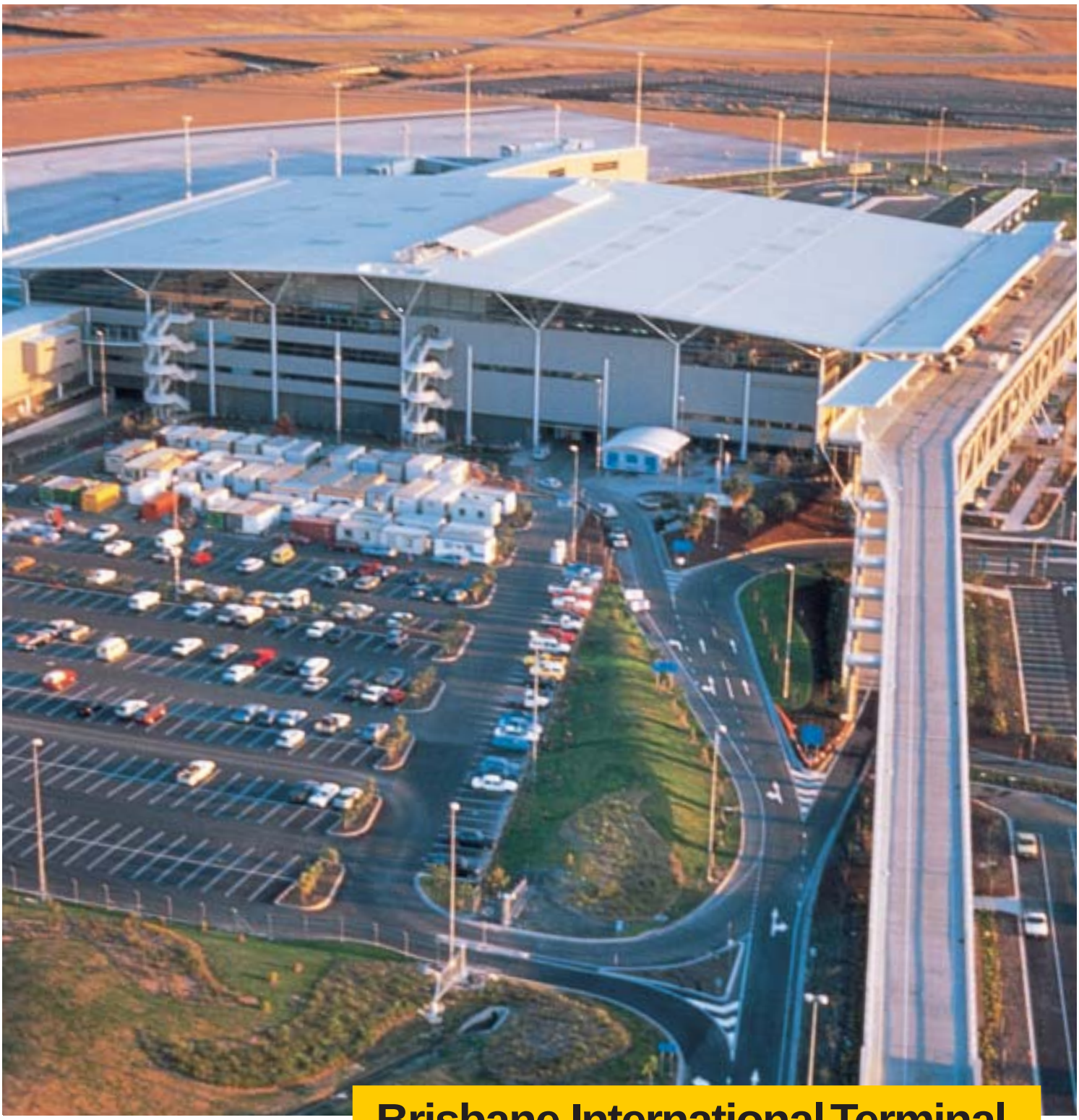
This case study was written at the time when OneSteel was part of BHP. In that context, in some instances within this case study, reference may be made to BHP.

Structural STEEL Casebook

Structural Steel
Development Group
Issue number 14
November 1996



Brisbane International Terminal

Travellers at Brisbane's award-winning international airport terminal know exactly where they are - coming or going, it makes no difference - the terminal is unmistakably Queensland. No sterile, neon-lit interiors here, rather tall palms, 'ghostly' steel column trees, natural light and a strong feeling of openness provide a microcosm of the exterior, saying "Welcome to Queensland!".

Translucent inwardly at night, panoramic outwardly by day, the terminal permits 270 degree views through glass clad walls and slim steel mullions. Eastward lies Moreton Bay beyond wetlands punctuated by refinery stacks and cranes at the river mouth; southwards the curve of the Brisbane River is truncated by the arched form of the Gateway Bridge; in the west the CBD skyline is backlit by the marvellous blue-green ribbon of the D'Aguilar Range stretching to the north-west.

The four storey, steel framed terminal building was opened in September 1995, four months ahead of the 24 month schedule and several million dollars below budget. Civil & Civic was the Project Manager for design and construction for the client Federal Airports Corporation (FAC) , the developer, owner and operator of the terminal. Structural steel framing was chosen because it best met the requirements of the project brief, ie cost efficient, fast to construct, easily extended, and able to be readily altered during construction.

