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PLANNING AND ARCHITECTURE

Tall Building Design Innovations in Australia

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1.0 ABSTRACT

This paper describes three examples of innovative tall building designs undertaken by the authors' firm in Australasia. These involve the design of building structures up to 88-storeys and as a multi-discipline group, the firm's innovations have embraced structural, M&E, façade and fire engineering disciplines.

The paper describes a number of innovative stability designs for tall buildings with minimum impact to the functional planning. The first case study involves a novel off-set outrigger stability concept, for the Aston Apartment building in Sydney. Further case studies are the 88-storey Eureka Place Apartment Tower currently being designed for Melbourne's Southbank and the 86-storey World Tower building currently under construction in Sydney.

2.0 CASE STUDY 1 – ASTON APARTMENTS, SYDNEY OFFSET OUTRIGGERS

Aston apartments is a slender 30-storey residential tower accommodating 145 serviced and owner occupied units. Its slender form and difficult positioning have required unique structural design solutions.

The reinforced concrete framed structure is 90 metres high and is only 13 metres wide in the north-south direction, resulting in a slender height-to-base ratio of 7:1.

An innovative wind resisting system using "offset outriggers" has been developed by Connell Wagner for this building, a first in Australasia. The "offset outriggers" shown in Figure 1 significantly reduce building deflections and core bending stresses. The offset system enables the outrigger arms to be placed across the full building width at locations away from the plane of the lift cores and mitigates some of the disadvantages of conventional outrigger systems, such as the outrigger arms obstructing occupiable and valuable floor space.

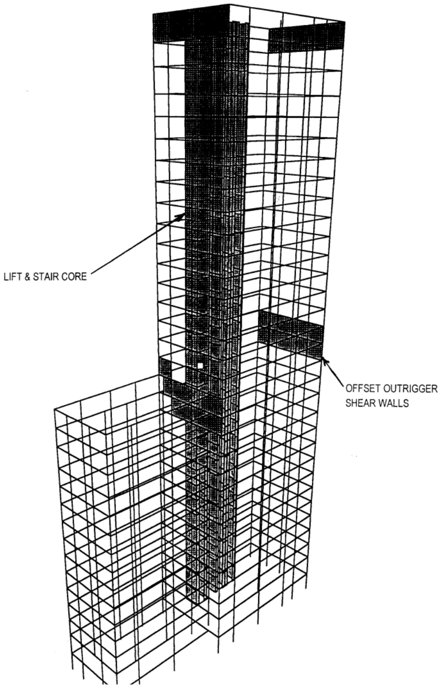


Figure 1 Frame Perspective – Aston Apartments.

A conventional outrigger system requires the core and external columns to be directly coupled. Detailed structural analyses conducted have shown that for typical floor slab plan dimensions and thicknesses, there is little reduction in the effectiveness of the outrigger as it is offset further from the centre core.

The outriggers system for the Aston Apartments rely on the floor diaphragms to transfer shear forces to mobilise the perimeter columns of the building, as shown in Figure 1.

The offset outriggers couple the columns and core by development of opposing shear forces in the floor diaphragms at the top and bottom levels of the outriggers.

In the Aston Apartments the offset outriggers, consisting of two storey high shear walls 200mm thick, are located on the side elevations at mid-height and the top of the building as shown in Figure 1. One of the advantages of this innovative wind resistance system is that it has virtually no impact on the planning of the building and permits a very simple floor plate to be achieved. This has maximised the floor layout for the client and provided greater flexibility for the architect to meet functional and aesthetic design requirements.

The offset outriggers are very economical and efficient because the system utilises the axial strength of the perimeter columns to resist the load at maximum lever arm. The offset outriggers limit the drift of the building and reduce the bending actions in the core, minimising wall thicknesses and core reinforcement. Optimisation of outrigger locations on the Aston Apartments project enables core wall thicknesses to be limited to 200mm even in the lower levels of the building, resulting in a very simple and quick to construct core with no variation of thickness over the entire thirty storeys.

The outrigger walls effectively link perimeter columns of similar load and hence no problems are encountered with regards to differential shortening between core and columns which would normally otherwise be expected where the core and columns are rigidly connected by outriggers.

The effectiveness of the outriggers has seen the requirement for only a lightly reinforced core, which is required to resist only 20% of the total base bending moment.

