping with the long-term life span and low maintenance of all buildings, colour-coated aluminum sheet was selected, roll-formed on site to a continuous length for each span, and clip-fixed to the purlins.

5 Completed cargo handling hall

CONTROL TOWER

The highest point on the new airport site is the control tower cab – now a defined iconic landmark. The operational requirements dictated a three-floor module, comprising 360˚ clear uninterrupted sight lines at the top controller level of 20 m diameter, at an eye level of 55 m, with service and equipment levels located on the two floors below. It was agreed that aesthetically the tower shaft should be as slender as practical, with the cab expressed as a clean tapering module clad with glass and aluminum panels. The challenge for the design and construction team was how to position this cab module at that height, within the time constraints of the project programme.

Foundation

The original geotechnical surveys indicated that the tower was located over a deep filled valley, arising from earlier earthworks, with the bedrock level in excess of 20 m.

The solution comprised "Franki" proprietary-type driven 610 mm diameter cast *in situ* piles, of 225 tonnes, based in the upper dense sand layer, of 8 m, which acted as a soil raft to distribute the load through the clay layer beneath.

A single 15 m x 11,5 m x 1 500 mm deep pile cap supports the main tower shaft on 24 piles, with the adjacent relatively light-weight single storey sheeted roofed structure simply founded into the consolidated fill material on pad foundations.

Structure

Due to the relative height of the tower, the method of construction became the principal consideration. Structural material stiffness was also required to provide stability and limit deflections at the control room level. The dominant loading in this case was wind with a return period of 100 years considered. The characteristic


We
Models

wind speed was based on category 2 terrain for a 5 second gust.

A 35 MPa reinforced cast *in situ* concrete shaft using the slip-forming technique was used with the internal shaft providing stair access, services fixings and lift guides, post-fixed using structural steel.

A detailed dynamic analysis was undertaken modelling the pile foundation, pile cap, shaft and cab lumped mass, to evaluate wind load response and serviceability performance.

To facilitate a cost-effective buildable solution, the structure for the three accommodation levels and roof comprised a structural steel framework fixed to the shaft.

A three-dimensional analysis was undertaken of the conical "doughnut" form in the fully assembled erected stage, thereafter being braced by the tower in the final fixed position.

The complex three-dimension steel structural framework consisted of four radial trusses free of the shaft core, braced circumferentially about the tower at each floor level. The shop details were created using a proprietary modelling package, which contributed immensely to understanding the layout of the system and provided the accuracy required for the erection.

Conventional hot-rolled sections and plate were used, covered with high quality coating systems, and all connection sites were bolted.

The three upper floor slab levels were formed in *in situ* reinforced concrete due to durability, cast on bondek permanent formwork over the steelwork.

The roof covering comprised an acoustically rated ply-board and fibreglass system with trapdoor access, to accommodate lightning and aerial masts. The external façade cladding was formed from corrosion-resistant prefabricated aluminium and glass curtain wall system.

6 Control tower cab being erected

Construction

The shaft being of ribbed profile to control staining of the constant cross-section, was therefore constructed using reinforced concrete placed using the sliding-shutter technique. The shaft was cast within a single 3 m shutter length, continually lifted by jacking off the sections cast below.

Now, how to construct the cab at the top of the shaft – some 50 metres and 18 storeys above the ground!

The solution was to firstly erect the structural steelwork frame about the shaft at ground level, but independent of it, supported on four symmetrically balanced points just clear of the shaft. In this configuration, the external façade cladding was installed, together with a stability portion of the concrete floors, cast on permanent steel-profiled sheeting.

A structural steel-lifting frame was then erected at the top of the shaft, designed such that it became part of the final structure at the control floor level.

Although the erection procedure was simplified by being carried out from ground level using conventional craneage, a high level of survey accuracy was required to relate the ground level framework to the future four matching bolted support beams at the top level. This was achieved thanks to the excellent coordination between the surveyor and the erection crew. The focus of the project then became the actual lifting of the cab to the final level.

The partially constructed cab of some 350 tonnes was then hung from the four support points, using a conventional proprietary post-tensioning jack and strand system. The technique involved jacking some 100 mm, wedging the cable strands to maintain position, retracting the jacks, wedging the cable strands and then repeating the cycle.

This process took in the order of 5 minutes, which gave an achievable rate of 1 m per hour, but was, however, severely influenced by persistent wind gusting up to 90 km/hour. Although the assembly was aligned by polyurethane wheels to run against the shaft face, lifting was shut down for wind speeds in excess of 30 km/hour. The complete lift was undertaken in seven days.

A jacking pressure equalising control module was developed for the project, relying on skilled operation to maintain an out of level differential requirement set at 20 mm across the lifting points.This was considered an achievable limit approved by the façade engineers, to avoid distortion to the already installed glass panels.