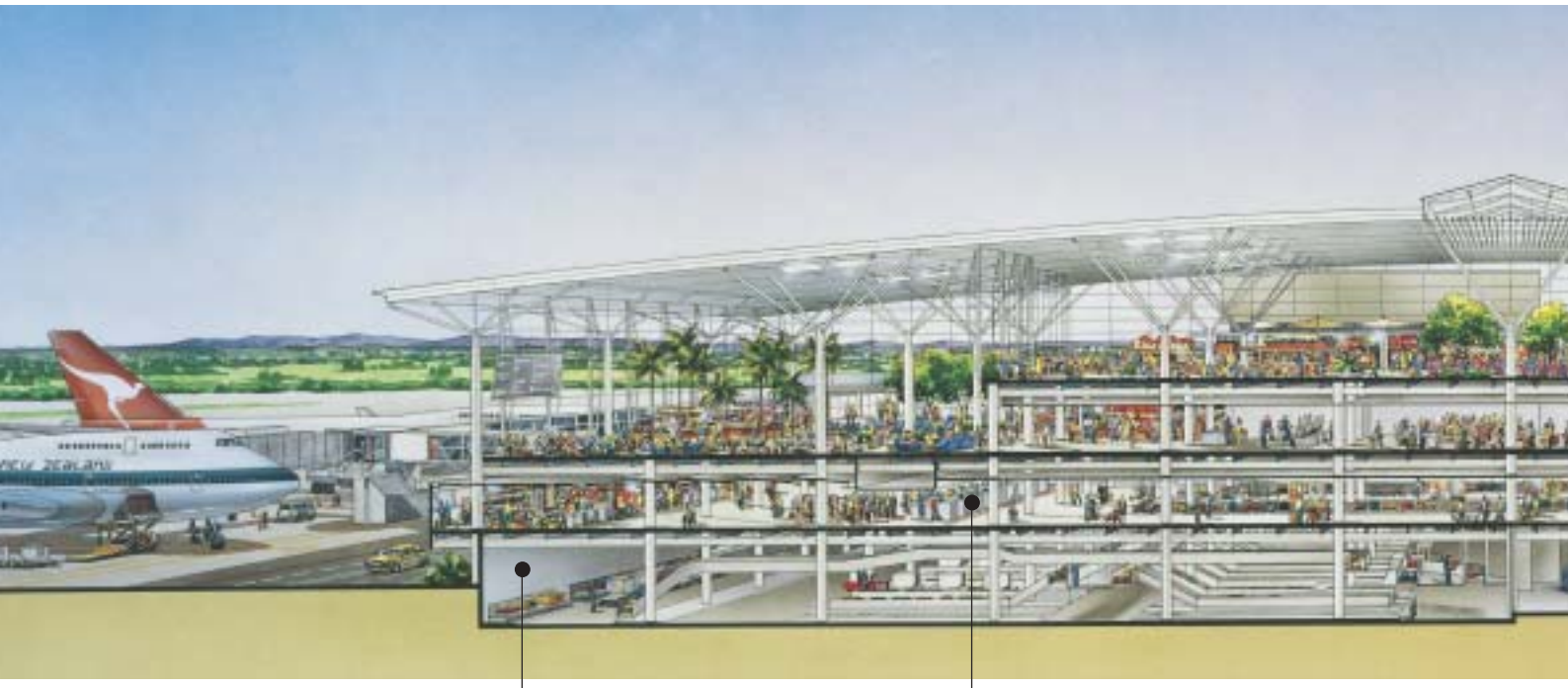
The new International Terminal at Brisbane Airport is a major international gateway into Australia, second only to Sydney, and handles 2 million passengers per year with expected growth to 4.5 million in the year 2005. It represents a major advance in the provision of services to international airlines with a passenger friendly environment, efficient processing technology, modern airport retailing and passenger convenient facilities.

The $240m complex comprises a 4 level terminal building and a 3 level concourse capable of processing arriving and departing passengers at a rate of 1200 per hour; two level elevated arrivals and departures road; 140,000 square metres of apron facilities to accommodate eleven aircraft including eight aerobridges; parking for 2000 cars and 70 buses, and landscaping of the remaining 55 hectares.

DESIGN AND CONSTRUCTION MANAGEMENT

Civil & Civic, as Project Manager for design and construction, delivered the project using a four stage process which involved:

(1) 'Proving up' of assumptions, functional integrity and costings arising from concept design.
(2) Confirmation Phase - development of the design to define the scope of work represented by a Guaranteed Maximum Price.
(3) Commitment Phase - detail design documentation, working drawings and construction.
(4) Post Opening - twelve month warranty and maintenance.



Level 1 - Baggage handling, offices, plant rooms and stores.

Level 2 - Arrivals level - aerobridges, arrivals concourse, duty free and retail facilities, immigration processing, baggage reclaim, customs and quarantine, arrivals hall and food and beverage, arrivals road pick up.

The sometimes conflicting motivation to provide the best design solution whilst wishing to construct to minimal time and cost was managed by Civil & Civic's single point accountability to the client. This flowed through to completion with Civil & Civic also acting as tenancy coordinator. Clear communication between Civil & Civic and the FAC was ensured by a Project Control Group which met monthly.

The design management process included the following two objectives:
• the endorsement of the design by the terminal users which was achieved through a consultative approach to all design issues and in particular, an understanding of world best practices for individual functional needs
• the fast tracking of the design to meet construction requirements.

