

The new Southern Cross Station

The iconic redevelopment of Melbourne's Spencer Street Station

The old Spencer Street Station in Melbourne's west end (renamed the Southern Cross Station Redevelopment last December) has metamorphosed into a modern airport style facility that operates as a catalyst for urban renewal.

The landmark \$700 million redevelopment – a Public Private Partnership between the Civic Nexus consortium and the Victorian Government - includes a railway station, bus interchange and commercial developments within the Station's precinct. The new Station will accommodate the city's projected transportation needs, estimated to be four times the current 55,000 a day by the year 2050.

The new design combines the best elements of a modern, international style station creating a comfortable, convenient, safe user friendly facility. The Station will be an impressive arrival point for international, interstate, regional and suburban travellers to Melbourne, efficiently handling 30,000 passengers an hour during peak periods.

Built by Leighton Contractors and designed by architects Grimshaw in association with Daryl Jackson Architects, the design emphasises space and light to meet the needs of people on the move by providing a clear sense of direction in a secure and uncluttered environment. The Station has been planned to integrate with the street pattern of the city centre as it extends west towards the regenerated Docklands. Concourses, subtly delineated from the pavement by a partial glass façade, expose the life of the Station to the three major boundary streets – Spencer, Bourke and Collins.

Keith Brewis, Project Director for the Grimshaw Jackson joint Venture, said that: "Southern Cross Station is a striking gateway to Docklands and the strategy behind its look and function is drawn from overseas experience such as London's Paddington Station and the International Terminal at Waterloo, and New York's new Fulton Street Station at the Ground Zero site."

"Within the brief there was a very dedicated line from the Government; they clearly wanted the Station to improve the experience of the passengers. Added to that was an underlying demand for the Station to help reconnect the city."

Engineering the structure

Rob Di Blasi, Senior Associate with Winward Structures, the structural engineers on the project said: "The redevelopment of



The main spine trusses are supported by Y-shaped column arms at 40 metre centres.

Southern Cross Station was undertaken while maintaining the Station as a fully operational facility throughout all stages of the works. This imposed significant restrictions for the construction methods available, and the working hours during which various activities could be carried out. The design of the buildings and structural elements was tailored to realise the most readily buildable and cost-effective solutions given these challenges."

The roof structure was a major element affected by the operational requirements and key issues had to be addressed during the design. Rob outlined these as:

- roof constructed in stages during relatively short periods of operational shutdown between rail activity
- structurally stable at each stage of construction and, given the short construction periods available, areas of the site had to be capable of rapid 'closedown' at the end of each period and rapid 'remobilisation' at the beginning of the next
- the structure had to be generally unpropped at all stages, particularly over the track areas
- disruption to commuters using the platforms had to be minimised. This meant the amount of space taken up by construction activities, and the length of time these spaces were to be inaccessible to the public, was restricted.

To address these issues, the roof design needed to satisfy the following basic principles:

- the roof framing system had to allow for erection in stages and each erected section had to achieve immediate strength without the need for propping, particularly over the track areas
- columns had to be sufficiently rigid to provide lateral stability to the partly erected roof at each stage, without the need for temporary bracing
- maximise prefabrication of structural framing elements
- where possible pre-finish elements to minimise later finishing above operational platforms and track areas
- connection of individual elements into the largest practicable sections for erection, to minimise the number of and time required for structural lifts
- bolted site connections rather than welded where finishes would be affected, or where connections were required to be made above operational areas; connection simplicity was crucial to minimise cost and construction difficulty - axial load connections were preferred to moment connections.
- standardisation of the individual elements and their connections as repetition improved manufacturing cost and time, as well as simplifying construction

- as tolerance is a key issue in erecting such a large and complex structure every connection was scrutinised for construction tolerance.

In addition to satisfying these principles, the roof design needed to:

- be physically capable of being erected above an operating rail station
- address the intent of the architectural concept
- optimise cost and program for both manufacturing and erection.

Unique design development

Commenting on the design process Peter Skene, Leighton Contractors Project Manager said: "The early engagement of the steel detailer (Precision Design Australia) in the design process significantly reduced the number of unnecessary and repetitive architectural drawings. By providing early input during the design development, the steel detailer was responsible for the roof geometry and all dimensional control. This design methodology also assisted in the off-site fabrication process and the on-site survey installation, enabling the interrogation of any part of the theoretical model of the roof. With the architects and structural consultants the steel detailer was an integral part of the design team."