3.0 CASE STUDY 2 – EUREKA PLACE TOWER, MELBOURNE

This project, under design at the time of writing this paper, involves an 88-storey apartment building to be located on the south bank of the Yarra River in Melbourne. With a height of over 300 metres, the building will become the tallest apartment building in Australia. Designed by award winning Architects Nation Fender Katsilidis, the building footprint comprises a central diamond section which extends over the full height of the tower. On each side of the diamond are offset rectangular tubes, which start at ground level but sequentially drop off at different heights up the tower, as shown in Figure 2. This architectural concept thereby takes maximum advantage of the stunning views over the city.

A major complexity for the project is the site geology which comprises 30m deep layers of silts and gravels with intermittent basalt flows, overlying siltstone bedrock.

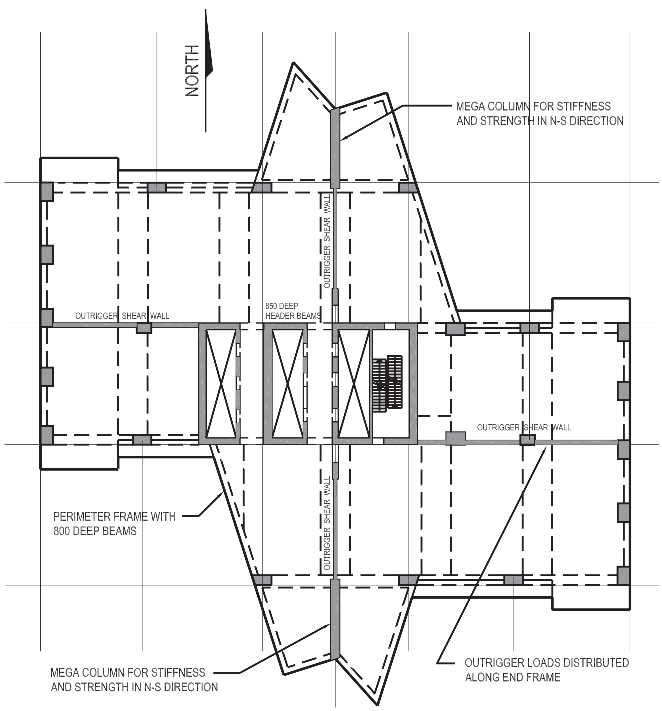


Figure 2 Typical apartment floor.

In consultation with the developer/builder, Grocon Constructions, a concrete structure was selected utilising high strength concrete up to 100MPa for the vertical elements to maximise the useable floor area. Post-tensioned floors are proposed for speed of construction and to minimise the structure self weight. The cladding comprises a curtain wall system with external balconies.

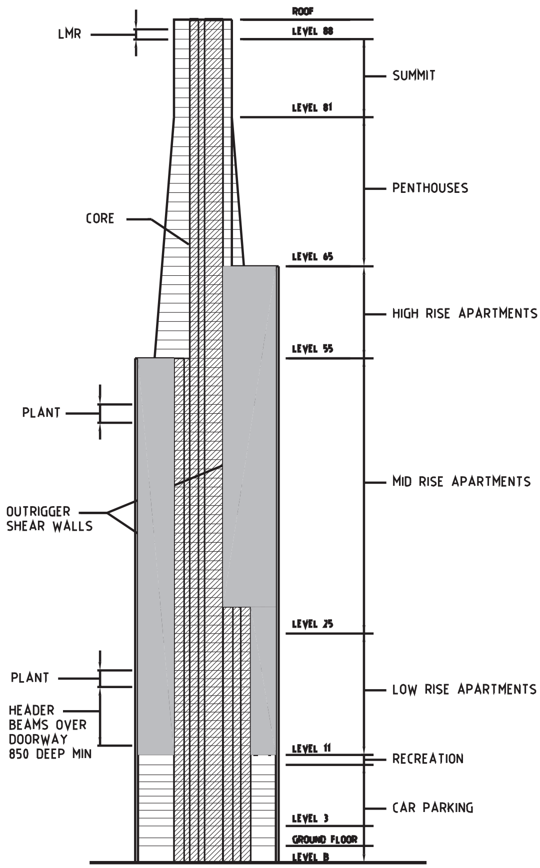


Figure 3 Outrigger/shear wall south elevation.