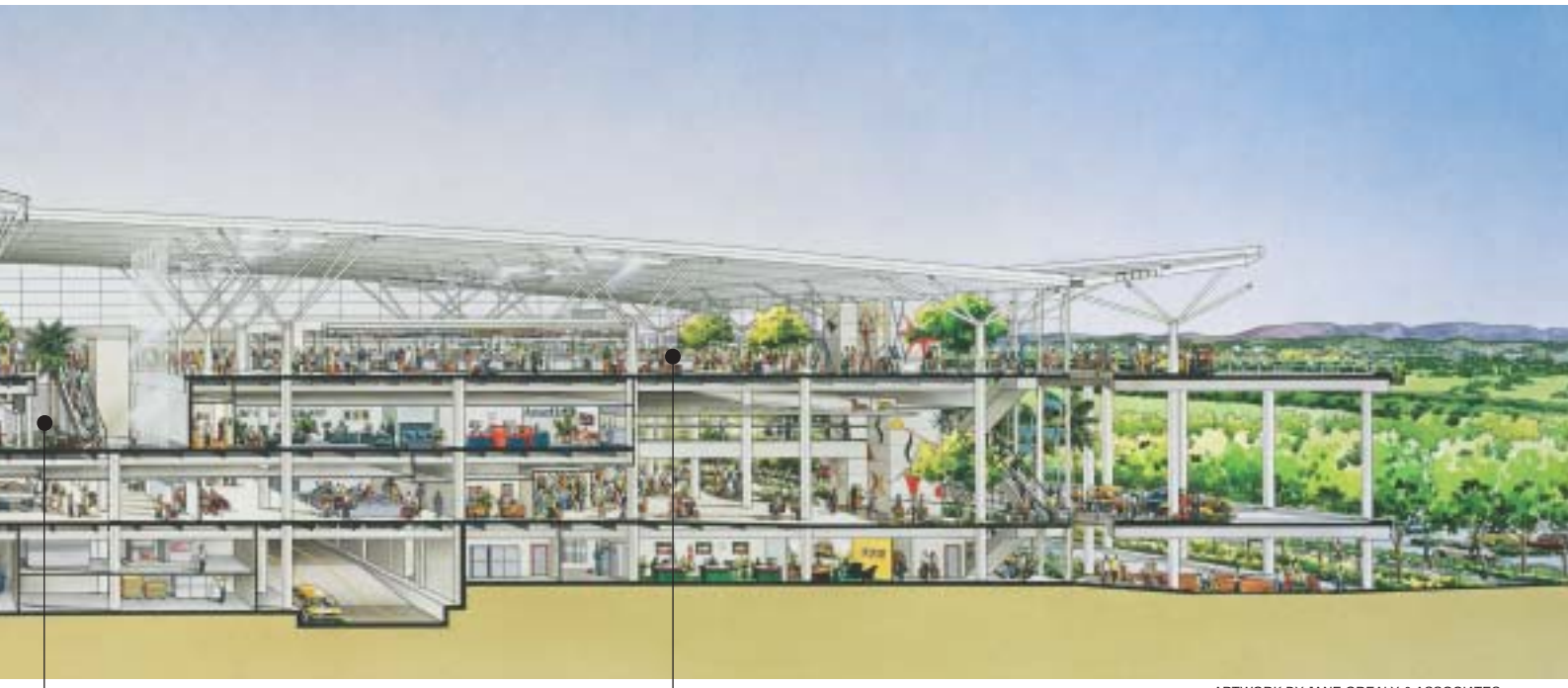
Construction management required commitment by Civil & Civic, subcontractors and suppliers to the systems and outputs established for construction planning, procurement, financial management, safety, industrial relations and quality. Construction programming involved preparation of a target programme which reflected optimistic best performance and which was updated every three months to incorporate progress over the previous three months. A medium range schedule for the next three months was then produced, monitored on a fortnightly basis, and from this a detailed fortnightly programme for each trade was produced, updated weekly.

An extremely effective steel supply scheme was adopted in order to fast track construction. The scheme involved Civil & Civic pre-ordering a start-up tonnage of approximately 1200 tonnes. This steel was subsequently purchased by the successful tenderer.

ARCHITECTURE

Bligh Voller was the architectural consultant for the project with Lend Lease Design Group providing architectural overview and review. The architectural design is clearly based on form and function with the major functional areas such as check-in, outward immigration, and security and baggage collection first being individually sized, and then positioned in relationship to one another. The four levels of the 140m x 100m building are shown in the cross section below.

FAC market research indicated that travellers using an international terminal were most anxious at check-in stage, but were considerably more comfortable once they had been processed through to the departure lounge. The building design helps to overcome this anxiety and achieves the relaxed, unimpeded movement of people through the building by simplified processing, clear signage, and comforting surroundings. The logical 'straight line' passenger flow for arriving and departing passengers has a major impact on the building layout, dictating the separation of arrivals from departures and necessitating a two level elevated access road on the land-side (west side) of the building.



ARTWORK BY JANE GREALY & ASSOCIATES

Level 3 - Departures lounge level - outward immigration and security, duty free, passenger retail, food and beverage, departures lounge, airline lounges, concourse and departure gates, aerobridges.

Level 4 - Passenger check-in level - departures road set down, check-in area, food court, public retail, public viewing terrace, duty free.

Opposite page:
Top: Check-in area, featuring steel column 'trees'.

Bottom: Wire wall with bowstring mullion.

Below: Departure lounge, level 3.

Arriving passengers disembark from the aircraft on the air-side of the terminal (east side), travel down the aerobridge, through immigration and baggage reclaim to road pick-up on the land-side (west side).

Departing passengers are set down at the departures road drop-off zone at Level 4, proceed to check-in and then descend to Level 3 to customs and immigration and thereafter to the departures lounge. A unique feature of the design is the Level 4 mezzanine area which overlooks the departure lounge and provides farewelling family or friends with a clear view of both passengers in the lounge and the aircraft beyond, from the comfort of a bar or lounge chair. The unparalleled viewing and acoustic interaction, in what is a sensitive security zone, is achieved by the use of a glass balustrade and a full height horizontal wire security barrier which is almost invisible. The 'wire wall' is monitored by a video alarm system and 24 hour video screening.

Bligh Voller's design team leader, Chris Clarke, recognised the need to provide large, open spaces at floor level (especially in the check-in areas) but to have closer spaced supports at the upper level so as to reduce the span and thereby minimise the depth of the roof structure. An 11.4m x 10.2m column grid provides maximum column centres at floor levels. At Level 4 a striking solution is achieved by continuing every second column and incorporating four splayed steel struts, in the form of 'tree branches', towards the top of each column. The tree branches are connected to the tubular steel column and steel rafters by an elegant pin detail- a perfect example of harmony in architecture and engineering. The roof is clad with 100 tonnes of BHP Building Product's Klip-Lok 700 Colorbond Off-white sheeting, in 24m long sheets, whilst the walls are clad in Stramit Industries C-Clad 203 wall cladding in Colorbond XSE Brolga and Morwell Grey colours.

