

One One One Eagle Street – setting new benchmarks

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Synopsis

One One One Eagle Street is a 57 level innovative high rise office development located within the prestigious 'Golden Triangle' riverfront precinct in Brisbane's CBD. The building has set new benchmarks for design and sustainability for Brisbane and Australia.

The paper describes its innovative structural design, the striking inclined perimeter column arrangement that was developed using a parametric model based on an algorithm of the way plants grow towards the light, and how the visually impressive 'fig tree' frame helped resist lateral loads allowing a significant reduction in the main lift core over the top half of the tower.

This paper also describes the collaborative approach adopted by the project team including the engineer Arup, architect Cox Rayner, and design and construct contractor Leighton Contractors, during preliminary design that generated enhanced outcomes.

1. Project Introduction

One One One Eagle Street in Brisbane's 'Golden Triangle', designed and constructed for The GPT Group, is simply unlike any other office tower. Its unprecedented, organic vertical structure is arguably the world's first high rise built using the principles of biomimicry inspired by the way plants grow upwards, towards the light. No two office floors are the same due to the shifting geometry and perimeter raking columns reducing in size from 800mm x 800mm at the base to a mere 300mm x 300mm at the top level. The structural design by architect Cox Rayner and ARUP cleverly addressed site constraints, and provided significant new knowledge from design accuracy, differential shortening, fire performance to construction techniques – setting new industry benchmarks.

Completed in June 2012, the office tower delivered more than 63,385m² of Property Council of Australia Premium Grade rated Net Lettable Area (NLA) to the local office market. At practical completion, One One One Eagle Street had successfully leased 83% to blue chip tenants, exceeding its 40% target.

At 199.7m tall, One One One Eagle Street comprises 57 levels including 44 typical office floors, two plant rooms, roof level, a six-level basement, as well as a foyer bistro by renowned chef Philip Johnson and an espresso bar at the mezzanine level. Every aspect of the project, from construction to completion, has embraced global best practice in sustainability, pushing design, aesthetics and construction boundaries.

The outcomes of the project are a direct result of the client's strong vision, the cutting-edge design by Cox Rayner and ARUP, and the collaboration between all project partners and Leighton Contractors during preliminary design to enhance project outcomes.

2. Design and Construct Contract

The GPT Group appointed the entire team including the design and technical consultants from the outset, under the leadership of Leighton Contractors. This approach enabled a number of early functions including preliminary design to proceed simultaneously, which under a normal tender contracting method could not have been achieved.

The Development Approval application/approval generally reflected the project scope, however during preliminary design Leighton Contractors managed the amendments.

At the time of Leighton Contractors' appointment, the project's final overall design and construction cost had not been established or agreed. The appointment of Leighton Contractors was on the basis that the final design and construction cost and contract conditions would be jointly determined and agreed over the first few months of the project as the design became more defined.

3. Project Technical Challenges

Site location, unprecedented design, ambitious architectural and client aspirations, and a tight program, presented numerous design and construction constraints. Many challenges were known at the project outset, however, overcoming some of the design constraints in the execution of works proved continually challenging, and in some cases, created additional challenges.

In particular, the site selected for the new tower presented major technical challenges:

- The client GPT set a challenge for the design team – could a 57 storey office tower with six basement levels and a plan footprint of approximately 40m x 40m be built on a site that is only half the area of the tower, with minimal disruption to the existing Riverside properties and users, and within the same timeframe as a conventional tower with an unimpeded site
- To take best advantage of the outstanding river views available from the tower, the tower's service core should ideally be pushed to the buildings south-west corner, the tower's perimeter columns should be smaller than conventional towers, and the ceiling heights around the perimeter of the office floors should be higher than normal. To achieve the higher than normal ceiling heights without increasing the floor to floor heights meant devising a new "thin edge" detail for the office floors.
- The proximity of the building to the river meant tricky ground conditions, with soft marine clay soils and a high water table. The challenge posed by the ground conditions was magnified by the proximity of the existing Riverside and Riparian towers, and the need to ensure that the development of the new tower would not affect these buildings or their foundations.

Arup worked closely with the architect Cox Rayner to develop the unique and innovative high-rise building design concept that cleverly addressed the challenges posed by the site. This concept not only offered a way of building the new tower on its restricted site without disrupting the operations of the precinct, but it incorporated a unique hybrid tower design that provided a powerful identity for the building and allowed the building's core to be offset. The offset core produced unrivalled view transparency for building users.