3.1.1 Stability

With a height to base width aspect ratio of 7:1, the building is relatively slender and a critical structural challenge is to resist the wind loading and control building accelerations in the most cost effective manner.

The structural stability is provided by a composite system comprising the following components:

- Coupled lift cores
- External tube beam column and frame incorporating two "mega columns".
- An east-west and north-south outrigger shear wall system linking the central core to the perimeter frame.

The extent of the shear wall outriggers are kept to a minimum and are positioned within the hotel/apartment wall layout to minimise loss of floor area. The outrigger locations have been optimised vertically up the building to maximise their impact.

A number of structural schemes were investigated for the tower using either composite concrete and steel construction or fully concrete construction.

For the floors, steel potentially offers the advantages of faster erection speed, however it is more crane dependent which can be a disadvantage in Melbourne, with significant downtime due to wind. Its other main advantage is reduced self-weight which is significant for such a tall tower reducing the column/wall sizes and the foundation costs.

Generally, in Australia, concrete is more cost effective, particularly for the vertical structure, columns and core. Concrete floor construction has been shown from previous projects to match the speed of steel in Melbourne. It is also more suited to apartment construction enabling lower floor to floor height, significantly reducing the lateral forces due to wind as well as reducing the cost of the curtain wall and vertical structure.

For Eureka, the floor spans are relatively long span for apartments (up to 11m) and these are best handled by post-tensioned concrete to provide a low deflection design.

With such a tall, slender building, a key structural challenge is to minimise the structural cost penalty associated with stability. Melbourne is a relatively low seismic activity area and consequently for tall buildings the wind forces govern the design. The highest wind forces are associated with thunderstorm activity, and generally emanate from the west.

The two main design criteria to be satisfied are, firstly the strength ultimate limit state and secondly the occupant comfort serviceability criteria, namely horizontal acceleration limits. The latter criteria is very important with a relatively tall slender tower having a minimum aspect ratio about 7 and a first mode natural frequency about 0.11Hz.

At the outset it was decided that we needed to mobilise the strength and stiffness of the outer tube as much as possible for structural efficiency, particularly as the central core structure is relatively small. However the architectural concept required that the building perimeter be as open as possible to take maximum advantage of the panoramic views. Consequently the outer tube by itself was relatively flexible.

We therefore examined several schemes with outrigger structures linking the central core with the outer tube. These included:

- Outrigger frames located at the plantroom levels and refuge level
- Outrigger shear walls located at discrete levels over the tower's height

For both schemes, multiple and single outriggers were investigated in each of the orthogonal directions.

A key feature of the design which emerged early in the process was the concept of a mega-column on the north and south corners sides of the tower diamond. The architect was keen to express this mega column as a bold element on the façade.

With such an unusual tower geometry, it was appreciated that a wind tunnel test would be required to verify the design forces and the horizontal accelerations at the top of the tower. Nevertheless, the preliminary design for market sales had to be undertaken prior to the wind tunnel test, and this was undertaken using the approximate dynamic analysis methods in AS1170 Standard.

The preliminary analyses using the ETABS computer programme indicated that discrete outriggers restricted to the plantroom levels did not provide adequate stiffness to the tower. To extend the outriggers into the residential levels required that they had to be located within the designated apartment walls and also required their width to be minimised to provide as much useable floor as possible. Furthermore, the analysis indicated the possible need for a roof top damper to increase the overall damping – see Section 3.1.2 below.

The stability concept therefore evolved to the scheme shown in Figure 3, comprising a central core linked to the outer tube and the two mega columns by way of two orthogonal shear wall/ outrigger systems extending over part of the tower height. Provision will be made in the shear walls for future openings enabling apartments to be linked in response to market demand as the sales progress.