Another key objective of the terminal design is to provide a facility which can be easily expanded to satisfy Brisbane International Airport's projected rapid passenger growth. The simple design philosophy of passenger movement along an east-west axis and terminal facility expansion along a north-south axis enables an additional module of steel-framed construction to be added at any time to the south side of the terminal building or the north and south sides of the concourse.

The use and control of daylight and artificial lighting utilising rooflights, a central skylight and a glazed facade, creates the perception of South-East Queensland sunlight and supports plant and tree growth. The central skylight incorporates sunshades designed to shield check-in desks and the central seating area from direct sunlight. At night, the sunshades are infused with colour to project light and shadows across the floor.

A vital aspect of the terminal, and indeed of any modern airport terminal paying its own way, is the retail component. Individual, chic, café style, the Brisbane terminal provides a shopping and dining experience beyond the fast food vernacular. With 27 outlets, the retail component is expected to earn $75m during the first year of operation.

STRUCTURE

The primary structural design requirements were that the terminal be a cost efficient structure, be readily extendable, and have maximum flexibility to accept structural alterations and additions. Connell Wagner, led by Max Kilmister, prepared 14 different structural schemes which led to the conclusion that a system comprising structural steel columns and floor beams, with a 120mm thick insitu concrete slab on steel decking, best met the design requirements.
In particular, the simplicity and repetitiveness of steel framed construction, the strong competition in the steel fabrication industry, and the ability of steel to be modified on site more easily and at a cost about $500,000 cheaper than a conventional concrete scheme made steel the obvious choice.

The terminal is constructed on sand fill above 30m to 40m of highly compressible clay overlaying basalt rock and is supported on piled foundations. All of the

concrete schemes were adversely affected by their increased weight which increased the number of piles required and would have cost an additional $0.5 to $0.75m in foundation costs.

Levels 2, 3 and 4 comprise 530UB82 twin primary beams which span 11.4m, continuous, in an east-west direction and support 360UB45 secondary beams spaced at 2.85m centres. Because the slabs were finished level and the beams were unpropped, the actual slab thickness varied up to 140mm in locations. Care was taken when levelling the wet concrete floor to account for any elastic deflection recovery of the floor beams as the construction load decreased on the span being poured. Since lateral load resistance in the direction of the primary beams (E-W) is by moment frame action, the primary beam connection to the column is required to be rigid. This is achieved by an assemblage of 32mm x 400mm deep steel plates which pass through the 610 OD x 12.7 and 9.5mm thick steel tube columns and are welded to the steel tube. The primary beams are connected to the steel plates by web side plates with 8M20 - 8.8S bolts.

The secondary beams sit on top of the primary beams, are continuous, and are fixed with two bolts through the flanges. Vibration considerations controlled the secondary beam design and because of the continuity it was not necessary to utilise composite action for either strength or stiffness. However, three shear studs per beam are provided to ensure lateral stability is achieved under all loading conditions, including the fire limit state. Neither primary nor secondary beams are cambered. The two-layer beam system provides a free zone for services with the main ducts running parallel to, and between, the primary beams.

Approximately 42,000 square metres of 1.00mm Bondek II profiled steel decking was used in the terminal and associated works. Lateral load resistance in the N-S direction is provided by five bays of inverted vee bracing comprising steel CHS sections up to 457mm in diameter for the diagonal members and 310UC sections for the horizontal members at the floor level. Shear connectors transfer load from the floor into the bracing. Bracing connections generally comprise bolted gussett plates with 36M24-8.8S bolts, but pin joints are used in public areas for aesthetic reasons. The steel framed concept also extends to the lift wells which are framed in structural steel.

The steel roof structure comprises a grid of continuous universal beams supported at 11.4m x 10.2m centres by the branches of the column trees, with the supporting columns being on a 22.8m x 20.4m grid. Secondary roof beams running E-W reduce the purlin span to 5.1m. Continuity of the roof beams in both directions is achieved by high strength bolted joints and was necessary to create stability since the branches of the column trees are pin-ended. The columns supporting the roof taper from a 'trunk' of 610mm diameter at Level 4 floor to 425mm diameter at the top. The tree branches comprise 273mm diameter tubes with cast steel sections welded at each end to create a smooth transition from the tube to the tongue plates at each

Right: Concourse steelwork under construction.

Below: Terminal steelwork and roof.

PHOTO: FEDERAL AIRPORTS CORPORATION

connection. A 75mm diameter steel pin, contained by a 125mm diameter face plate each side, passes through the cast steel tongues and a 50mm thick gusset plate at the top of the trunk.

The perimeter walls of the terminal comprise both glass and aluminium walling and steel cladding on steel framing. Vierendeel bowstring trusses spanning a maximum of 10.8m, and spaced at 3.4 to 3.8m centres, provide a lightweight appearance. The truss chord members are 89mm diameter steel tubes and the web members are 10mm plates; lateral bracing is provided by stainless steel wire strand ties at 2.4m centres vertically. Pin connections are provided at each end, continuing the theme of the column tree connections.

Because the Level 4 slab was the first floor to be poured (so as to provide access for roof erection equipment), the steel tube columns were concrete filled with 40Mpa concrete prior to pouring Level 4 slab in order to increase the column stiffness. There is no internal bar reinforcement in any column.

FABRICATION AND ERECTION

The $15.5m supply, fabrication and erection contract included approximately 4,200 tonnes of structural steel and 670 tonnes of Bondek II steel decking. Principal steel fabricator and erector, Alfasi Constructions, subcontracted the fabrication component of the steel tube columns and roof structure to Austin Engineering. Alfasi supplied rafter members, cut to length and holed, to Austin Engineering, and coordinated and managed the delivery of the fabricated members to site. The floor beams were cut to length and drilled each end by steel distributor, Union Steel, using computer numerically controlled machines. Tubemakers of Australia supplied 150 tonne of plate connections to the project. Cost benefits were achieved through the distributor's use of automated processing combined with the large volume throughput of members.

