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Advancing Timber for the Future Built Environment

STRUCTURAL FIRE ENGINEERING FOR ATLASSIAN CENTRAL

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ABSTRACT: This paper presents the fire engineering design for the Atlassian Central building that will be built in Sydney, Australia. At 39 storeys tall, and adjacent to Sydney's Central Train Station, it will be the tallest hybrid-timber commercial tower in Australia. The building features four-storey mass timber habitat structures located between megafloors located on every fifth floor, which are supported by a perimeter steel exoskeleton structure. The fire engineering and structural fire engineering strategy of this unique and complex building is presented to produce a robust design. The key points of consideration of the fire engineering strategy are the location of the building in a land-locked site adjacent to Australia's largest train station, Sydney Central Station, the presence of the mass timber structure, consideration of the ever-changing state-of-the-art knowledge of mass timber structures in fire, safe occupant egress and safe fire fighter access into the tower. Non-linear thermal and structural finite element analyses were utilised to test the effects of severe fires and subsequent cooling on the timber structures and the exoskeleton structure, to inform the fire protection strategy. The paper highlights the need to consider more advanced forms of analysis to inform the structural design for fire resistance for complex structures, beyond standard and simple analysis methods that are prescribed by the building code.

KEYWORDS: timber, hybrid construction, structural fire engineering, finite element analysis

1 – INTRODUCTION

This paper presents the structural fire engineering design for the Atlassian Central development, the tallest hybrid-timber commercial tower in Australia. The paper discusses the fire engineering and structural fire engineering challenges of this unique and complex building to produce a robust design for fire safety. This paper will discuss the structural fire analysis of the timber structure and the exoskeleton structure.

2 – BACKGROUND

The design and construction of multi-storey timber buildings is still in its infancy compared to other forms of construction such as structural steel and reinforced concrete framed construction. Structural steel and reinforced concrete buildings have been tested by time and real fires, and lessons have been learned which have been since implemented into building codes and standards.

The aspirations of designers to build taller mass timber buildings still poses many questions and challenges to structural engineers, fire engineers and researchers to understand how such structures would perform in real fully developed fires and how high rise timber buildings can be safely design for fire. These questions include the understanding of the fire dynamics of timber compartments, fire performance of available products and structural fire performance of mass timber buildings.

National design codes are also trying to set appropriate rules and guidelines in national building codes. Currently there are no consistent set of rules globally between different national codes that provide a consistent set of rules between countries.

3 – PROJECT DESCRIPTION

The 39 storey Atlassian Central building features a unique hybrid steel-timber structure featuring a steel exoskeleton structure wrapping around the central concrete core of the building. The exoskeleton provides vertical support to steel mega floors which located on every fifth floor, as well as the façade (Figure 1 and Figure 2). The exoskeleton members are 711mm diameter hollow structural steel sections which are directly integrated into the façade system and are architecturally exposed. The primary

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exoskeleton rises from Level 7 up to the remaining upper floors of the building. The four storey mass timber habitat structures are supported on each megafloor. The mass timber habitats are built of glulam columns and beams which support 200 mm thick CLT panels; these mass timber habitats are structurally independent and do not provide structural support and stability to the primary structure.

The design of the Atlassian building with hybrid timber-steel-concrete construction combines the unique strengths and benefits of each material, resulting in structures that are both efficient and sustainable. Timber contributes to environmental benefits by reducing carbon emissions and offering a renewable resource, while its lightweight nature simplifies transportation and assembly. The steel provides high strength and stiffness to weight ratio, enabling flexible and durable designs, particularly for the long spans of the exoskeleton members and the megafloor beams. Concrete adds compressive strength and fire resistance, ensuring structural stability and safety. Both the steel and concrete also provide greater predictability in regard to performance in a fire, particularly for such a unique and complex structure.

