Brookfield Place – Safe Design and Construction of the "Building Capitol"

James Taylor[1], Angus Leitch[2], Declan Barrett[3], David Eden[4]

ABSTRACT: *Brookfield Place Tower is the new 250m tall high-rise in Perth's Skyline overlooking the Swan River. The tower is crowned with a 40m tall, 700 tonne steel "Building Capitol" structure completing the architectural vision for the project. The design and construction of this complex structure had many challenges to overcome to allow the safe construction of this structure 200m in the air and to maintain it into the future. This paper outlines how safe design principles and a collaborative approach were used to embed safety into the capitols design and construction. This allowed the structure to be built and maintained with safety being the primary objective from concept to completion.*

KEY WORDS: Safe Design, Steelwork, Safety, Building Capitol, Construction

1 INTRODUCTION

Safety is a key behaviour integral to the success of the design, construction and future of any new development and the Brookfield Place Building Capitol is an outstanding example of how this can be implemented to successfully deliver a project.

Figure 1: *Brookfield Place Tower*

The tower is a 47 storey, 250m, 5 star Greenstar building completed in mid 2012. The unique tower design combines a slender offset, open-faced core with two exposed 'Mega-Frames'. This provides large uninterrupted floorplates overlooking the Swan River to the south while the exposed movements of people within the lifts connect it to the city to the North.

The tower is capped by the 'Building Capitol' or 'Tiara' structure which completes the architectural vision for the tower. This consists of two 40m tall by 35m wide steel frame structures which complete the exposed structure concept for the tower and support the rooftop signage. Safety was the primary consideration in the design and construction of this building element. There were many challenges involved in both the construction of this 700 tonne structure and in its permanent (maintenance) state 200m on top of the tower.

The safe design procedure and collaborative approach used by the design and construction teams was key to the successful completion of the Building Capitol. The safety processes and procedures implemented during the 16 month design and construction period of this large structure highlight how these can be used for the successful delivery of a difficult project.

2 DESIGN BACKGROUND

The success of the building capitol design required balancing multiple conflicting design drivers while overcoming some complicated design challenges of the structure while keeping safety the primary focus.

[1] James Taylor, Structural Engineer, Aurecon Pty Ltd, Email: james.taylor@aurecongroup.com
[2] Angus Leitch, Buildings Leader, Aurecon Pty Ltd, Email: angus.leitch@aurecongroup.com
[3] Declan Barrett, Associate, Aurecon Pty Ltd. Email: declan.barrett@aurecongroup.com
[4] David Eden, Construction Manager, Brookfield Multiplex. Email: David.Eden@brookfieldmultiplex.com

2.1 Design Drivers

There were many design considerations that drove design decisions including:

- Safe Design
- Construction Safety
- Structural Stability
- Architectural Intent
- Access (permanent and temporary)
- Construction Methodology
- Fabrication
- Program
- Cost

These were all addressed in collaborative design workshops involving the design team, builders, fabricators and riggers so that any conflicting considerations could be resolved and incorporated into the design.

2.2 Structural Design Drivers

Some of the structural issues which were required to be worked through include the following.

2.2.1 Structural Form

The Building Capitol structure comprises of two separate 40m tall by 35m wide steel frames. These have a mixed system of portal frames in the east west direction combined with 50mm diameter post-tensioned, tension tie bracing. In the north-south direction the frames are braced with large diagonal braces. The two frames are supported by the external Mega-Frames at the edges and then internally on the core and internal columns.

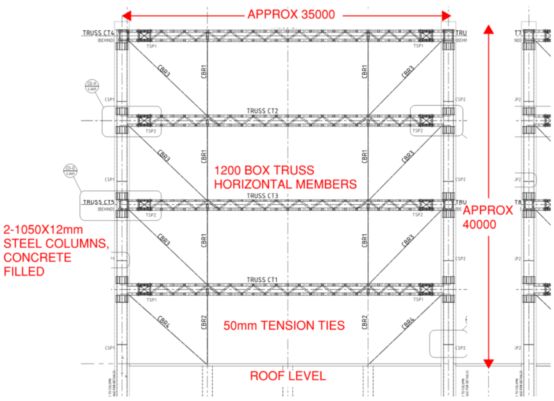


***Figure 2:** Building Capitol Structure–Front Elevation*

There were multiple schemes considered for member types including fabricated plate girders, box sections, circular hollow sections and trusses for all members. The final design makes use of box truss horizontal members fabricated from 200SHS and 150SHS sections, columns of 1050x12 circular tubes filled with reinforced concrete and box truss rear diagonal braces. The main drivers for the final selection were safe access, achieved by moving within trusses, reducing weight of members to reduce cost and lifting difficulties, ease of construction and connections.