Keith Cheney, Precision Design's project manager on the Spencer Street Redevelopment, said that the most challenging aspect of the project was the complex geometry. "We had to maintain the integrity of the architectural design and build the design into the software. This was a rather special project in as much as the 3D model started from day one with the architects, Grimshaw Jackson Joint Venture, structural engineers Winward Structures and ourselves sitting around a table to realise the concept for the client."

"Precision design co-ordinated the 3D model for the architectural and engineering concepts into a millimetre perfect 3D model. That early collaboration and coordination saved hundreds of requests for information (RFIs) on the project, reducing these down to a mere nine RFIs over the project."

"The detailing statistics are staggering with 65,000 drawings issued with 7,200 triangular ceiling penetrations generated from a purpose written Autocad software program. In some areas Precision Design assisted the fabricators with jiggling drawings."

Peter Skene said that: "The new interchange covers the existing rail station with a vast 'wave form' roof spanning 37,000 square metres and reaching 23 metres at its highest point. The wave roof is the first of its kind in Australia and the country's largest undercover concourse spanning an area of 211 x 180 metres."

"One of the most challenging aspects of the project's design and construction was building a complete roof covering the entire Southern Cross Station site over a live operating rail station. This is a feat never before attempted in Australia," Peter said.

The choice of structural connection types and the location of construction splices was another key factor in the design stage. Connections had to be designed at convenient locations for installation. Connection types had to achieve the architectural and structural capacity needed by the roof designers, while at the same time allowing for easy installation given the time constraints of constructing over an operating rail facility. The preferred choice was for bolted connections. However it was necessary to site weld the large primary arches (roof rafters) as they were delivered to site in transportable segments.

Construction challenges

Peter said that the challenges facing the project fell into two main categories. "Approximately one quarter of the roof was built over the metropolitan (electrified lines) with the balance over the non-electrified country or regional platforms. The particular challenge over the electrified lines was that installations could only occur after last train at night and before first train next morning. Once all the variables had been factored in, such as isolating the overhead power and set up time, the window of opportunity to install all the elements of the roof was reduced to two and a half hours each night."

The steelwork erection contractor on the project was Rigweld. Ray Richards, the erection supervisor said that the Southern Cross Station was one of the better jobs Rigweld have worked on. "The architectural design was well thought through and a lot of effort went into planning the erection of the steelwork."

"This thought was evident in the job safety analysis (JSA). Leighton scheduled frequent 'toolbox' meetings with the riggers to analyse the dangers of working over live power lines as well as other safety issues. The riggers put forward a lot of good ideas and these were incorporated into the erection process, giving the workers a sense of involvement and personal responsibility," Ray said.

To minimise the number of lifts over the metropolitan lines the team decided to construct large roof modules at the side of the site, in the Wurundjeri Way median strip, and lift these large units into position with a 600 tonne crawler crane. The main spine trusses that support the roof modules and run along the length of the platforms (supported by Y-shaped column arms at 40 metre centres) were also installed with this crane. The 54 spine trusses were fabricated off-site at three different workshops in Geelong, Launceston and Tomago near Newcastle, NSW, and transported on large barges over water. They were then transported to site from the South Wharf in Melbourne (approximately 5 kilometers) in the middle of the night and lifted directly into their final position. A truss section was installed firstly over each column and then an infill piece was dropped into position and bolted. A similar process was adopted for installation of the remaining spine trusses over the entire project. Smaller cranes were able to be used in other areas of the station (over the regional platforms) where the construction team had full time access.

Given that access to the railway was at various stages, the roof segments were installed



The spine trusses were fabricated off-site at three different workshops and transported on large barges over water.



Trusses were transported to site at night and lifted directly into position.

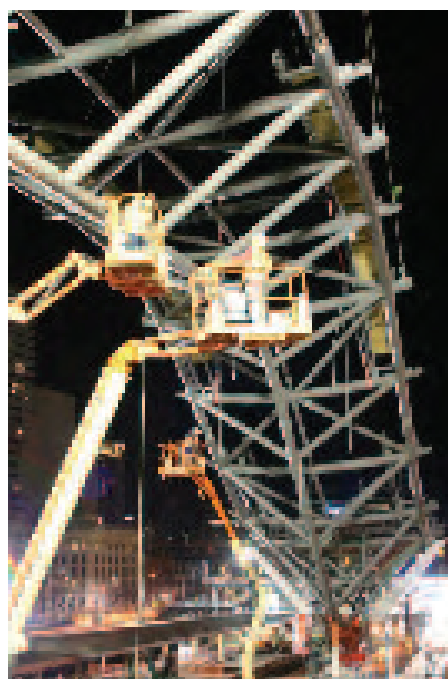
between trusses, piece by piece. This meant that the primary arch, or main roof rafter, was installed first, followed by a series of secondary members and diagonal members in conjunction with the ceiling panels. The ceiling panels' installation ensured that a working deck, as well as providing a ceiling, was in place to enable the roof sheeting to be installed during normal working hours. This provided a safe barrier between construction works and the Station public.