The unique nature of the building results in the need to provide extensive fire engineering Performance Solutions as the designs do not fit with the Deemed-to-Satisfy Provisions that are typically applicable to conventional buildings. However, the focus of this paper will be on structural fire engineering that was undertaken for the structural frame system.

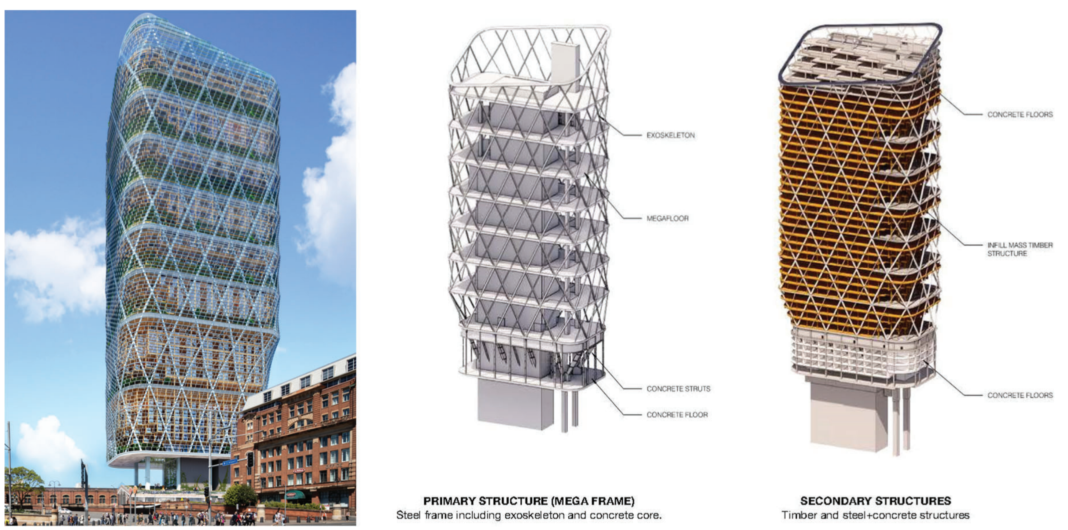

Figure 1. Exterior render and schematic showing primary and secondary structural frames.

Figure 2. Renders of the timber habitats

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4 – FIRE PERFORMANCE OF TIMBER STRUCTURES

Concrete and steel structures have had many decades of experiences learned under exposure to real fires. Over time, these historical fire events have enabled engineers and regulatory authorities to understand the different failure modes in real fires and to be able to differentiate the structural systems which perform well from those which do not. These events would have tested the performance of real structural systems, under real fires which have heating and cooling with realistic support boundary conditions.

Unlike concrete and steel structures, mass timber structures have not undergone such real-world tests. Hence there needs to be a considered approach to designing for mass timber structures given the many unknowns associated with the many proprietary structural systems (structural members, connection types and mix of hybrid options [1][2]), in the aspiration to build taller and bigger mass timber structures. There are still numerous fire related issues, such as glue performance and delamination of CLT, connection design and response, fire stopping issues and structural response that need to be understood and adopted by building codes for building practitioners and approving authorities to use.

For instance, the fire resistance of timber structures is typically determined based exposure to the Standard Fire. Gernay et al[3] have shown that timber columns could fail in a fire during the cooling phase a fire even after a relatively short heating phase. Hence, there is a need for continual research into more realistic structural fire phenomena to cater for realistic building performance, and not just to comply with Standard Furnace test criteria.

The fire behavior mass timber structures has been subject to significant amount of research over the past decade, from furnace tests to small scale room tests, and only recently to larger open plan compartments[4][5][6]. Some of the recent findings have not been included into building codes. Many building code requirements for CLT members have been based on smaller scale fire tests and furnace tests, however, recent larger compartment fire tests have shown that the fire dynamics in fire compartments are sensitive to multiple factors, including orientation of the panels, the types of glue used in the CLT and ventilation conditions. The effect of the exposed CLT have been reported to be increased duration of the fire due to the contribution of the timber, as well as causing secondary flashover in fire, as the CLT layers delaminate, and faster rates of fire spread. In addition, fire tests[4][5] have shown that after a fire, some structural elements such as columns, are susceptible to ongoing heating from the fallen char on the floor which exposures the base of the columns to high temperatures.