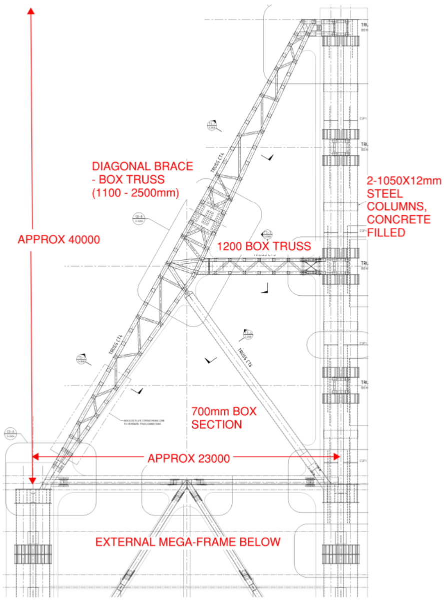


***Figure 3:** Building Capitol Structure–Side Elevation*

2.2.2 Aeroelastic Instabilities

A key design aspect is the fact that the Building Capitol is a very wind sensitive structure. This is due to shape and stiffness of the members which mean they are susceptible to aeroleastic instabilities. Using calculations in [1] the structure was reviewed early on and it was found that the members were in the range associated with vortex shedding and galloping. This was due to the aspect ratios and the square, sharp-edged, shape of the members along with the mass and stiffness of the members.

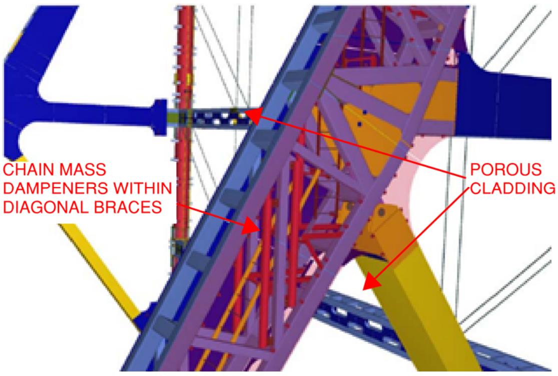


***Figure 4:** Perspective of the Aeroelastic Instability Mitigation Measures*

Working with the wind consultant mitigation measures were incorporated into the design early in case they where needed to avoid these effects as wind tunnel testing had yet to be carried out. These included adding vertical members to trusses which could have chain mass dampeners attached if

required, removing top and bottom cladding off members and allowing an option for porous front cladding. As the design progressed the structure was then tested in a wind tunnel. The testing showed the members would experience significant deflection at low wind speeds with the original shapes and cladding arrangement. The final solution utilised chain mass dampeners in the rear diagonal members which could be simply bolted, the front cladding was made porous to allow wind to flow through and out the top and bottom faces without causing vortex shedding.

2.4.3 Joint Design

The difficulties in the joint design was driven from the difficulties in getting a thin walled tube to transfer portal frame loads from beam to column without causing local buckling of the tube. The options involved changing the shape of members to a truss or plate girders, stiffening the circular column locally by using much thicker plate (50-70mm) or have plate stiffeners and concrete fill the columns.

The final design used the concrete filled columns and local vertical and annular stiffening arrangements to resist local buckling. This was justified using finite element analysis where the concrete acted to resist plate buckling inward and stiffeners resist buckling outward. This can be seen in [2]. The advantages of this solution are that it reduces the weight of column sections for lifting and allowed for a relatively simple on site connection to be made with the main joint shop fabricated.