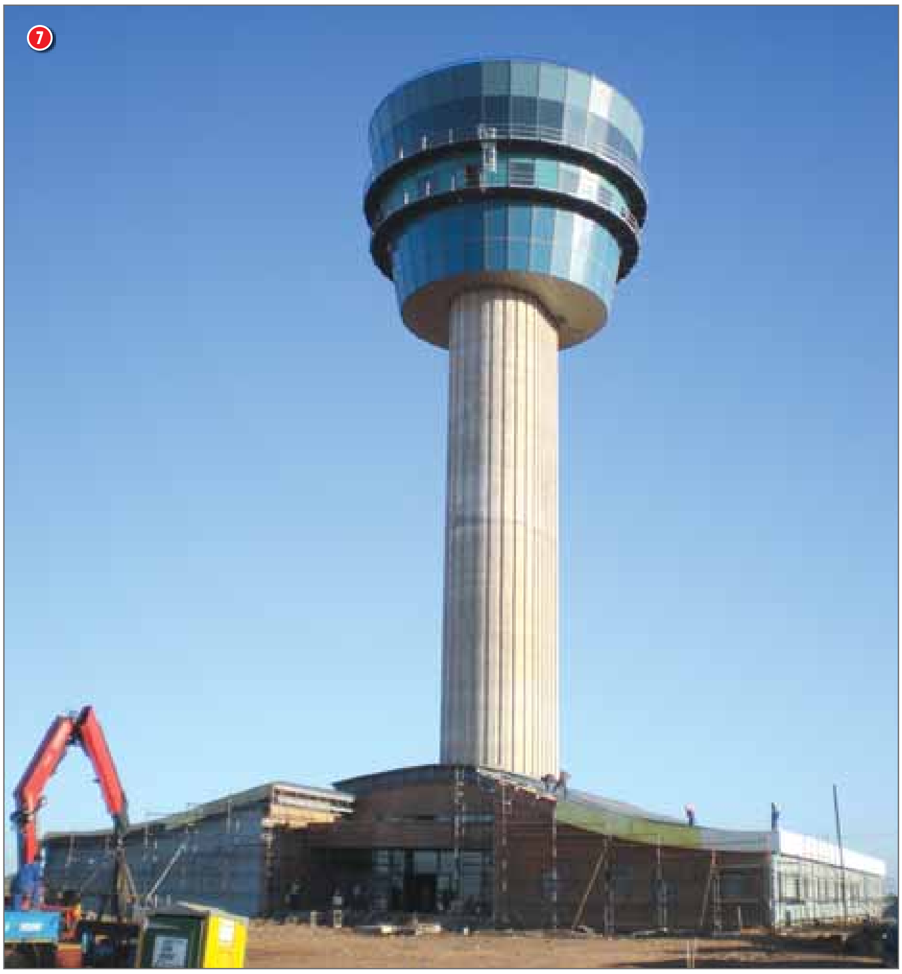
Incremental monitoring was undertaken throughout the lift from a

continually manned station at the top of the shaft due to the high risk of this operation.

After reaching the final level, the cab weight was finally transferred directly to the shaft by bolting to the jack support beams and at the level of the lower floors by means of steel corbel brackets, bolted to the cab structure and then grouted into previously located pockets within the shaft wall.

The structural steel framework was then completed by erecting the central portion of the radial roof truss structure above the shaft using the adjacent tower crane.

7 Completed control tower
8 A new interchange with the N2 provides access to and from the airport



From this stage onwards, normal building techniques were used to complete the control tower – although at 60 m into the air, careful coordination was required.

This unique "one-off" project required extensive innovative skills at every level, covering concept, design, detailing, fabrication, erection and implementation.

ACCESS ROAD N2 INTERCHANGE

The N2 interchange provides access to and from the airport. A late start to construction in May 2008 resulted in the monumental task of delivering a fully operational interchange within 22 months.

Rapid construction without compromising the quality of the end product, with minimum disruption to traffic along the busy route, were the main objects of the implementation of the design.

The design included four ramps, a 222,5 m incrementally launched bridge deck, an 80 m conventionally reinforced bridge, and a toll plaza. The bridges were constructed by Stefanutti Stocks Civil KZN as a major subcontractor to the Ilembe Civil Construction Joint Venture.

The most significant structure is the upper ramp bridge carrying outbound traffic to the south, comprising seven spans of 40 m maximum, founded on 900 mm concrete auger piles into the sandstone bedrock.

A unique feature of this bridge is the common pilecap in the median of the N2, due to the restricted area of the median. The two bridges share a pilecap which was specially designed to take the axial forces and bending moments from both bridges.

The ramp bridge was designed to be constructed by the incremental launching technique using a 24 m nosing girder launched in 15 stages. Apart from facilitating rapid construction, this method minimised disruption of traffic on the N2 freeway. The safety risks were also reduced by using incremental launching, as the workforce was predominantly away from the road traffic. Incremental launching was also a well-suited construction method, as most of the bridgeworks were confined to a single work area. The fixing of reinforcement, casting of the deck, prestressing and launching, were all carried out in a designated area. This allowed for roadworks and construction of the second bridge to continue unhindered and be completed on time.

High early strength concrete, which was designed to achieve concrete cube strength of 35 Mpa in 60 hours, facilitated high-speed construction of the bridge deck while still being economical. □

PROJECT TEAM

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Airports Company of South Africa Limited
Architects
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Ilembe Engineering JV:
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Goba (Pty) Ltd
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