A series of safety nets were also installed immediately beneath the top of the trusses where the Ethylenetetrafluoroethylene (ETFE) skylights were to be installed. Again, these nets enabled installation of the skylights to proceed during the day.

Structural system

The roof system acted as a one-way system during construction, enabling erection over the operating Station with the minimum use of temporary propping. In the final condition, the structure utilises the wave-form geometry to act as a series of domes effectively spanning two-way to the columns, achieving greater design efficiency when considering final condition loading.

Primary spine trusses running north-south above each alternative platform support arches at four metre centres spanning in the east-west direction up to 40 metres. The arches



Installation of the 3rd spine truss. A lot of effort went into planning the erection of the steelwork.

span one way between spine trusses in the construction condition. Arches are connected via a secondary series of members to achieve a two-way system in the final condition. The spine trusses are connected to columns which have a 'fixed base' via a rigid pile-cap and group of piles. The columns are rigid in both the truss direction, and transverse to it, forming a stable system when truss sections were erected. Prefabricated truss sections required temporary propping midway between columns. These props remained in place until the roof structure was complete in this localised area.

Between platforms 8/9 to 11/12, the one-way arches were connected together into modules of three to five arches wide and lifted into position on the trusses. The modules were preclad with ceiling panels. Stressing strand was tied between the feet of the arches to prevent spreading of the feet when the arches were erected into position and loaded. These ties will remain until the transfer deck of the adjacent commercial building is completed. The arch modules were erected in a specified sequence to minimise unbalanced loading within the system, and to ensure that stability and appropriate stress levels and deformations were maintained during each stage of erection. Greater site access enabled the arches between platforms 1 to 7/8 to be erected individually.

The structural design

The complex two-way wave-form geometry relies upon the stiffness of each of the individual roof members, columns and footings to carry design loads and provide lateral stability to the total roof structure.

The roof design was carried out using a powerful 3-dimensional computer modelling / analysis program and evolved by an iterative process of numerous computer runs to address different load combinations, individual member shapes and size, different roof configurations and support conditions.

For each of the numerous stages of construction the roof was analysed and all structural elements (over 8,000 members and 3,500 nodes) were shown to achieve structural adequacy and appropriate deflection performance.

All primary roof members utilised circular hollow sections (CHS). Primary spine truss top and bottom chords have 356CHS with wall thicknesses varying from 6.4 millimetres to 32 millimetres. The truss verticals have 273CHS and 168CHS for the diagonals. Arch sections have 356CHS with varying wall thickness from 6.4 to 24 millimetres. Secondary roof members are constructed using 168CHS.



Lowering a roof truss over the rail lines into position on the station platform. All the work over the rail lines was carried out at night.

Member sizes and connections were optimised for all roof construction stages and load conditions. Minimum wall thicknesses were used where possible. However this was balanced with the need to strengthen tube-to-tube connections using internal stiffening. This balance was achieved by carrying out rigorous computational analyses to optimise steel tonnage and connection complexity.

Innovation

The constraints of the site dictated that the main spine trusses ran centrally down the platform centres on every other platform. This set the grid lines in the east/west direction whereas, along the length of the platform, a nominal grid spacing of columns of 40 metres, and therefore main roof arches at 4 metre centres was adopted. However, the platforms are not parallel to Spencer Street but at a 12 degree skew, resulting in the need to design and fabricate all connection details and plate profiles to accommodate this skew. It also added a further complication where two grid lines, and therefore spine trusses, intersected at the corner of Spencer Street and Collins Street. This posed a detailing and fabrication challenge. The entwining of these trusses at this point meant having to site-weld sections of the truss on the ground and then lift them into their

final position. What was originally a challenge has now become a feature of the Station's main entrance on the Collins and Spencer Streets corner.