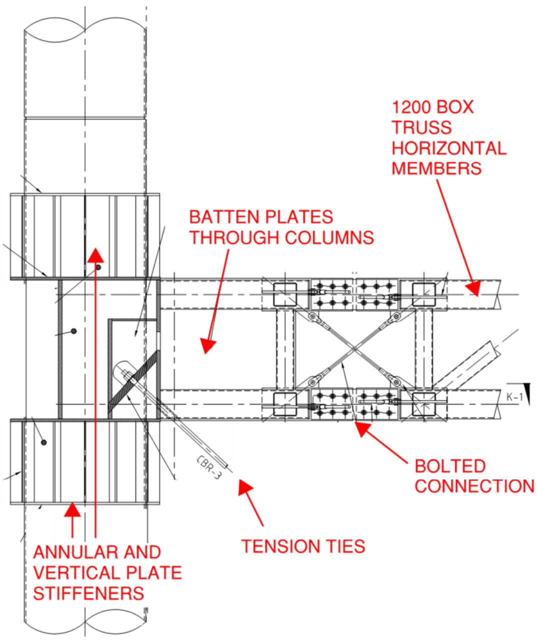


Figure 5: *Typical Beam Column Joint*

3 SAFE DESIGN PROCEDURE

The aim of the safe design procedure was to eliminate 100% of all safety risks identified at the design stage and to control safety risk "above the line", refer to figure 6, via elimination or engineering as opposed to "below the line" controls such as policies, procedures and PPE. The design and construction teams regard health and safety as a key behaviour integral to the success of the project. The design process for the Building Capitol had safety at the forefront of decision making.

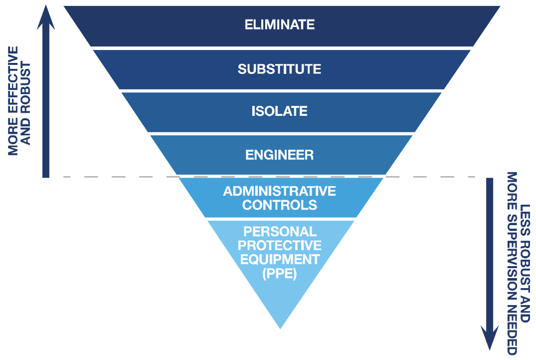


Figure 6: *Hierarchy of Control*

The detailed procedure that was followed ensured it captured the knowledge and experience of all operatives and carried the decisions through concept, design development, construction and operation of the Building Capitol.

The stages of the safe design procedure used included:

- Safe Design Report and Risk Register.
- Design Workshops
- Construction Workshops
- Construction Phase
- Maintenance and Use

Safe Design requires a risk assessment of a building to be provided for the end-user in accordance with Section 28 OH&S Act 2004. As the Building Capitol was seen to have a much higher risks associated with it due to its size, location and non-typical nature a much more detailed process was followed by the design, construction and maintenance teams.

The process allowed risks to be identified, measured and mitigated by embedding safety elements into the design and communicating this clearly through the design, construction and maintenance phases. This approach facilitated review and input from all levels through collaboration capturing a wide range of knowledge.

A strong safety culture was established from the top down with the emphasis placed on safety going well beyond contractual obligations.

3.1 Safe Design Report and Register

Safe design workshops were carried out for the entire Brookfield Place development as well as separately in detail for the Building Capitol. Risk workshops were conducted prior to the commencement of specific activities, attended by senior management representatives, Aurecon and Brookfield Multiplex engineers and supervisors, architects, safety coordinators, union representatives and subcontractors. This process captured the knowledge and experience of all operatives, ensuring process ownership and achievement of best practice

The risk assessment for the development identified over 600 risks associated with the design which would affect end users in both operations and maintenance. This allowed for the elimination of known risks, optimising safety for all workers who would use the building. The risk assessment was communicated throughout the project as a report.

The Building Capitol was identified as a higher risk element and specific risks were identified and communicated within the report on this. This was then used and fed into the detailed safe design process for this structure which aimed to embed safety into its design and succeeded through this safe design process and implementation. It was the goal of the design workshops to reduce the risks identified through “above the line” controls by embedded them into the design.

4 DESIGN WORKSHOPS

The Design workshops started the 16 month design and planning process for the Building Capitol. The design workshops brought the key stakeholders together to review all the design drivers and agree on outcomes that allowed it to be built and maintained safely. The primary attendees at these regular workshops were the structural engineers, architects, design managers, wind consultant, access consultant, fabricator, main contractor and others as needed. This team could effectively use the safe design report and register to feed known risks into the decision making process throughout design development and identify new risks.

The following are some of the safety initiatives which were embedded into the design through this process.

4.1 Integrated Access System,

One of the key aspects to the safe design of the Capitol was how to provide safe access both during construction and for maintenance once complete. The aim of the team was to try and provide permanent access systems that could be used safely during construction to construct the steelwork. Basically there had to be a way of safely accessing across all members of the Building Capitol.