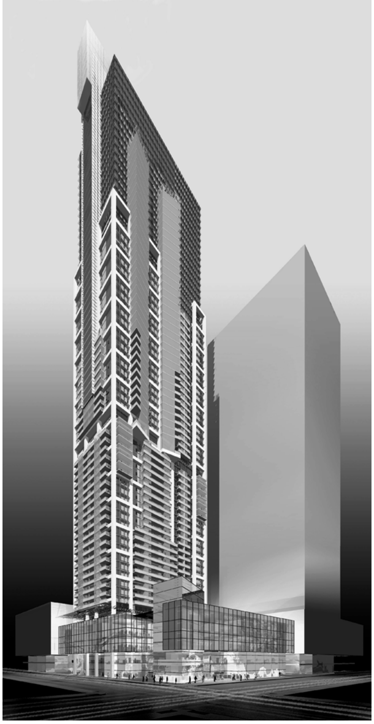
3.1.2 Wind Tunnel Test

A 1/400 aerolastic scale model of the Eureka Tower was tested in the wind tunnel at Monash University in October 2000. The aim was to confirm the preliminary design wind forces and in particular the predicted accelerations at the top of the tower. The test used a linear mode aerolastic model pivoting about the basement level. Strain gauges directly measure the base moments and torsion of the building. The wind tunnel test results generally confirmed the overturning moments, except that cross wind response caused by westerly winds at about 250° was significantly higher than predicted by the approximate method in AS1170.2.

Regarding the predicted accelerations, the wind tunnel test indicated that these will be lower than the generally accepted limit, however there is a narrow band of wind direction for which the accelerations are considered marginal. It is therefore proposed that allowance will be made for a rooftop damper to provide additional damping.

A cost effective form of damper, presently proposed is to configure the rooftop water storage tank as a liquid damper.

CASE STUDY 3 – WORLD TOWER



The World Tower has been designed by Connell Wagner, Sydney and is currently being constructed in Sydney's CBD at the corner of George Street and Liverpool Street. With a height of 260 metres and comprising 80 storeys, this will become Sydney's tallest building. The tower floor plan has an overall rectangular shape of dimension 55m × 29m with long span cantilevered wintergardens and balconies on many levels.

The development consists of a podium with 6 levels of basement carpark below 7 levels of retail/commercial, and low, medium and high rise residential levels comprising about 705 apartments. Intermediate 2 storey high plant and recreation/pool levels are located at quarter heights in the building at Levels 14, 37 and 60 with additional plant located within a 10m high beacon at the top of the building.

Designed by architects Nation Fender Katsalidis for developer Meriton Apartments, the tower is very slender with a height to base ratio of 9.5 and a core which is only 9 metres wide. A feature of the building is the expressed perimeter "superframe" of columns, and beams located on every third level.

The floors will be post-tensioned flat plates spanning 9m between the core and the perimeter columns.

4.1 Stability

The stability design comprises an innovative combination of structural systems which are outlined below.

The vertical structure of the tower comprises a central core of reinforced concrete shear wall elements and 20 perimeter columns. The central core is made up of 6 discrete core box elements which progressively terminate at low, mid, and high-rise levels.

The lateral load resisting system for the tower comprises:

- Coupled cores.
- 2 pairs of 8 storey high triangulated post-tensioned outriggers between core and perimeter columns centred about both mid-height plant levels.
- 2 storey 2 span spreader walls located at the ends of each outrigger.
- Outwardly spreading tower columns in podium levels.
- Inclined wind columns forming deep outrigger trusses in podium levels.
- Perimeter belt beams at top and bottom of mid-height plant levels.
- Edge thickenings at the north and south ends of the floors.

High strength concrete, up to 90MPa has been utilised to maximise the stiffness of the tower columns which when outrigged to the core resist approximately 70% for the lateral loads. The core elements are coupled by header beams at every level and link walls at discrete locations in plantroom levels.

The spreader walls connect each outrigger to 3 tower columns thus maximising the area of vertical perimeter structure mobilised to resist wind and earthquake forces.

A temporarily adjustable connection between outriggers and spreader walls will be provided to allow differential shortening between cores and tower columns, and then fixed after construction once most of the differential movement has occurred. The triangulated outrigger blades are located within apartments on inter-tenancy wall locations. Connection to spreader walls occurs in the plant levels where adjustment access is available.

The tower columns are outwardly inclined between Level 14 and 9 to provide an increased spread at the base of the tower. This had a threefold benefit of reducing the slenderness of the tower, enabling reuse of original tower pad footings built in 1990 for a previous commercial tower development, and also utilises the existing provisions for tower column penetrations in the as-built carpark slabs.

