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# ***Designing for whole of building resilience: A Case study of non- structural elements in a viscous damped moment frame building***

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## **ABSTRACT**

This paper looks at how the secondary and non-structural elements were detailed in a high performing Viscous Damped Moment Frame (VDMF) building to ensure a whole of building resilient outcome. The building is a five storey Importance Level 3 building housing the outpatients facilities for the Canterbury District Health Board, Christchurch Hospital, and has recently been completed.

As part of the resilient design philosophy, secondary structural and non-structural elements such as stairs, façade, partitions, ceilings and building services were detailed to accommodate the building seismic movement. This paper details the design philosophy, design challenges and final outcomes. It also highlights some of the difficulties with achieving a whole of building resilient outcome incorporating secondary and non-structural elements within the current construction industry framework.

## 1 CHRISTCHURCH OUTPATIENTS BUILDING OBJECTIVES

The overall brief for the Outpatients Building was to provide a modern purpose-designed building which would deliver on the Ministry of Health's (MOH) drivers of 'Long Life, Loose Fit'. In essence, the building would have an open, floor plate which allows maximum flexibility of use to maintain the building's usefulness through rapidly changing health delivery models and equipment. The building would also have a higher level of resilience, given its importance to the community and learnings from the Canterbury Earthquakes.

The Christchurch Outpatients Building is a new five storey office building constructed on a brownfield site overlooking Hagley Park, on the corner of Antigua, Oxford Terrace and Tuam St. The building is irregular on plan, having been designed to maximise use of the tight triangular site. The structural system is a steel moment frame with supplementary fluid viscous dampers. This is the first public building in New Zealand to incorporate this technology which has enabled a very high level of seismic performance to be achieved while meeting short construction time frame constraints and within budget.

The viscous dampers can only dissipate energy when the building is moving during earthquake shaking, and therefore understanding the behaviour of the building and demonstrating performance of the system is complex due to the velocity relationship of the dampers. Displacement based design and non-linear time history analysis were used to validate performance. Fundamentally, the building must move for the dampers to dissipate energy and this movement needs to be accommodated by the façade, partitions, staircases and anything else crossing floors, without causing damage which could affect occupancy of the building. While seismic movement has to be managed in design details, the damping levels achieved provide structural benefits, and the lower floor accelerations improve resilience for building contents.

## 2 STRUCTURAL PERFORMANCE OBJECTIVES

In the Christchurch Earthquakes, there were a number of examples of buildings which suffered relatively minor structural damage, but the movement of the structure had damaged glazing or partitions which impacted the amenity of the building. For example, damage to fire rated linings of egress routes prevented reoccupation of some buildings (Canterbury Earthquakes Royal Commission, 2013). This was especially frustrating for building owners and occupiers given the number of aftershocks causing damage of this nature. The MOH were clear about wanting to avoid this type of disruption on the Outpatients Building.

The structural engineering brief for the Outpatients Building was for an Importance Level 3 Building, with a greater level of resilience than a building which would only meet the minimum Building Code requirements. This came about partially in response to the Christchurch Earthquake sequence in 2010-2011, and the Ministry of Health had developed its policy in this area, which became known as IL3+.

The specific client objective beyond the Building Code was to, as far as practicable, maintain functionality of the fire egress so that there is no disproportionate loss of amenity due to damage to these elements. For the purposes of determining the interfloor movement allowance, the Serviceability Limit State 2 (SLS2) return period event of 1/500 years was used to set the movement allowance for this objective.

## 3 RESILIENT DESIGN

Resilience can be defined as, '*The ability of an asset or community to withstand or recover in a timely manner from a significant disruptive event*'. Resilient design is becoming increasingly important, as the exposure to natural disasters or extreme events is increasing globally, as reflected by insurance data

(Deloitte, 2016). This is important for design of buildings in New Zealand with its level of seismicity, especially as there is a disproportionate economic and societal cost to loss of function of key facilities following seismic events in a small country such as this.