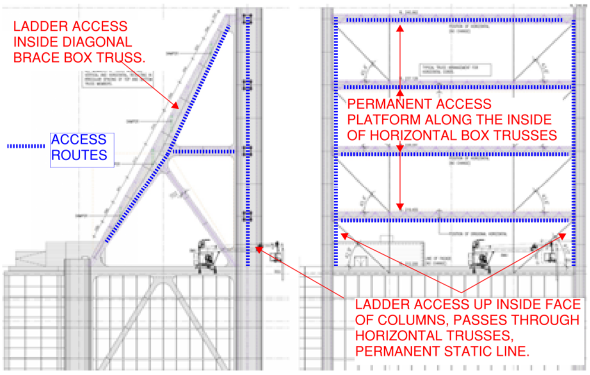


***Figure 7:** Access Paths on Building Capitol*

There were a number of concepts that were worked through during the design process outlined below.

4.1.1 Internal Column Access

Early ideas felt that if you could walk through an access hatch in the base of the columns and climb up internal ladders in the columns and then out through another hatch onto the horizontals this would be the safest option. However when this was worked through it raised a number of technical and safety issues including the access hatches significantly weakened columns, large bolted flange moment connections where difficult to fit internally, welded connections were seen as a safety concern as internally could be confined space and working at heights. These items and others led to looking at an external ladder system.

4.1.2 Horizontal and Diagonal Member Access

As the structural form of the Capitol was being evaluated, and which type of members to use, a number of member options presented. The members were large (1200mm) welded plate girders on their side at one stage which allowed someone to walk on top of the web and have the two flanges acting as handrails. However this worked well if you could come out column hatches on top of the member but if the access was below you needed to penetrate the member which weakened it at the joint. Also box and circular members were reviewed but access on these were more difficult requiring a static line as the primary safety system unless handrails were added which effected architectural intent.

4.1.3 Final Solution

The final solution for the access resolved multiple concerns in regards to structural integrity, architectural intent, construction access and most importantly gave safe access routes with multiple controls to reduce any risk of falling. The solution has external ladders up all columns with a permanent static line and internal access inside the horizontal and diagonal box trusses. The choice of using box truss members for the horizontal and diagonal members allowed two key things,

personnel could access them within the box trusses and when going up columns they could also go through the trusses.

The top and bottom faces of the trusses are vierendeel trusses which leaves 900mm square openings throughout truss. At the beam column joint a bespoke sliding hatch was designed so personnel could climb the ladder, unhook and slide the hatch back, pass up through the truss and then slide the hatch back to allow them to safely step down at each horizontal. Using this sliding and locking mechanism they can be safely standing on the horizontal enclosed by the box truss sides and from here they can crawl along the horizontals on a plastic webforge decking and still stand up whenever needed due to the vierendeel arrangement. Figure 8 shows the access from column, through hatch and onto horizontal members.

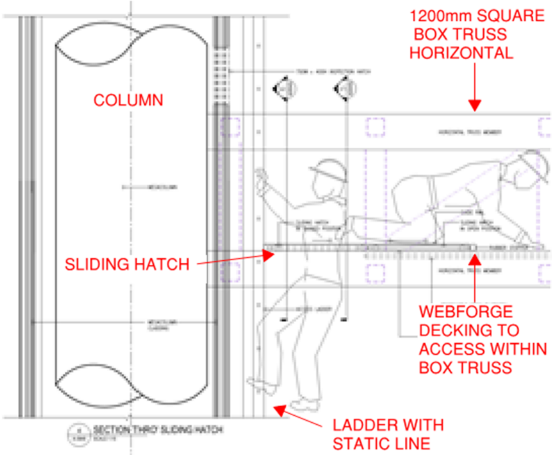


Figure 8: *Access Paths on Building Capitol*

The diagonally members had a full ladder and platform system inside the box truss as it is a much deeper section. Personnel are therefore always enclosed as well as have static lines. These ladders can be seen in Figure 4.

These systems were also all able to be utilised during construction as the ladders where fabricated with columns and spliced at same locations and Webforge was preinstalled in members so riggers could use these when the members arrived on site.

4.2 Connections

The connections throughout the structure were critical to the safety of the construction personnel during construction and ongoing maintenance. The suggestions from the safe design risk register was to use bolted connections where possible to avoid hotworks at height, keep connections simple and ensure the structure is temporarily stable prior to the permanent connections being completed. Tolerance was also a key driver to all connection design to assist improve constructability due to the size of members.