4. Structural Description

Half the tower footprint overhangs the existing two level Riverside basement car park. The tower floors were typically post-tensioned concrete flat plates, with the tower floors supported by an offset reinforced concrete core, widely spaced internal reinforced concrete columns and the fig tree façade frame. The façade frame consists of an organic pattern of inclined perimeter columns constructed using concrete filled steel box sections. Resistance to lateral loading from wind and earthquakes is provided by the fig tree façade frame and the core acting in combination. The lateral stability design was informed by a High Frequency Force Balance (HFFB) wind tunnel study that was carried out to accurately determine wind forces, moment and accelerations due to the unusually close proximity of the Riverside and Riparian towers. The buildings foundations comprise large diameter bored piles and large ground bearing strip footings founded on high strength rock below the basement.

The design of the typical floors was driven by the need to have very large internal column free spaces with a relatively thin structural framing system. Several options were looked at during schematic design including composite steel beam and bonded slab, precast beams and slabs, and normally reinforced concrete. A post tensioned flat plate system was adopted due to the benefits of achieving large spans with minimum structural depth and providing least impact to services in the ceiling space. A shallow edge beam was used around the perimeter of the floor plates to help tie the inclined Figtree columns and respond to the different span conditions generated by the varying column positions.

4.1 Structure features

The most striking feature of the competition winning design for this building is the inclined perimeter column arrangement that appears to randomly weave its way from ground level to the top of the tower. This innovative column arrangement had its origins in the need to support the northern half of the tower perimeter on only four points dictated by the configuration of the existing Riverside car park, loading dock, and substation. This translated into a need for a perimeter column system that could support the tower floors at close enough intervals to allow the “thin edge” floor whilst bridging between the perimeter support points at ground level. This physical constraint of the site was then combined with a unique and clever integration of architecture and structural design. Arup developed a parametric design model that enabled hundreds of viable column patterns to be developed very quickly based on a defined set of structural rules including maximum and minimum column angles, maximum column loads, and zero sum of angles at each floor to ensure overall stability. The resulting patterns were then reviewed with the architect to carve out the most appropriate architectural solution.

This innovative approach produced an ‘organic’ pattern to the facade columns. The organic nature of the pattern is not accidental – one of the algorithms used to generate the hundreds of patterns considered during the initial design phase was derived from a seed germination and ‘growing towards the light’ algorithm. This application of biomimicry not only results in an impressive visual presence but also provides an efficient structural solution that offers substantial benefits. The final perimeter column arrangement has been dubbed the ‘fig tree’ frame through the similarity between the organic column pattern and the large Moreton Bay fig trees on the opposite side of Eagle Street. As well as providing a distinctly unique architectural identity, the frame achieves the goal of efficiently gathering together

perimeter columns towards the base of the tower, utilising the available support points within existing operational loading dock and existing substation. This avoided the expensive and time-consuming transfer structures that would otherwise be required to bridge over the existing facilities with a more conventional solution. The fig tree frame by its nature also provides a substantially higher degree of redundancy and resistance to accidental or deliberate damage, than would be provided by a conventional facade with vertical columns. The partial triangulation that exists within the fig tree frame provides an inherent lateral stiffness that supplements the lateral and torsional stiffness of the tower core. This extra stiffness gained from the perimeter column framing allowed the central concrete core structure to be offset to the south-west corner and substantially reduce in size in the top half of the tower which gave valuable additional net lettable floor area for GPT. Lateral deflections of the combined fig tree frame and concrete system are approximately less than half those which would be induced if the building was reliant on only the core to resist lateral loads.

To enhance the visual statement of the fig tree frame and improve buildability the fig tree column section were kept remarkably slender by utilising composite concrete filled steel boxes. The relatively thin box section utilised the benefits of high strength 80MPa concrete infill to maximise the strength capacities of the slender columns. The inclined composite columns were accurately analysed in the overall building Etabs model and were designed in accordance with AS 5100.6-2004 - Part 6. Eurocode 4 was used for the fire analysis as this was deemed the most comprehensive and rigorous design specification for large concrete filled box sections.

With the design location of every column different from floor to floor, the perimeter columns could not be easily coordinated into any standard formwork system. Lifting and standing tabs were added to the column, and plates were also added to top of each column to support the formwork, and seal it, thus reducing the amount of slurry to clean off the primed steelwork.

4.2 Fire engineering

The columns were required to be fire rated to a minimum of two hours. The fire engineering solution that was developed for these columns used the strong thermal benefits of the concrete infill. The 'heat sink' effect of the concrete infill was modelled using sophisticated finite element software coupled with correlation to industry test data on similar but smaller column sections from around the world. This approach allowed the fire safety engineers to prove that an intumescent paint system that has previously been tested and certified as providing one hour of fire protection to unfilled steel box sections would provide a two hour protection to the concrete filled sections due to the heat sink effect. This outcome presented significant savings to the client.