While response and recovery are often the focus in a natural disaster, there is a unique opportunity when designing a new building to design or prepare for a natural disaster. Understanding of the overall building performance not just the Building Code is required to achieve a whole of building resilient approach, a risk based approach should be taken to ensure that objectives are realised in the final design across all components. This risk-based process can be outlined simplistically as shown below.

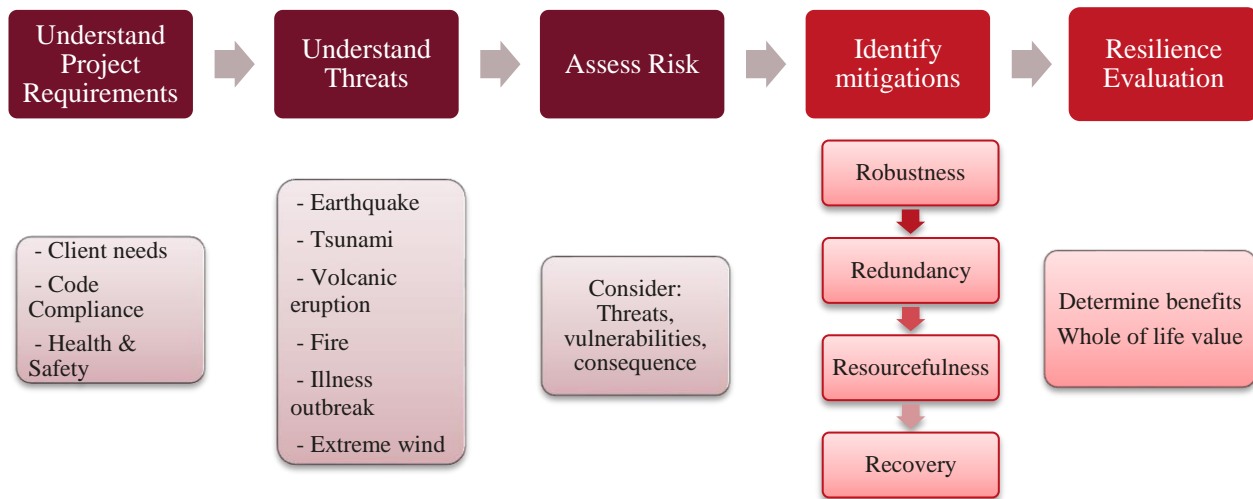


Figure 1: Risk based process to achieve whole of building resilience.

The key component of this process is the implementation of the design measures required to achieve the resilience specified. While the most obvious aspect is in the choice of primary structural system, a key component is in detailing of secondary and non-structural elements that represent much of the building's value, or are vital to its functionality (Mayes, 2013). Outlined in this paper is the significant effort required to realise these resilient seismic design objectives in the design and construction of the Outpatients building.

#### 4 PRIMARY STRUCTURAL SYSTEM

The primary structural system selected was a Viscous Damped Moment Frame (VDMF) structure. The key performance benefit of this system is elevated levels of damping, and reduced floor accelerations, which make this solution second only to base isolation for seismic design performance (Brown, 2016). The use of the dampers also lowers the risk of yielding the primary structure in a seismic event, and therefore this can be considered a true low-damage system. Design displacements are not greatly reduced by the inclusion of dampers due to the velocity-dependant nature of the response, and as a result, displacements are only slightly reduced when compared to conventional moment frames.

#### 5 BRIEFING & COMMUNICATION

In the initial design stages, once the adoption of the viscously damped moment frame had been decided, the full design team understood the importance of designing all aspects of the building with the expected seismic movement in mind. This was outlined in the initial Design Features Report and explained fully in the Building Movement Report – refer to an extract in Figure 2 showing the movement allowances for vertical fire separations, and an example illustrating the different façade supports and how this affects their movement.