All the most complicated connections were shop fabricated as this is a safer, more controlled environment to carry this out. This included all the beam/column connections and top of the diagonal member. The connections used in the structure that were connected on site and the safety aspects embedded included the following.

4.2.1 Horizontal Members

A bolted splice connection was used with loose cover plates. This allowed for tolerance on site, a simple bolted connection which only took some time to do up the 48 bolts in each. Also the much more complicated knee connection was shop fabricated which allowed the access ladder and sliding hatch platform to turn up to site ready to be used in the connecting of the horizontal. A seating plate that was added to the horizontal 'Stub' that formed the start of the horizontal that come to site to allow the horizontal beam to be seated safely in position, with the connection plates pre connected so riggers could quickly complete the connection. Refer to figure 5 for the typical beam column joint and to figure 10 for the temporary platform used to connect it.

4.2.2 Diagonal Members

The diagonal member had a plated splice similar to the horizontals at midspans. Although this had many bolts it was a simple connection to complete. The top connection was also required to be welded due to its tapering size, complicated load paths and tolerance required as it was the last member to be installed. However a large locating pin was designed which allowed the connection to be easily fixed temporarily to allow the crane removal and then the site measured RHS sections could be welded in to complete the box truss.

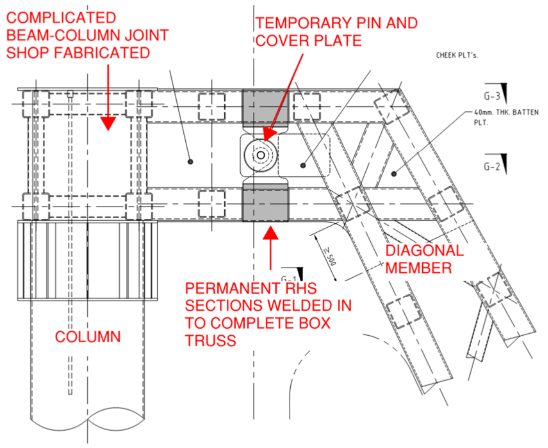


Figure 9: *Temporary Pin Connection at Top of Diagonal Member*

4.2.3 Columns

The columns went through many options for the splice connections, all of which raised issues that needed resolving. Bolted flange splices were the other primary option but this increased the column wall thickness greatly (50mm) which increased lifting weights and increased the number of splices required. Therefore the final solution was to site weld the columns splices with FSBW. This went against the original thinking from the safe design register however with the appropriate controls which were included into the design and procedures it was seen as the best and safest option.

The advantage of the welded splices included reducing the number of slices to 3 per column, only 2 of these were above the roof slab and gave site tolerance for the connection. The additional controls included a temporary bolted connection, backing plate and locating spears that were incorporated into the permanent design which allowed the columns to be located and made temporarily stable to allow the crane to be removed and then the welding could occur when required. Also temporary platforms were designed to allow safe access to the welding, refer to section 5.1.

4.3 Roof Slab Upgrade

The original roof slab had a similar design as the typical office floors with the exception of falls for drainage. However during the design process and review of safe access during construction it was decided to increase the roofs capacity.

The first change included thickening the slabs and increasing beams sizes to allow multiple large (16T) boom lifts and crawler cranes to have unrestricted access on the roof slab. This allowed construction personnel to have greater, safer, access to the whole capitol structure during erection. The greater slab capacity also allowed members to be lifted and temporarily stored on the roof ready for erection as there was limited storage area at ground level.

Photograph 1: *Cranes being moved onto Roof Slab*

Secondly the framing was redesigned in areas to allow the primary tower cranes to be able to be moved onto the roof structure rather than next to the tower. This increased the lifting capacity in the required areas from about 12T to 36T. This allowed the Building Capitol members to be increased in size to minimise the number of connections required on site, the largest lift was 36T, 220m up onto the roof.

4.4 Proposed Construction Methodology

A staged analysis was carried out to assess the potential temporarily loads of the structure. This allowed the connection design to be incorporated into permanent structure as well as advise the proposed construction sequence. This resulted in drawings showing a 22 stage erection sequence which highlighted sequencing, crane lifts, temporary connections, props required, temporary platforms required in a diagrammatic step by step process. This was vital in communicating to the construction and temporary works teams what had been assumed and what was required, in effect the building capitol had its own Construction Management Plan. If they wanted to modify this process additional analysis and design would be required. The visual nature of the methodology also helped new people in the team quickly grasp the concept so improvements and solutions could be discussed in the construction workshops.