5 – DESIGN AND ANALYSIS PROCESS

5.1 -PROPOSED FIRE PROTECTION STRATEGY

For the configuration of the structural timber frame, the Deemed-to-Satisfy Provisions of Building Code of Australia (BCA)[6] does not require the beams, columns and CLT floor slabs to be encapsulated in fire rated plasterboard. The BCA DTS Provisions require the structural timber members achieve a specified FRL (120/120/120), but do not explicitly consider the true behavior of combustible structural members in fire, nor the potential contribution of fire load from CLT floor panels to the fire. The DTS provisions are generic with no context of the uniqueness of this structure, its height, proximity to other critical infrastructure and the potential challenges for fire fighter access into the building.

The proposed fire protection strategy for the timber structure comprises the application of two layers of 16mm fire rated plasterboard to the soffit of the CLT. The glulam beams and columns which support the CLT are proposed to be unprotected; non-linear thermal and structural fire modeling was undertaken to check the response of the structural elements in real fires. The primary structural elements of the exoskeleton structure, megafloors and structural core are protected to a 120 minute fire resistance rating. Some of the secondary long span beams in the megafloors were proposed to be unprotected, verified by structural fire analysis.

The proposed fire protection strategy is intended to address:

- The issues and risks in regard to exposed timber under exposure to a fully developed fire, in the remote condition when sprinklers do not suppress a fire.
- Safe occupant egress.
- Safe fire fighter intervention during and after burnout of a fire. For a building of such height, fire fighters could require considerable time to access the floor of fire origin. Therefore, by the time fire fighters have reached the floor of fire origin, the fire (if sprinkler fail to suppress the fire) could have developed considerably. Therefore, the application of passive protection to the CLT serves to reduce these risks and

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phenomena associated with significant exposed surface area of CLT.

- The proximity of the building to adjacent critical infrastructure being Sydney's Central Station.

- The questions raised from ongoing research of mass timber buildings in real fires, including the fire dynamics and structural fire response of timber structures, performance of adhesives of CLT and their influence on real fire dynamics, and configuration and orientation of timber members within a fire compartment.

5.2 – ANALYSIS PROCESS

The structural fire engineering design process and philosophy comprises:

- The consideration of the overall structural fire performance of the key primary elements being the timber structural frame and the exoskeleton structure.

- Considerations where the DTS could have shortfalls in realistic performance and where design would fall outside assumptions of Standard fire tests

5.3 - PROPOSED DESIGN FIRES

The FRLs which the BCA DTS Provisions require for structural elements are based on Standard Furnace tests which include only the heating phase of a fire, with no consideration of cooling. Real fires naturally have a cooling phase after the fire load is consumed, which can have a significant effect on both the steel structure and timber structure. For structural steel and concrete members, the cooling phase can cause significant forces in the structure due to contraction. For the timber structures, the cooling phase of timber can result in structural failure of elements as it cools due to the thermal wave propagating through the timber, which results in loss of strength.

The likelihood of a fully developed fire occurring is expected to be low, given the provision of sprinklers throughout the building, with fast response heads and dual water supply. However, the scenario of a sprinkler failure condition is considered in the structural fire design of the building as a redundancy condition.