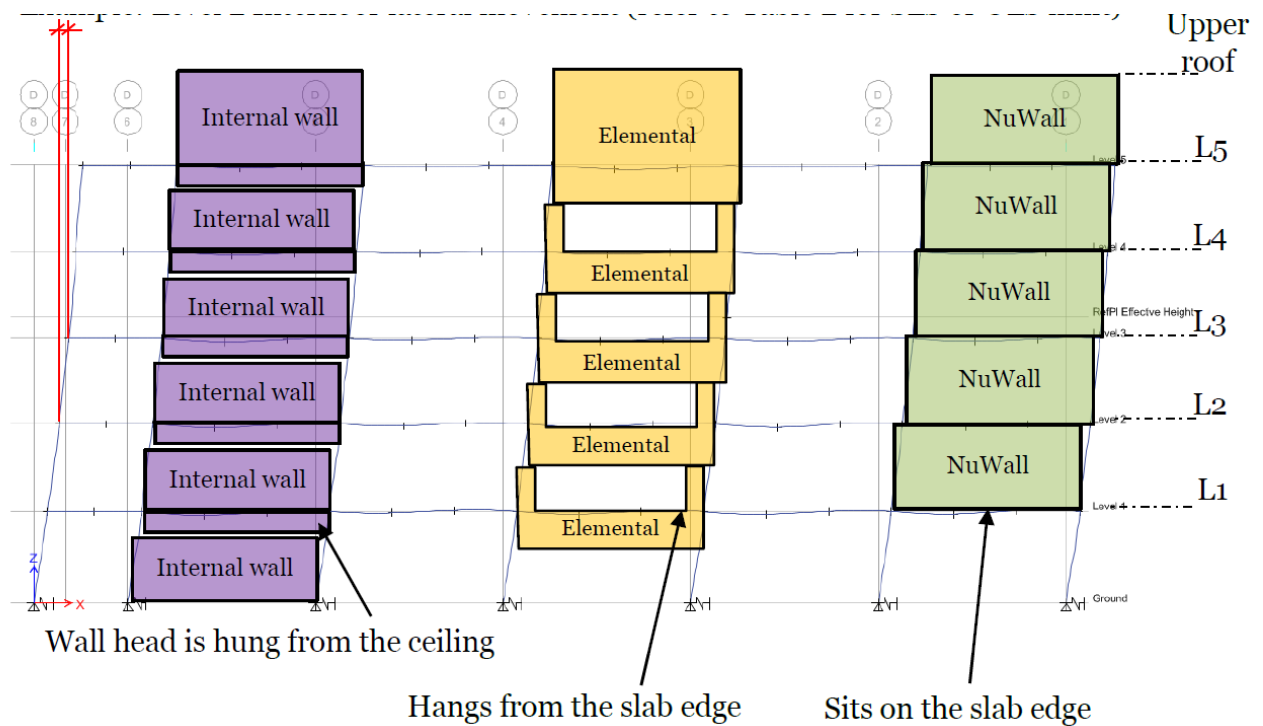


Figure 2: Building Interstorey lateral movement

Table 1: Design Interstorey Movement Allowances

| Building Element                              | Storey   | Limit State Movement ( $\pm$ mm) |     |      | Comment   |
|---|----------|----------------------------------|-----|------|---|
|   |          | SLS1                             | ULS | SLS2 |   |
| Vertical fire separations for stairs and lift | 4th -2nd | -                                | -   | 45   | At SLS2 event the vertical fire separation treatment to the walls and the structure supporting this remain sufficiently undamaged to avoid extensive repair of these elements with consequential closure of the building for an extended period of time whilst fire separations are reinstated. |
|   | 1st      | -                                | -   | 55   |   |
|   | Ground   | -                                | -   | 65   |   |

The building Movement Report was a very important document as it helped the multi-disciplinary design team understand how the building would move, and how the elements of the building which extended across multiple floors, e.g. lifts, service risers and stairs could maintain their function while the building was undergoing lateral seismic displacement.