4.5 Pre-cladding

All members were pre-clad as much as possible to allow the cladding to be carried out in the controlled workshop environment and reduce the working at heights on site to the minimum. This included columns, beams and diagonal members. The only cladding required on site was where there were site splices required.

Photograph 2: *Pre-clad Columns with Horizontal member being installed.*

4.6 Durability

The durability of the structure was raised in the safe design register as decreased durability would increase maintenance inspections and maintenance work required in the future. Therefore improving the durability of the structure increases the time between inspection and maintenance reducing peoples exposure to having to work at height.

Elements that went beyond the specification of paint finishes to increase the life span included a number of items. RHS sections were used in box trusses which reduced the number of sharp corners on the structure so paint edge where not effected. Webforge grating was made plastic to reduce any effect with the corrosion at steel supports. Having items pre-clad and finished meant less chance of damage on site and a reduced requirement for touch ups. Inspection hatches were also included on column cladding at safe locations, the horizontal members, to allow easy inspection of the steel beneath.

An inspection regime and program was formulated at the design stage and communicated with the end users. This advised of how the structure can be accessed, how it can be inspected, what to inspect and when to inspect. The inspection program started more frequently to review post construction items and then extended out over time.

4.7 Podium Slab as Crash deck

The base of the tower is surrounded by a podium slab structure which is above 4 levels of basement. The area below the Building Capitol was programed to be in construction at the same time as the Capitol as they were both items that were to be left to last in order to allow access to the site.

Building the basement and podium structure below the Building Capitol structure raised safety concerns which were reviewed and a solution was found. It was decided to modify the design of the podium structure to allow it to be built first via a four level structural steel frame "jump start" followed by top down reinforced concrete construction of the basement levels below. This meant that podium would act as a large crash deck to protect the workers below and allow work to continue on both fronts. This was made possible by changing the podium to steel framed structure which could be built safely four levels up off the lower basement raft.

5 CONSTRUCTION WORKSHOPS

Once design had developed to a firm solution there was an overlap between design workshops and construction workshops. The construction workshops were key in further carrying the design philosophies through to the construction team, drawing from their experience to make improvements. This also got buy in from the whole team on the final design and construction process. There were design items which had been identified by the design team that also needed construction team input to complete the collaborative process and safety review.

5.1 Temporary Access Platforms

Although the permanent access systems could be utilised during construction there were still requirements for temporary access to allow the completion of connections. This was done using the permanent systems, boom lifts from the roof slab and the use of temporary access platforms at member connections. These were worked through with the design and construction teams so the final solution incorporated experience form the temporary works engineer, permanent works engineer, main contractors and site personnel who would actually using the platforms. The final bespoke platform solution used a combination of 'Saddle' type platforms for the horizontal and diagonal members and gravity ring type platforms for columns.

The horizontal member platforms worked by simply first being dropped onto the prefabricated 'stubs' extending from the beam column joints. This allowed workers to climb the ladder and get onto the platform. Once the horizontal member was dropped in the platform could then be slid across by workers allow them to access the inside and outside of the bolted splice connections to quickly complete these. Figure 10 shows the design of these platforms and photograph 3 show these on site.

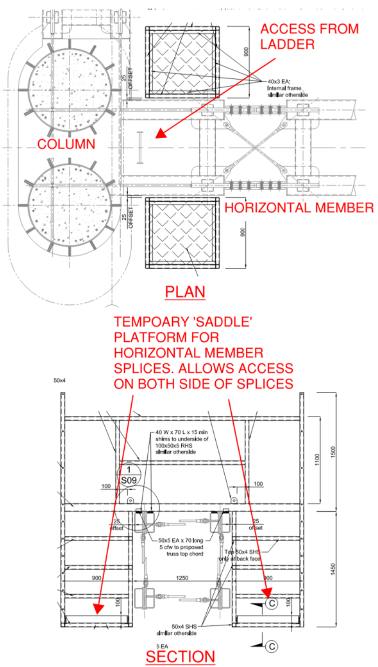


Figure 10: *Temporary Access Platform for Horizontal Member*

At columns, circular platforms were used by being dropped in in two sections. These where braced down to the annular stiffener arrangement above the beam column joints and cleats which had been added. The column splice was located approximately 3m above the beam column joint which was required to be welded. The platforms could be installed first on the lower column and could be accessed from the permanent ladders. From this workers had the splice at a good working height to complete the temporary bolted connection when the next column was lowered onto the splice and then welders could then complete the connection.