The proposed design fires that were used for the structural fire analysis of the timber and exoskeleton structures were based on the IBMB[8] Parametric Fire formulation and utilised a Fuel Load Energy Density (FLED) of 760 MJ/m^2. This FLED represents the 95th percentile of fire load as presented in the International Fire Engineering Guidelines[9]. However, this data originates from the 1970's where offices had significant amount of paper. A survey conducted by the authors based on three operational modern offices in Australia showed that FLED values in modern offices ranged from 220 – 280 MJ/m^2. Therefore, the use of a FLED of 760 MJ/m^2 provided a conservative fire load and hence longer fire duration compared to what could be expected in a real office. Figure 3 shows some of the design fire curves that was considered based on the IBMB formulation with different ventilation and areas of involvement. The EC1 Parametric fire curve is also shown for comparison.

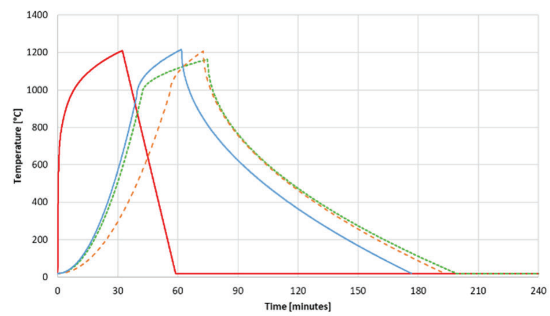

Figure 3. Examples of design fire curves

5.4 – STRUCTURAL FIRE ANALYSIS OF TIMBER STRUCTURE

The SAFIR[10] non-linear finite element program was used for the thermal and structural finite element analyses of the timber habitats and the supporting exoskeleton structure. The temperatures across the heated structural elements are determined using 2D thermal analyses for each type of structural element under exposure to the design fire. The representative cross-sectional geometries of the structural members are analyzed to obtain detailed time-temperature distributions through the section of each of the structural members. The program utilizes non-linear temperature dependent thermal and structural properties. These thermal models are discretized using 5 – 10 mm triangular and quadrilateral solid finite elements. The components of the thermal models (steel, concrete, timber or insulation) for each structural section are assigned with respective thermal properties.

Non-linear FEA modelling was undertaken for the timber structure to analysis the performance of the structural frame under realistic fires with long cooling phases. Specifically for mass timber structures, there has been considerable research into the fire dynamics and fire behavior of individual components (CLT panels, beams, columns) in isolation, the response of the combined

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structural members into structural frames is analyzed here.

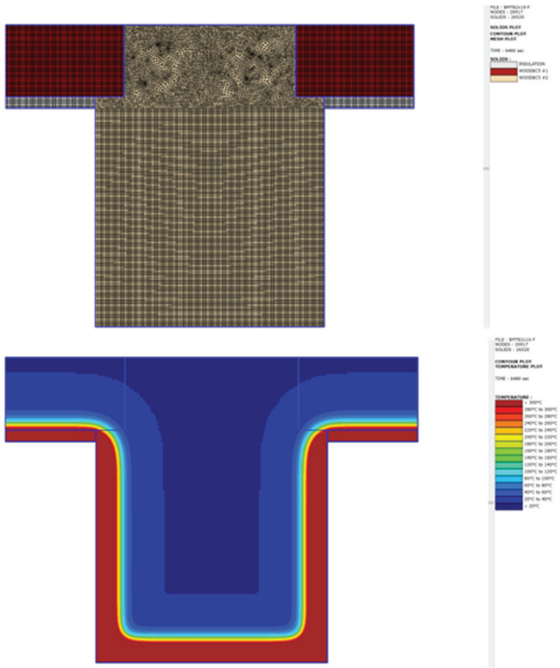

Figure 4. Typical finite element heat transfer model of timber beam supporting fire protected CLT