Alfasi carried out further fabrication of the beams and the remainder of the steelwork in Brisbane, except for the stairs, wall mullions, and 'wire wall' which they fabricated in Melbourne. A feature of the terminal is the upper level tapering columns which have an elegant 'mouse ears' connection to the column branches. The connection comprises a baseplate and four inclined plates holed for a 75mm diameter pin, and was fabricated by Austin Engineering Pty Ltd. The smooth, streamlined transition between the column branches and the column trunk at one end and the rafters at the other end consists of a 225mm diameter steel casting. Austcast, of Brisbane, manufactured the pattern and produced a total of 332 castings at a cost of $257 each.

The building structure was erected in eight vertical segments, rather than floor by floor. This enabled rapid construction of the Level 4 deck so that earlier erection of the roof and commencement of the facade works was achieved, thereby providing a waterproof construction environment. Steel fabrication and erection took 40 weeks and finished ahead of schedule notwithstanding

Beam to column connection.

Steel columns and decking.

Steel wall bracing.

Right: Steel column 'trees'.

Below: Column branches and eaves overhang.

Right: Steel wall mullions.

a six week period of rain after Christmas. Typically $2^1/_2$ bays at a time were erected with the crawler crane. The steel roof beams were pre-assembled in an 11.4m x 10.2m panel on the ground, complete with pin-ended column branches and purlins, then lifted into position, the branches then rotated into position and bolted to the column trunks. Roof purlins for the roof infill bays were also pre-assembled on the ground, lifted into position using a specially designed lifting frame, and bolted to the roof beam panel. All roof steel fitted together with no need for alterations on site.

Steel erection was completed by site staff which averaged about 20 people for the structural steel work and 5 people for the steel decking, depending on the stage of the project. Cranage included a 150 tonne crawler crane operating at the sides of the building, an 80 tonne crawler crane operating at the leading edge of erection, and an all-terrain feeder crane. Various other small cranes were utilised as needed.

SAFETY

According to Civil & Civic OHS&E Manager, Frank Welch, a critical safety aim for the project was to erect the steelwork in compliance with the Workplace Health & Safety Act whilst preventing injuries due to falls from elevated work places. To achieve this aim, Civil & Civic adopted a consultative risk management approach to identify, assess, and control risks in both the pre-construction (design) and construction phases.

Design risk control measures focussed in particular on reducing the number of connections to be made at height. The measures included such initiatives as the use of full-height columns, the pre-assembly of roof panels on the ground, and the use of continuous beams with the secondary beams supported on top of the primary beams. Construction risk control measures included the use of boom and scissor lifts, and the attachment of temporary guard rails to perimeter beams at ground level prior to erection.

An independent general risk assessment of steel erection was undertaken by Alfasi, which was then reconciled with the risk assessment carried out by Civil & Civic. The Code of Practice for "Steel Construction, Part 1- High Rise" was referred to, to determine suitable solutions to the identified risks. The successful safety management of the project ensured that, although the steel erection involved over 42,000 manhours of time, there were no Class 1 injuries, and the project received a Highly Commended Award in the Queensland Division of Workplace Health and Safety "Best Practice" awards.

SURFACE TREATMENT

Structural steelwork received a Class $2^1/_2$ abrasive blast clean and was generally protected as follows:

Steelwork Type	Generic Paint Type & Thickness	Paint Brand
Beams- Internal (hidden)	Primer - urethane alkyd primer (75 microns)	Dulux Luxaprime Zinc Phosphate
Columns & Roof- Internal (exposed)	Primer - polyamide cured epoxy phosphate primer (75 microns)	Dulux Durepon P14
	Top Coat - catalysed epoxy acrylic (50microns)	Dulux Acrathane IF (2 pack enamel, high gloss)
External Steelwork	Primer- inorganic zinc silicate (75 microns)	Dulux Zincanode 304
	Mid Coat- high build epoxy (125 microns)	Dulux Amercoat 385
	Top Coat- catalysed epoxy acrylic (50 microns)	Dulux Acrathane IF (2 pack enamel, high gloss)

All exposed steelwork had an additional top coat applied on site after installation.

Left: Steel rafters during fabrication.

Below: Tubular steel roof struts.

Far left: Cast steel roof strut end connectors.

Left: Column to roof strut 'mouse ears' connection.

Right: Pre-assembled rafter panel.

Below: Pre-assembled roof purlin panel.

Above: Edge beams with safety rail attached.

Right: Steel roof framing, and roof safety mesh rolls.

FIRE ENGINEERING

Because all prescriptive parts of the building regulations cannot simply be applied to a building of this size and layout, a fire engineering approach was adopted for the design of the building's life safety systems. CSIRO undertook a study to model smoke and egress movements within the complex and undertook a detailed evaluation of all requirements to provide the basis of a fire safety design which complied with the objectives of the Building Code of Australia (BCA). Connell Wagner applied the results of the CSIRO study to systems such as smoke control, fire sprinklers, emergency warning systems and building security systems.

BHP Research, Melbourne Laboratories carried out an investigation, on behalf of Civil & Civic, into the need to fire-protect the steel structure of the terminal building. The investigation drew on BHP Research's experience with 'real' fire tests and their knowledge of the performance of steel structures at elevated temperatures. The study concluded that the building, although not complying with the prescriptive requirements of the BCA in respect of required Fire Resistance Levels (FRL's) or fire-isolated exits, provided a level of life safety and property protection which met the objectives of the BCA and the building owner, FAC. The building incorporates unprotected steel columns and beams. A discussion and summary of the BHP Research study follows.

Fire statistics

The fire statistics for airport terminal buildings for the United States for the period 1983 to 1991 (equivalent to 40 years of fire experience for Australian airport terminal buildings) reveal no deaths and only seven injuries due to fire over this period.