Intumescent paint is a specially engineered coating which at approximately 180 degrees expands and chars to insulate and protect the structural steel fig tree columns in the event of a fire. For example, a 2mm thick coating of intumescent paint can expand beyond 50mm thick and char when exposed to fire. It can provide up to 120 minutes fire protection.

The expanding, charring and insulating nature of the intumescent paint was selected for its performance, as well as a means of not impeding the proposed custom-made light-fitting to be fixed to the fig tree columns as part of the proposed artworks for the building.

Fixing of custom-made lighting fittings to the columns resulted in technical challenges including the need for research and testing into the sustaining the performance of the intumescent paint, and the method of fixing the light fitting to the intumescent paint/fig tree column, as well as the design of the custom-made light fitting. The team undertook analysis to prove/disprove the following hypothesis:

- It will be technically feasible to design/engineer a custom-made light fitting fixed to the fig tree columns without impeding the performance or warranty of the fire protection to the structural steel provided by the intumescent paint.

Approximately 5,500sqm of intumescent paint with an approximate thickness of 2mm was applied to the One One One One Eagle Street's structural fig tree columns. To Leighton Contractors and Arup's knowledge, intumescent paint had never been utilised on such a scale nor manner, hence limited knowledge surrounding its application and performance over an extended period of time.

Further, given light fittings need to be attached to the columns, there was a significant amount of uncertainty as to how the fittings and the paint would interact in a range of environmental conditions over time. Given there was no 'off the shelf' solution fit for the specific purpose, investigations were undertaken, in an iterative manner, to allow for a range of fixing options to be assessed. During investigations new knowledge was gained in relation to each material type in the context of performing as part of a light fitting. These fixing options included but were not limited to:

- Double sided tape – investigated and evaluated as a method of adhering the light fittings to the fig tree columns. It was determined the tape would not be suitable to adhere the fittings to the columns due to the textured finish of the paint and no technical data being available on the long term transfer of chemicals between the tape and the paint (e.g. would chemicals from the tape leach into the paint and affect its performance and/or would chemicals from the paint affect the adhesive ability of the tape?).
- Low melt plastic adhesives – similar to the issues for double sided tape, it was not able to be determined whether or not a chemical transfer between the adhesive and the paint would occur and affect the performance of each element.
- Magnetic strips – magnets were considered and tested as a means of fixing the light fittings. However the approx 2mm of intumescent paint impeded the magnetic attraction between the light fitting and the steel substrate.
- Silicon – it was investigated and evaluated as a method of adhering the light fittings to the fig tree columns. Silicon was considered to be good alternative to tape and plastic adhesives because of its "neutral" chemical nature. It was determined this product was designed to retain strength and essentially not to 'let go' during extreme heat conditions.

The final solution comprised a 'fusible link' which melted and allowed the light fitting to fall away. Further evaluation including furnace testing was undertaken once the fittings had been implemented.

4.3 Differential Shortening

As concrete high rise buildings undergo shortening, generally consistent throughout the structure there is no need to customise the design to accommodate differential shortening. However, as this project had an offset core, large floor spans to highly

stressed internal columns and an irregular diagrid of composite perimeter columns, design did need customisation requiring on-site analysis. Analysis commenced as early as August 2010, and an independent review was undertaken in addition to ARUP, to validate recommended cambering and to mitigate impacts to construction.

A preliminary report by ARUP highlighted the need for the structural design to be reviewed to incorporate the requirements of differential axial building shortening. However, the analysis needed to be calibrated with real on-site survey data:

- In July 2010 there was enough dead load from the completed typical floors to begin an analysis of if/how the building was differentially shortening.
- In August 2010 weekly survey data/monitoring began on Levels 13, 18, 23 and 28. Level 33 was added to the analysis in September 2010.
- In August 2010 ADG was engaged to carry out an independent review of the differential axial shortening.
- Monitoring of Levels 13, 18, 23, 28, 33, 38, 43, 48 and 53 continued on a weekly basis for four months to allow the survey data to continually calibrate the theoretical shortening computer modelling.

The independent analysis by ADG confirmed assumptions in line with ARUPs, and their independent analysis showed a cambering of 25mm was required beyond Level 35 – ARUP had advised 30mm. Weekly monitoring continued and feedback into ARUP's theoretical model and to the extent of pre-cambering was continually reviewed.

The full effect of the benefits of the cambering will not be known for up to 30 years.

4.4 Design Accuracy and Requirements

Significant attention to the design was required – the loads produced by each of the angled columns at each level had to be equalised at the slab edge/perimeter beam – the vertical and horizontal loads produced by each angled column requires an opposing load by a corresponding angled column to offset (or equalise) the loads created due to having the columns on angles (in lieu of vertical). The complexity of the project was further intensified by the location of the building's core. Specifically, the location of the core in corner of the structure results in further structural issues balancing out the loads within the buildings extremities.