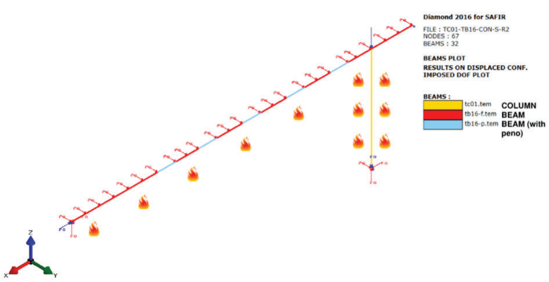

Figure 5. Finite element model of timber structural frame

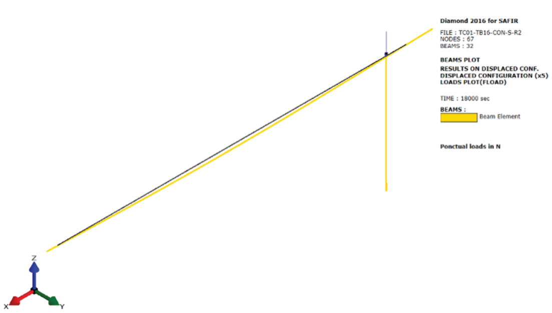

Figure 6. Deflected shape of timber structural frame (Visually amplified by 5x)

The thermal and structural properties of the timber for the FEA modelling were based on Eurocode 5[11]. The thermal modelling was used to predict the extent of charring in the exposed timber columns and beams (See *Figure 4*), whilst for the protected CLT members, the FEA modelling was used to predict the efficacy of the fire rated plasterboard in mitigating exposure of the timber. The glulam beams also had penetrations through the webs, which were also incorporated into the FEA modelling. The FEA modelling was able to predict if there would be structural instability issues of the beams due to the web penetrations.

Figure 5 shows an example of the structural finite element model of a typical timber structural frame comprising a glulam beam supported by a glulam column. The beam is laterally braced by the CLT floor. The fire protected CLT provides a stiff and reliable diaphragm to laterally brace the beams to mitigate lateral instability of the beams during fire exposure. Figure 6 shows the deflected shape of the structure after the cooling phase which showed no structural failure, with a downward midspan deflection of the beam of 22mm. The deflected structure is graphically amplified by 5x for visual clarity.

The analysis was undertaken to check the response of the structure due to a "thermal wave" phenomena travelling through mass timber structural to verify check that there were no instability issues in the timber structure during the cooling phase, as was observed by researchers[3]. Such a phenomena would not have been possible to be detected with simple hand equations, and was specially considered given the criticality of this structure in regard to its height (for occupant egress and fire fighter access) and its proximity to Central Station.

Other challenges that are unique to the building are the exoskeleton members which pass through the CLT floors. The penetrations of the CLT by the hollow section exoskeleton members are required to be fire stopped. There are no standard fire stopping systems that have been developed to date specifically for such configurations, and as such a bespoke fire stopping system had to be developed together with various product suppliers and the builder. The fire stopping system had to satisfy the requirements set out for insulation in AS1530.4 and to prevent integrity failure of the penetration. The fire stopping products also had to be sufficiently flexible and elastic to be able to accommodate the lateral movement of the exoskeleton members are they move about within the aperture of the openings. Finite element modelling (Figure 7) was undertaken to support the development of a bespoke fire stopping system, prior to full scale fire testing of the system in a furnace to verify compliance of the system.

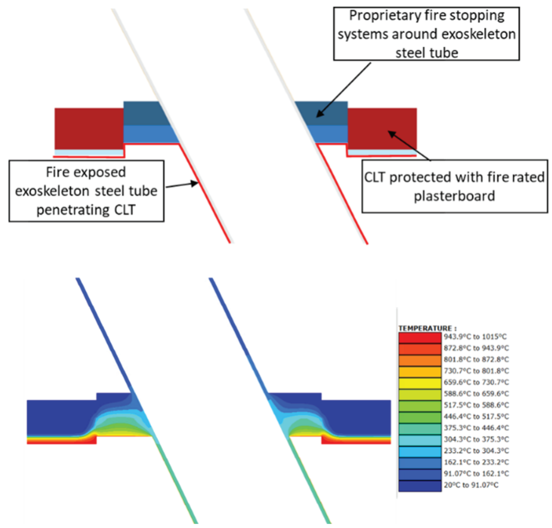

Figure 7: Schematic showing detail of typical thermal analysis of bespoke fire-stopping system