Cause of Fire (>$US1000damage)		Suppression of Fire	
deliberate (arson)	12%	self extinguished	20%
smoking	15%	make-shift aids	13%
involuntarily started	15%	portable extinguishers	42%
electrical fires	58%	hoses	21%
		sprinklers	4%

Fire starts appear to be equally distributed between well populated areas and low populated areas such as plant rooms, storeroom, ceiling assemblies, and offices out of working hours. Electrical faults are the main cause of fires and most fires are extinguished by hand prior to the fire brigade arriving. The apparently low percentage of fires extinguished by sprinklers can be attributed to two factors; firstly, sprinklers are not incorporated in many terminal buildings in the US, and secondly, the fires are most often extinguished by other means before they get to the size necessary to activate the sprinkler heads. These statistics illustrate the importance of having portable extinguishers and hose reels located in appropriate areas throughout the terminal building.

Without sprinklers, the statistics showed that fire often spreads beyond the room of fire origin, whereas with sprinklered terminals, there was no case where fire spread beyond the room of origin.

Assessment of life safety

As there are relatively few people in the terminal building outside the normal hours of operation and those that are present would be most likely to be staff who are familiar with the exit routes, it follows that it is very unlikely that life will be lost should there be a fire in the building during non-operational hours. Therefore, as far as life safety is concerned, only the hours of normal operation are considered as it is only during this time that any significant number of people are present.

It is important to understand the relevant factors influencing life safety in the event of a fire. They are:

1. fire characteristics, including the potential to generate smoke
2. cues and early warning about the presence of a fire
3. extinguishment of the fire through extinguishers or make-shift aids
4. untenability due to fire and smoke
5. means of evacuation and ability of persons to evacuate
6. the performance of the sprinkler system
7. the role of the fire brigade.

1. Fire characteristics

In assessing the fire safety of airport terminal buildings, it is necessary to select appropriate design fires and then determine the fire characteristics associated with each fire. Three fires were selected as representing the upper end of the distribution of likely fires in the building; the first was a fire associated with 'link' seating found in departure lounges; the second, a fire associated with soft furniture found in airline lounges; and the third, fire in a typical retail area. The three 'real' fire tests were conducted at the Scientific Services Laboratory (SSL) in Melbourne in a warehouse having a volume of 14000 cubic metres and a height of 10m.

All tests incorporated a 610mm diameter circular hollow steel column having a wall thickness of 12.7mm, a 4m length of 360UB51 connected to the column, and a ceiling below the beam. This combination of column and beam (see fig 1) was incorporated in the test set-ups to provide a basis for assessing the likely performance of the terminal building structure in the unlikely event of a *non-sprinklered* fire. The tests also included sprinkler heads in the ceiling which were pressurised with air and a very small amount of water for the purpose of determining their likely times for activation.

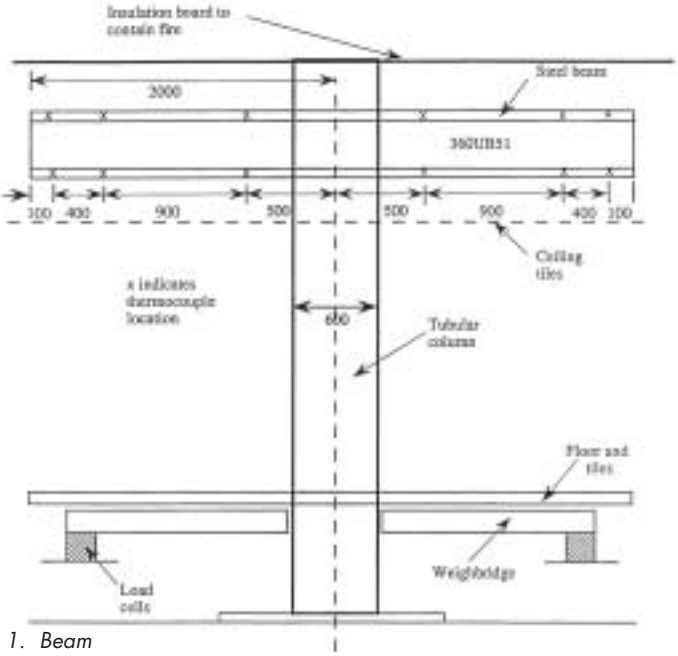


Figure 1. Beam and column set-up used for fire tests.

The **Link seating test** (see figs 2a, b) consisted of four link seats arranged symmetrically around the column. Following initiation of the fire in a waste paper basket, the fire developed but was confined to one seat. After 11 minutes, the fire effectively extinguished itself. The sprinkler heads were not activated during this fire and whilst the air temperatures at ceiling level rose to 100°C, the steel temperatures rose only slightly above ambient temperature.

The **Tub seating test** (see figs 3a, b) comprised four two-seater lounge tub seats which were arranged around the steel column. The fire was again initiated in a waste paper basket and spread to the tub seats from the basket. Throughout the 25 minute test, the air temperatures at ceiling level reached 500°C, whilst the temperature of the steel column only reached 60°C and the beams above ceiling only reached 22°C. Large volumes of black smoke were generated during the 1.3 megawatt fire, requiring the evacuation of the building after about 20 minutes. The sprinkler heads were activated after 10 minutes but, because the sprinklers were not connected to a water supply, no water was delivered to the fire.

The **Retail area test** (see figs 4a, b) was represented by an 8m deep by 3m wide enclosure which was bounded on three sides by plaster walls which extended up through the ceiling space. The enclosure was open at the front and had a mineral-fibre tiled ceiling which was positioned 3.25m above the floor. The retail area was set up as a typical shop with shelving and a mixture of cellulosic and plastic materials which represented a fire load, in terms of wood equivalent, of 57kg/m^2 of floor area.

Again the fire was initiated in a waste paper basket, this time at the rear of the retail area near to combustibles, and after 7 minutes, the fire developed rapidly with air temperatures reaching 1150°C. About 12 minutes after ignition, the fire began to reduce in intensity and was extinguished 35 minutes after ignition - the air temperatures having fallen to below 200°C. During the first few minutes of the test, two ceiling tiles fell out, which led to intense flames directly entering the ceiling space. Shortly after, the ceiling collapsed.