5.2 Temporary Works

Although efforts were made in the design to embed temporary connections in the permanent works there was still a requirement for some propping and temporary works at the base. In the construction workshops it was critical to transfer information from design assumptions to temporary works engineer to allow them to effectively design platforms, props and lifting arrangements.

Safe design was included in the temporary works by using simple props which could connect simply to permanent cleats, were minimised and not complex so it was relatively easy to connect elements on site even though the elements were very large. The work from the temporary engineer was then feed back to the permanent works engineer to check sequencing and adequacy of the structural members for the temporary cases.

5.3 Welding and Bolting Procedure

The processes used to complete the bolting and welding procedure was reviewed to make these both as safe as possible. This meant giving workers safe access, allowing them to complete connections simply and quickly as well as ensuring the connections were completed to meet the structural requirements.

With the bolted connections it was decided to use hydraulic tensioning devices. As all bolts were tension friction bolts this was seen as the most accurate way to ensure the correct tension was in each bolt. Using multiple tension devices the connections could be made relatively quickly and easily by the riggers. Locking nuts were also added to all non-tensioned bolts (ie cladding plates) to reduce any risk of the bolts becoming loose due to their exposure to wind.

Welding procedures and welders were prequalified in the large welds in the columns splices. This was due to the welds being outside of the prequalified procedures in [3] due to the increased plate gap to allow tolerances. This meant the welds and welders had practiced and tested the welds prior to doing them on site. This coupled with the access procedure using the platforms and hot works mitigation measures and testing lowered the risks from welding as low as practicable possible.

5.4 Pump Concrete

The columns were designed as reinforced, concrete filled columns. When it came to assessing how this would be carried out on site it was decided to include two aspects which made it safer for site personnel.

Firstly the concrete was changed to self-compacting concrete mix which could be pumped safely from the roof slab. The pour was split in two where the first half of the column was filled with concrete via a spigot at roof level. The second half was filled via a pump line which was connected to the lower half of the columns so that it could also be connected into and pumped from roof slab to fill the upper half of the column. This stayed in place and was covered by the column cladding so cannot be seen.

Secondly the concrete was made fibre reinforced concrete. This reduced the reinforcement requirement in the columns to reduce congestion, which reduced risk of blockages and helped reduce the lifting weight of the columns.

5.5 Detailed Construction Methodology

Throughout the ongoing construction workshop process a detailed construction methodology was compiled by the contractor. This took the original proposed methodology but detailed it to include all aspects from sequencing, installing temp platforms and props, to how connections were to be completed.

This was a very important document as it outlined to all site personnel installing each element what was required to install each section and what safety measures were required to make sure all the planning was carried through on site. This feed straight into site safety plans, signoff and certifications.

6 CONSTRUCTION PHASE

The construction phase of the project is critical in the safe design process in the fact that the plans put in place during the design process are implemented in fabrication and on site. There are a number of checks and balances carried out by the design and construction teams to make sure the plans implemented and safety is kept in the forefront of the teams mind in construction. The processes carried out to confirm all aspects have been captured for the Building Capitol included detailed shop drawings and 3D models for review, prototypes, fabrication inspections, pre-fitting permanent and temporary elements in the

workshop, site inspections and review of site issues.

The shop drawings were a critical item for the success of the capitol as there was complex connections and multiple elements that needed to be included to avoid issues on site. Therefore detailed 3D models were also submitted with shop drawings so each element, member, plate and connection could be review and checked.