5.4 – STRUCTURAL FIRE ANALYSIS OF EXOSKELETON STRUCTURE

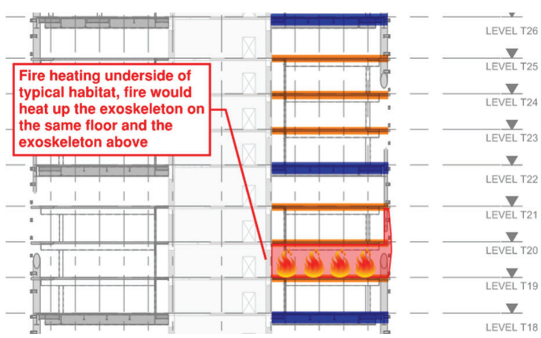

Figure 8: Schematic showing section of assumed fire exposure to exoskeleton structure

To test the response of the exoskeleton members due to a fire within the office occupancies, thermal and structural fire models of the exoskeleton structure were carried out with the SAFIR FEA program. The thermal and structural properties of the steel and concrete structure for the FEA modelling were based on Eurocode 3 and 4 [12][13].

The BCA DTS provisions assume that vertical fire spread via the façade in a sprinkler protected building is mitigated via the provision of sprinklers. Due to the unique nature of the exoskeleton members which span across four floors, FEA modelling was undertaken to check the stability of the exoskeleton structure under exposure to a worse case condition of multi-level fire exposure to the exoskeleton structure. Fires were simulated to occur at different floor levels of the building. Fire scenarios were modelled to occur directly under typical megafloors and also at mid-height between the megafloors. For each condition, the fires were modeled to simulate the heating of the exoskeleton structure of the floor of fire origin and the level above the floor of fire origin, assuming flame projection from the floor of fire origin to the level above as shown in Figure 8.

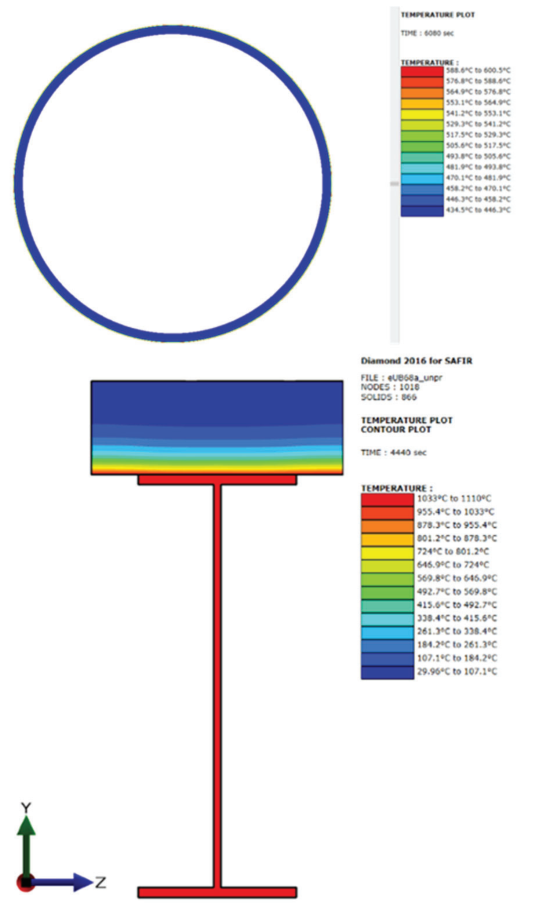

Figure 9: Thermal FE results of typical exoskeleton and beam sections

Figure 9 shows the typical thermal contours of the various typical structural beam / column members that form part of the structural frame. The composite slab of the megafloors were modelled as a reinforced concrete flat slab with an effective thickness, calculated in accordance with Eurocode 4 [13].The temperature variation in the slab section is determined using a slice model of an equivalent flat slab section, in which the reinforcing bars / mesh were defined at different depths representing the locations of the reinforcing steel. The beams, columns and exoskeleton members were modelled with beam finite elements that are linked to the thermal distribution of the cross section, determined from the thermal analysis. These elements are associated with its corresponding section properties and material characteristics. The floor slab of the megafloors were modelled with shell finite elements.