4.5 Major Column Lobby Transfers Structures

The podium's layout was constrained by the close proximity to the existing riverside plaza and the very tight site boundaries resulting in the offset lift core being 'squeezed' as small as structurally possible to provide suitable circulation spaces in the lobby. With these planning constraints three of the main internal tower columns had to be transferred above the podium. Storey deep cantilevered transfer walls were designed to carry column loads of up to 80,000kN down to the core walls in the basement. The core wall thickness was also limited by the space constraints and high strength concrete alone was not enough to carry the large strut forces generated in the transfer walls. Following the modification of the building's podium structural design, Leighton Contractors was required to realign/transfer around 1000 tonnes of load within two columns (CC1 and CC2) and a transfer wall (CW10) from one location to another. This load transfer in columns CC1, CC2 and CW10 was particularly challenging due to the short height in which this load needed to be transferred.

Through carefully analysing the loads and spatial constraints, a complex structural steel transfer structure was developed for each case. Development of fabricated steel had to also consider the available installation methods and the ability to be positioned within the fine tolerances of the structure. The transfer solution was a combination of fabricated structural steel cast into concrete that allows the load to transfer in the most efficient and effective manner possible. Also using the proximity of columns CC1, CC2 and CW10 to the main building core it was established that we could use the weight and stiffness of the core to triangulate and offset some of the transferring load. Triangulating the load and pinning it to the core allowed the load to transfer configuration.

4.6 Quality Management

The Project Manager implemented a comprehensive quality system which included:

- A project-specific Quality Management Plan detailing the systems and procedures required to meet the quality requirements of the contract.
- A web-based quality system in Incite which tracked Corrective Action Requests (CARs), Non Compliance Reports (NCRs), and Lot Management.
- A detailed defects management process which incorporated both web-based and database management systems

Due to the QA systems being implemented, any deviations from the required finish were identified early enough to allow corrective actions to be put in place to improve quality. Core quality issues that required stringent quality control included:

Process Issues

- reinforcement deliveries for suspended slabs and other reinforced concrete
- delivery and erection of structural steel 'fig tree' columns

Final Product Issues

- the painting of the fig tree columns to achieve the specified finish
- the finished levels of concrete which had strict contractual tolerances

The key to ensuring that all quality records were obtained and contractual quality obligations were achieved was the implementation of the Lot Management System.

The Lot Management System:

- enabled the works to be subdivided not only into manageable portions but also to a detailed level (eg the lot system can identify a particular column on a particular floor which makes records easily retrievable at a later date)
- ensured all required records relating to a particular area of work were identified
- identified and tracked required approvals and hold and witness points
- ensured all test, quality and completion records were obtained and any non-conformances closed out
- ensured records related to a particular area of works are easily retrievable at a later date

The Lot Management system was monitored on a weekly basis by the QA Manager whose main focus was ensuring all required quality obligations with respect to individual lots were obtained/achieved enabling lots to be progressively closed out. A specific quality assurance KPI tracked the performance of the Lot Management system to ensure the pressure on closing out of lots was maintained.

Monitoring and controlling quality outcomes was undertaken via a comprehensive auditing system covering:

- External Audits eg by SAI Global
- Branch Audits ie audits of the project by Leighton Contractors' Queensland head office
- Internal Project Audits ie audits of the project systems
- Subcontractor Audits ie audits of subcontractors Quality and Safety Systems
- Consultant Audits ie audits of consultants quality assurance
- An annual Project Management review covering all project systems

Monitoring of schedules and results against KPIs was also a key factor underpinning the success of the quality outcomes, in particular the structure.

5.0 Conclusion

One One One Eagle Street is quite unlike from other high rise tower worldwide, not only because its organic vertical structure is unprecedented, but because it defines the architecture of the tower.

Equally, it also defines the interior office space, such that no two floors the same due to the shifting geometry and to the reducing size of the columns.

One One One Eagle Street shifts tower design, which in recent years has tended to be universal in typology to a typology of site and context specifically – One One One Eagle Street has embraced and embodied both the 'subtropical' city and the 'river' city.

This project showcases the benefits of architect, engineer and constructor Leighton Contractors working together at the inception of a project to enhance project outcomes. The collaboration during preliminary design continued into construction where ARUP, the architect and Leighton Contractors engaged whole heartedly to help bring the design to life.

Project Participants and Acknowledgements

Client: GPT Group

D & C Contractor: Leighton Contractors

Architect: Cox Rayner

Structural/Façade/Fire/Civil Engineer: Arup

Geotechnical Engineer: Butler Partners

Building Services Engineer: WSP Lincolne Scott

References:

ARUP Technical Paper: One One One Eagle Street – Innovative High-Rise Office Tower