Figure 2a. Link seating, prior to fire test.

Figure 3a. Tub seats, prior to fire test.

Figure 4a. Retail area setup, prior to fire test.

Figure 2b. Fire test - burning of link seating.

Figure 3b. Fire test - tub seats.

Figure 4b. Retail area during fire test.

Due to the confined nature of the enclosure and the early collapse of the ceiling, the temperature conditions achieved in this test are considered to be as severe as those likely to be experienced in a retail tenancy that has no ceiling at all. The maximum temperature reached by the steel column was 720°C, whilst that part of the steel beam which was attached to the column reached 710°C. These temperatures cannot be directly taken as those likely to be achieved by the beams in the terminal building but can be used as the basis for determining the likely temperatures and level of structural adequacy that may be associated with these members.

The total rate-of-heat release associated with this fire reached a maximum of 15.7 megawatt at about 8 minutes, and between 7 and 13 minutes averaged about 12 megawatt. In this test the sprinkler heads activated at about 2.5 minutes, but as noted before, did not deliver water. The smoke generation was not as severe as with the Tub Seating Test.

Discussion of test results:

The **link seating** tests indicated that a fire associated with such seating in the departure lounge, check-in, or concourse areas will have little influence on the surrounding structure and generate only a small amount of smoke - assuming that such a fire is allowed to develop in the first place. The test involving the **tub seating** indicated that for this fire scenario, although large amounts of smoke are generated, there will be almost no influence on the surrounding structure. Given the amount of smoke generated by this fire, it is difficult to imagine that its presence will not be readily noticed and the fire extinguished.

The **retai**l test was clearly the most severe of the three fire tests and resulted in significant temperatures in the steel column and beam. Because the 360UB51 secondary beam, in service, will be in direct contact with the concrete slab and therefore exposed to a fire on only three sides (unlike the four-sided exposure in the test), the average steel temperature is calculated in accordance with AS4100, Clause 12.7(b) to be 610°C. The secondary beams are supported by 530UB82 primary beams which, although not in contact with the slab, have a lower exposed surface area-to-mass ratio than the 360UB51 used in the test. Based on the measured temperatures it is expected that the primary beams could reach an average temperature of up to 575°C. These temperatures apply to beams in the lower ceiling areas; for steel members located in the high roof area such as the arrivals area or the roof of Level 4, the temperatures will be very much less due to the cooling effects of air entrainment and reduced radiation heat transfer. Of course, the above temperatures assume that the sprinklers have not operated. This is an unlikely occurrence.

Having established the likely maximum temperatures in the steel members, it is now necessary to determine the temperatures at which the members begin to off-load and undergo substantial deformation. As both primary and secondary beams are continuous, the value of Limiting Temperature is a function of the *length* of beam at these *maximum* temperature conditions, and the load applied to the member during the fire.

Calculations carried out in accordance with AS4100, Clause 12.4, indicate that even if an 8m length of beam is subject to *maximum* temperature conditions, the beams will have sufficient capacity. Similarly, the concrete-filled columns provide very high levels of fire resistance when analysed in accordance with BHP Research Report "Behaviour of Composite Columns in Fire".

In summary, the fire tests and associated analysis demonstrate that the *unreinforced* concrete-filled tubular columns have sufficient fire resistance to resist any building fire likely to occur in the building. The steel beams have sufficient fire resistance, by virtue of their continuity and size, to resist most non-sprinklered fires likely to occur in a terminal building. The building however is extensively sprinklered and it is unacceptable to permit the occurrence of a fire as severe as that represented by the third test, as such a fire may seriously impede the normal operation of the terminal.

2. Cues for warning of a fire

In the highly populated parts of the building - Levels 2 to 4 - early fire detection will occur due to the number of people present and alert. Some areas of Level 1 have relatively few people present and it is less likely that a fire will be detected by human observation. The presence of smoke detectors in return air-handling ducts will also provide early warning by sounding an alarm in the building.

3. Extinguishment of the fire

United States statistics described before indicate that the majority of fires occurring in airport terminals are either self extinguished, or extinguished by make-shift means, portable extinguishers or hose reels. It is only in relatively few situations that the fire will be extinguished by sprinklers or the action of the fire brigade. This is not surprising considering the large number of people present throughout airport terminals. This explains the high level of safety experienced in terminal buildings in Australia - despite the fact that, in the past, these buildings have not been sprinklered.

4. Untenability due to fire and smoke

The fire tests described for lounge tub seats showed that untenable conditions were achieved in a compartment of 14000m^3 after about 20 minutes. If it is assumed that the fire is not extinguished, it follows that in smaller areas such as airline lounges (volume approximately 1000m^3) which are not served by a smoke exhaust system, untenable conditions could be achieved in a lesser period of time - probably about 4 minutes.

In the larger compartments (eg arrivals hall, departures lounge, concourse etc) which are served by smoke exhaust systems, based on the fire tests and ignoring the presence of any smoke exhaust system, untenable conditions could occur in times varying from a minimum of 5 minutes to a maximum of 20 minutes. It is important to note though that it is highly unlikely that a significant fire could develop in these well populated areas, and if it could then it would be rapidly extinguished by the sprinkler system.

5. Evacuation

Estimates of evacuation time made by Professor Hamish McLennan indicate relatively short times for evacuation of the major compartments in the terminal building. These times are well within the estimates of time for the achievement of untenable conditions.

6. The sprinkler system

Numerous fire tests incorporating fire loads at least as severe as that which is likely to be encountered in the terminal building have been conducted at BHP Research, Melbourne Laboratories. Automatic sprinkler systems have been included in these tests and, in all cases, the fires were rapidly extinguished after activation of the sprinkler heads, with the maximum air temperatures at ceiling level being less than 100°C. The above tests show conclusively, that with a functioning sprinkler system, any fire that occurs in the lower ceiling areas in the terminal building will be rapidly extinguished. It also follows that the amount of smoke generated by the fire will be greatly reduced and a situation requiring evacuation of the occupants is therefore unlikely to occur. In the high ceiling areas such as the Arrivals Area, the sprinklers will take longer to activate due to their height above the floor, but when activated, will reduce air temperatures dramatically and eventually extinguish the fire.