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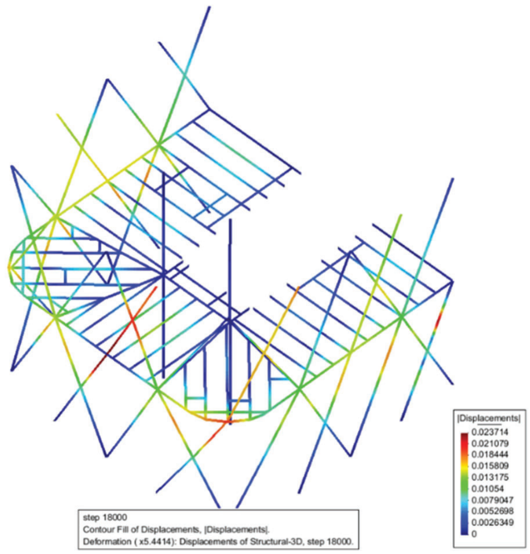

Figure 10: FE result of exoskeleton frame for fire in between megafloors (Slab visually not shown to provide clarity to exoskeleton behaviour)

Figure 10 shows an example structural fire model of the exoskeleton structure after the fire, when the structure would be in the cooling phase. The fire is simulated to occur at mid-height between the megafloors, which would impose the greatest deflections to the exoskeleton structure. It shows that the structural frame has low residual deflections and structural stability is maintained.

Figure 11 shows the structural frame under fire exposure under the megafloor, to test the stability of the megafloor. Some of the long span secondary beams are proposed to be unprotected. The analysis shows that stability of the megafloor at the exoskeleton frame is maintained.

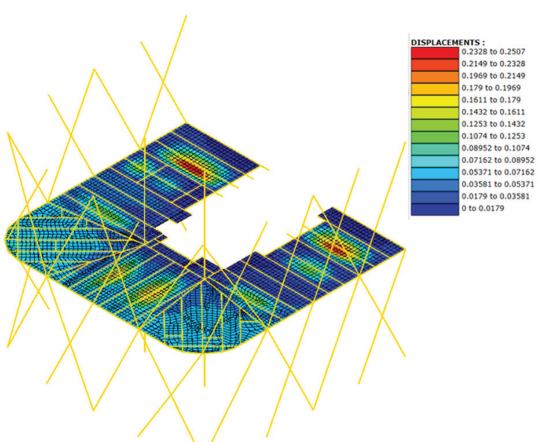

Figure 11: FE modelling of exoskeleton frame for fire under the megafloor

6 – CONCLUSION

The Atlassian Central project serves as a case study for future high-rise timber buildings, showcasing the potential for combining sustainable materials with advanced fire safety engineering to create resilient and innovative structures. The paper highlights the need for careful consideration in the structural fire design of hybrid-timber structures and complex structures, not just to achieve Standard Fire resistance values, but also to design for structural fire robustness for real fires.

The fire protection strategy that is proposed for the structural elements considers the unique nature of the structure, the height of the building in regard to occupant egress and fire fighter access and its proximity to other infrastructure.

The structural fire analysis presented in this paper has demonstrated that the steel exoskeleton and megafloor, and the mass timber structural frames, can withstand severe postflashover fires, and that the fire protected steel exoskeleton members maintained structural stability during intense the heating and long cooling phases of the fire.

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