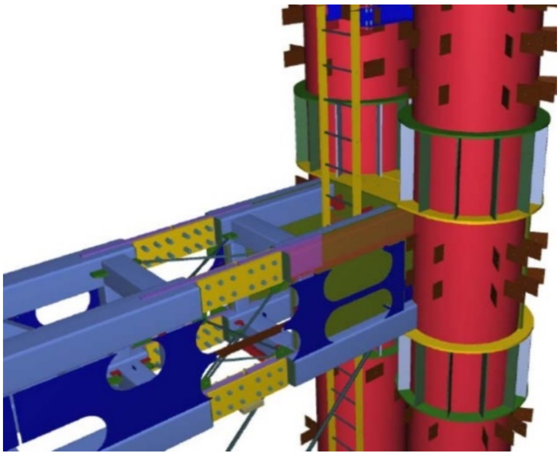
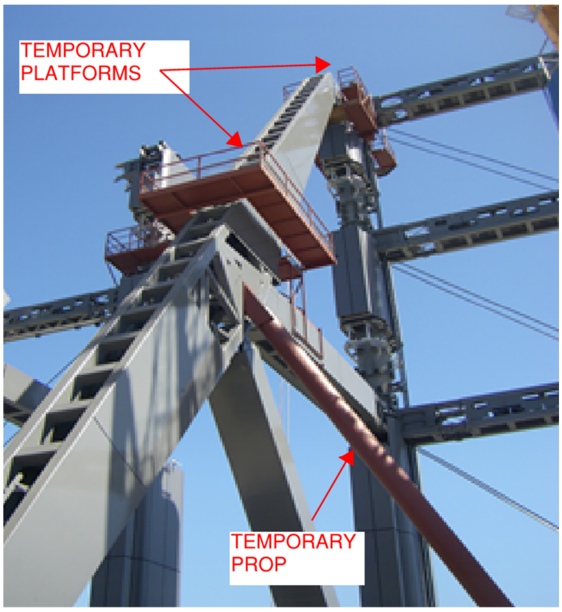


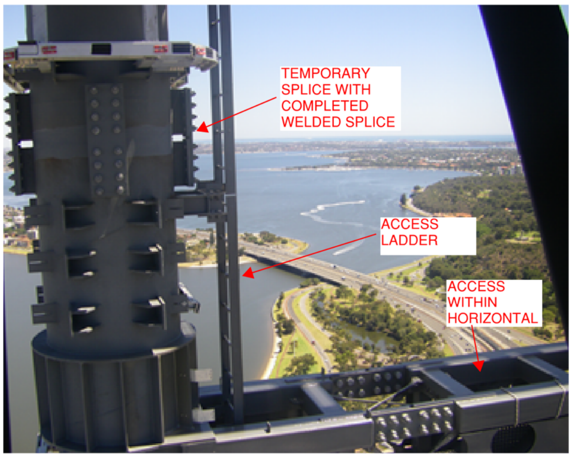
Figure 11: *Image from 3D Shop Drawing Model*

This process was then carried through to inspecting the fabrication in the workshop. This allowed review of what was built matched design intent. In addition it allowed pre-fitting connections in the workshop to check they fit and connecting temporary platforms onto members to check they are usable as intended.



Photograph 3: *Construction Photo Showing Temporary Platforms and Props*

The site monitoring by the design team but more importantly from a safety standpoint, the construction team is critical to the safety of all the workers. The plans set in place were followed and reviewed and inspections carried out to check it had been installed as intended. The site procedures, forms, signoffs, inspections, result review and certifications all form part of the initial safe design planning to confirm it has been carried through to completion.



Photograph 4: *Construction Photo Showing Beam Column Connection, Column Splice and Access systems*

8 MAINTAINENCE

Once construction is complete the project moves to the operation and maintenance phase. The safe design and design development process incorporated safe systems and plans to allow operators, users and maintenance personnel to carry work out safely.

The plan outlined in the design process is passed onto the building owner. The safe access systems are all checked at the completion of construction to check they work as intended. The plan includes how to access all members of the structure, how the rooftop BMU fits within the building capitol members to allow window cleaning as well has how the sign members and lighting can be accessed and maintained. Also, what should be inspected in the primary structure and an inspection program was included in the report.

9 CONCLUSION

The Building Capitol was an impressive project which completes the Brookfield Place tower in Perth. The complex design elements of the structure meant a challenging design and construction process. The Safe Design process used by the team was paramount to the structures success and the safety aspects of the structure drove many key decisions in its development. The

collaborative approach used by the design and construction teams was key to embedding safety into its design. The safe access and construction elements which were integrated into the temporary and permanent structure meant a much simplified and safer construction sequence for the large complex structure.

The collaborative safe design approach used throughout the structures design, construction and use resulted in the successful completion of the impressive architectural vision.

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Universal Rigging – Steel Riggers

REFERENCES

[1] British Standards Institution: Eurocode 1: Actions on Structures –Part 1-4: General Actions-Wind Actions (BS EN 1991-1-4:2005), Annex E, BSI, London

[2] Barrett D., 2011, 'Nonlinear FEA of Joint Behaviour of Thin Walled Concrete Filled Composite Tubular Column', paper presented at *Concrete Conference,* Perth.

[3] Standards Australia, AS/NZS 1554.1:2004: Structural Steel Welding Part 1: Welding of Steel Structures.