Keith Brewis paid tribute to the work of Geelong Fabrications on the project who constructed a full-scale prototype of a section of the roof early in the design development. This served a number of functions: it provided a "real-life" part of the roof to be reviewed for its architectural aspect; it confirmed concepts developed for the connection details of both steel members to steel members and the ceiling panels and roof sheet purlins to the main structure. Standard connections had to be adaptable for the full range of geometry the intersection of members would undergo for the entire roof. It also confirmed a connection detail for the triangulated ceiling panels that are provided over the entire roof. There are over 7,000 individual triangulated ceiling panels each with their own unique geometry. However, the connection details had to be applicable over the entire structure.

Temporary works

A significant number of temporary works were also required to both stabilise the roof during the construction and to avoid "beefing-up"



Cranes installing the roof structure which can accommodate movement from both construction loading and long term expansion and contraction.

member sizes in the permanent structure.

Temporary works included:

- an arch tie "bow-string" which connected at the base of all primary arches – roof rafters, designed to remove the out-of-balance lateral forces on the spine trusses prior to the adjacent bay being installed
- temporary spine truss prop located midway between columns to provide support for the spine truss until the roof modules were fully completed in adjacent areas of the roof. These were required as the completed roof modules provided their own structural capacity to transfer vertical loads back to the columns
- An adjustable 'jig stand' was installed in the median strip at Wurundjeri Way for assembly of the large roof modules to be installed over the metropolitan lines. This jig had to replicate the changing geometry and the connection details of the spine trusses to which the roof modules would be landed.

Roof system

The roof sheeting system adopted for the roof is a proprietary system called Kalzip. It is an aluminium standing seam roof sheeting. This overseas system was chosen for its long-term durability and flexibility in both design and installation. The system had to accommodate the continually changing space of the Southern Cross wave roof in three directions.

A series of circular steel purlins "snaked" their way continuously along the entire length of the roof supporting the Kalzip. Over 24 kilometres of unique shaped purlins in nominal 8 to 9 metre lengths were designed, drawn, fabricated and installed on the roof.

The unique geometry of this roof meant that there was effectively no repetition in any elements. Each member was logistically expedited to fit in its own unique place. Although there may be isolated repeat of members, it was not possible to replace one member with another. Each element had its own unique location.

The use of (ETFE) skylights was unique to this project. It is a product that is new to the building and construction industry in Australia. The skylights consist of a 2 layer "cushion" of ETFE. The bag is continually inflated with air to maintain strength and shape. ETFE is a fabric structure and is a hybrid of Teflon. It allows natural light into the station but can accommodate movement in the roof structure from both construction loading and long term expansion and contraction.

Status of an icon

The Southern Cross Station Redevelopment has achieved a number of firsts and already earned the status of an icon. In its final configuration, the redevelopment will feature:

- an innovative wave design roof spanning all platforms
- fully sheltered, high quality waiting areas, equipped with comfortable seating, lighting, heating and air conditioning
- access to toilets, telephones, catering facilities and other retail outlets
- passenger security facilities throughout the Interchange including CCTV monitoring
- efficient baggage-handling facilities for interstate and long-distance rail and coach operations
- a 30 bay bus station accommodating terminating and transiting coaches and buses and providing ticketing facilities and waiting areas for their passengers
- secure, sheltered parking facilities for 800 cars as well as kiss and ride areas
- links to Docklands via the Collins and Bourke Street alignments with direct access to these bridges for all platforms.

Project Team

Client: Spencer Street Station Authority
Victorian Government

Developer: Civic Nexus consortium,
ABN Amro – leader and financier

Architects: Grimshaw in association with
Daryl Jackson Architects

Building Contractor: Leighton Contractors

Structural Engineer: Winward Structures

Civil and Rail Engineer:
Maunsell Australia

Façade Engineer:

Connell Mott MacDonald

Steel Detailer: Precision Design Australia

Steelwork Contactor: Geelong
Fabrications

Steel Fabricators: Geelong Fabrications,
Haywards Steel Fabrication and Construction
(Tasmania) and A J Mayr Engineering
(Newcastle)

Services Consultant: Lincoln Scott

Steel Rolling Contractor: G and L Bolnar
(South Australia)

Roof Sheeting: Unison/BSI Joint Venture

Steel Supply: OneSteel Distribution

Coating Suppliers: Jotun

Services Consultant: Lincoln Scott

Additional Steel Fabrication: Alfasi Steel
Constructions, Riband Steel and
Downer Engineering