7. The role of the fire brigade

The fire brigade may be notified of the presence of a fire through the Fire Indicator Panel or by building occupants using manual call points which are located throughout the building. Response time from the brigade located on site is about 5 minutes.

Assessment of property protection

Property protection, especially with regard to continuity of operation of the terminal building, does not relate simply to the building structure for in the event of a fire, computer, communication and electrical systems, and service facilities may be damaged by smoke and flames. It should be clear from the previous discussion however that it is extremely unlikely that a significant fire will develop in the terminal building during the normal hours of operation due to the number of people present. It is more likely that a fire will be unnoticed during the non-operational hours of the building - when there will be relatively few people present.

Although a range of fires are possible, the occurrence of a fire as severe as that represented by the Retail Area Test would be highly undesirable because of the interruption to the terminal operation due to fire and smoke damage. Smoke in particular can cause extensive damage due to soiling of the building contents and discolouration of walls and ceilings. It is important therefore for fires to be extinguished as soon as possible, and this would be achieved by a sprinkler system which is close to 100% reliable.

Extinguishment by sprinklers

The sprinkler system in the building is the most important component of the fire-safety system in ensuring that a fire does not develop, and in ensuring that a fire is extinguished before any significant damage

occurs. The reliability of the sprinkler system therefore is of critical importance. The reliability of an individual sprinkler head is very high (failure rate less than 1 in a million), however the reliability of a sprinkler system is dependent upon:
(a) the reliability of water supply to the building
(b) the likelihood that a sprinkler valve has been intentionally or unintentionally turned off
(c) the likelihood that a blockage has been introduced into the pipe work resulting in isolation of sprinkler heads to part of the building.

The water supply to the terminal building is provided by a large ring main and it can be assumed that adequate flow and pressure will be supplied to the building at all times. A statistical study of mains breakdown in the older Metropolitan areas of Melbourne indicates that the probability of there being no water supply to a building due to mains breakdown is about 1 in a million per year. The mains supply to the terminal building is considered to be of a higher standard than those associated with the surveyed areas in Melbourne. In addition, all valves in the building are locked open and electronically monitored to guard against closure.

Water to a sprinkler valve may be infrequently turned off for short periods of time for maintenance, but this will have little influence on the reliability of the sprinkler system. An activity that has a greater effect on the reliability of the sprinkler system is the refurbishment of areas in the building (most likely retail), which may see part of the system being drained and the temporary removal of sprinkler heads, or in some cases, the introduction of blockages into the pipework. History suggests that the likelihood of a fire start during the refurbishment process is considerably higher than at other times due to cutting, welding and other activities involving the use of heat.
The management of the sprinkler system during refurbishment is therefore of great importance.

All areas in the terminal having ceilings such that there is a space between the ceiling and the floor are required by the sprinkler code to have sprinklers within the ceiling space, and given the depth of the ceiling space, the sprinklers are required to be at extra-light hazard spacing. For areas in the terminal building subject to refurbishment such that ceilings are likely to be removed (and therefore ceiling sprinklers as well), sprinkler reliability may be improved by the following methods:

(a) effective *management* of the sprinkler system during the refurbishment process so as to minimise the number of ceiling level sprinkler heads isolated at the time of refurbishment and to ensure that any blockages or 'frying pans' inserted into the system prior to commencement of refurbishment are removed.

(b) designing the system such that the sprinklers *within* the ceiling space are not isolated when refurbishment work is carried out. Provided the sprinklers in the ceiling space are sourced from a different section of pipe work such that isolation of the sprinklers at ceiling level in a specific location will not result in both sets of sprinklers being isolated at the one time, then it can be assumed that a significant fire cannot develop in these areas.

Fire engineering conclusions

As discussed above, the terminal building will provide a very high level of life safety as a result of:

- the types of activities in the building
- the large number of people in the building during normal hours of operation making it likely that a fire will be detected during its early stages
- the fact that most fires will be extinguished by the occupants of the building before the fires have developed
- the fact that the building is divided into large volumes which can contain smoke resulting from a fire and allow sufficient time for egress
- the provision of adequate exits
- the presence of a functioning sprinkler system, which is properly commissioned and managed
- the unprotected steel floor beams having a high level of fire resistance to a local fire and the concrete-filled steel columns having a very high level of fire resistance, in the unlikely event of a fully developed fire in which the sprinklers do not operate.

CONCLUSION

The new Brisbane International Terminal building, constructed under budget and four months early, has drawn praise from the FAC, user organisations and the travelling public alike. Structural steel strongly contributed to the success of this project through its cost effectiveness, adaptability during construction and its ability to be easily extended in the future. In particular, steel contributed to the project's earlier completion through off-site fabrication which parallelled on-site work, its faster installation capability, and its ability to 'jump' to Level 4 by using single-length 20m high steel columns, thereby enabling earlier construction of the upper floor, roof and facade. The application of fire engineering analysis and testing to the design of the terminal building enabled cost savings to be achieved whilst providing a satisfactory level of life safety.

Terminal Building Project Participants:

Client (Owner & Developer):	Federal Airports Corporation
Project Manager for Design & Construction:	Civil & Civic
Consulting Architect:	Bligh Voller Architects Pty Ltd
Consulting Engineer - structural, civil, traffic, electrical, mechanical services:	Connell Wagner Pty Ltd
Consultant Quantity Surveyor:	Rider Hunt & Partners Pty Ltd
Steel Contract:	
Principal Steel Fabricator & Erector:	Alfasi
Fabricator - tubular columns & roof:	Austin Engineering
Supplier of pre-processed beams:	Union Steel
Shop Detailer:	Bayside Drafting (Aust) Pty Ltd
Fire Engineering:	CSIRO BHP Research - Melbourne Laboratories