Increasing the overall base dimension of the tower by spreading the tower columns at the base reduces the tower slenderness and provides additional lever arm. This has a significant effect on reducing building sways and accelerations. Forces resulting from outwardly spreading tower columns between Levels 14 and 9 are restrained by post-tensioned tie and strutting beams built into the floors of Levels 9 and 14.

A wind tunnel test was undertaken at Monash University by MEL Consultants to enable more accurate assessment of wind forces and sway induced building acceleration. Lateral forces in the east-west direction, are governed by westerly winds on the larger building “sail” area whilst in the north-south direction earthquake forces are the governing design lateral load. The building’s first mode natural frequency is 0.14Hz and the predicted ultimate limit state wind deflection at Level 80 due to a westerly wind is about 500mm which is height/520. The predicted 5-year standard deviation acceleration at RL=234 is less than 5millig and within acceptable limits.

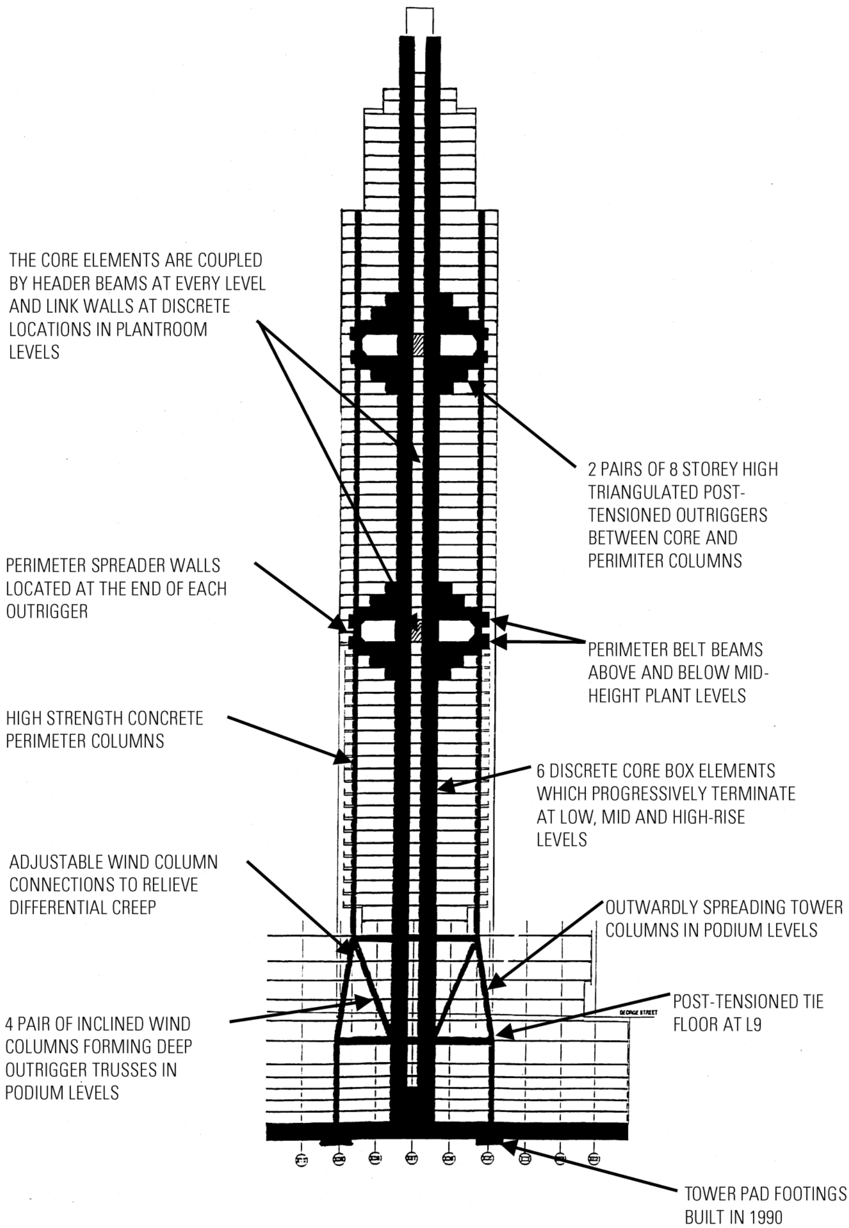


Figure 4 World Tower – east/west section.

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Multiplex Constructions – Aston Apartments;
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Meriton Apartments – World Tower

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