As an output of the non-linear time history analysis of the structure, building floor response spectra were developed. This provided floor accelerations which could be used in lieu of NZS1170.5 Parts Loading. The Floor Response Spectra allowed for the benefits of a VDMF to be incorporated in the non-structural design. Figure 3 shows the typical Floor Response Spectra comparison with the Parts Loading for 1170.5. This enabled the design of seismic restraints for components of the building to be designed for the reduced floor accelerations provided by the increased damping of the viscous dampers. The reduced floor accelerations will also result in reduced damage to other building contents.

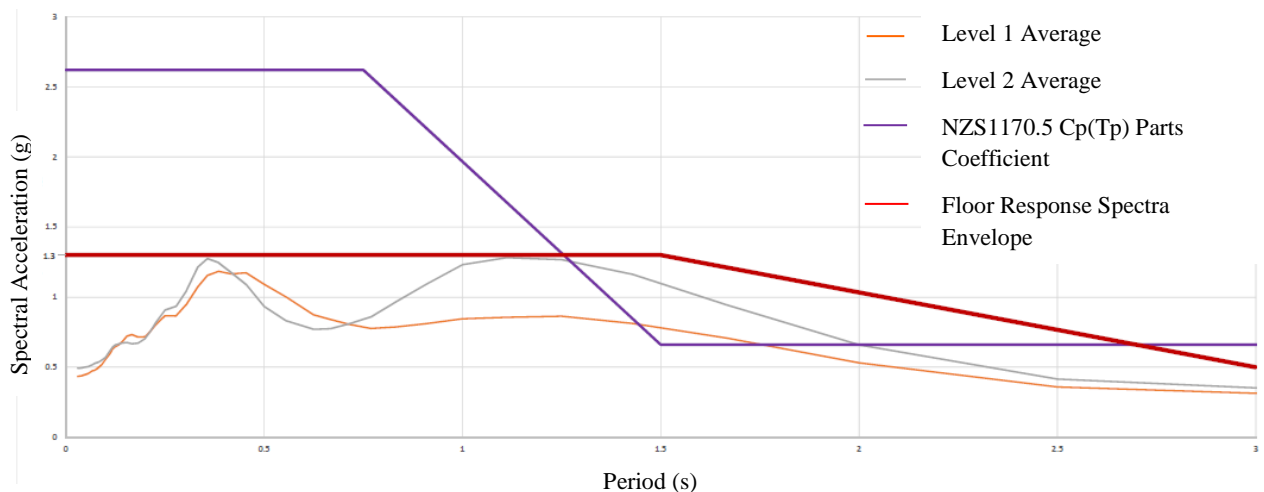


Figure 3: Floor response spectra comparison with NZS1170.5 parts loading

## 6 COORDINATION

Close collaboration between the architectural and structural teams was vital to establish the movement/separation philosophy and best locations for seismic joints in facades and partitions, especially those that create fire compartments around stairs. These decisions also required input from the services engineers to ensure sufficient space for ductwork which would move with the floor above and ceiling below, but be clear of partitions. Given the nature and non-linear response of the building with the high level of damping provided, it was not possible, as it would have been for a conventional steel frame building, to provide an accurate prediction of the displacement at each level without completing the non-linear analysis. This was an important programme consideration, as it was not possible to complete these calculations until all the primary steelwork had been designed.

To fast track the programme, it was decided at the very early stages to consent and tender the building in stages. It was therefore important to finalise the movement report at the end of the first package (primary steel) to enable the façade and secondary steel to be tendered and designed in the second package.

The primary steel package structural drawings showed zones (which included Reduced Beam Sections (RBS) and column collars) where no attachment could be made to support secondary steel or services supports and restraints. This was necessary to ensure that the building performed as intended, but did restrict the locations for restraints, and in some cases added complexity to the steelwork.

Revit was used for coordination utilising an agreed process through the BIM Execution Plan. Services model coordination of all the building services was undertaken by one person during construction. This was vital to ensure effective coordination and buildability.

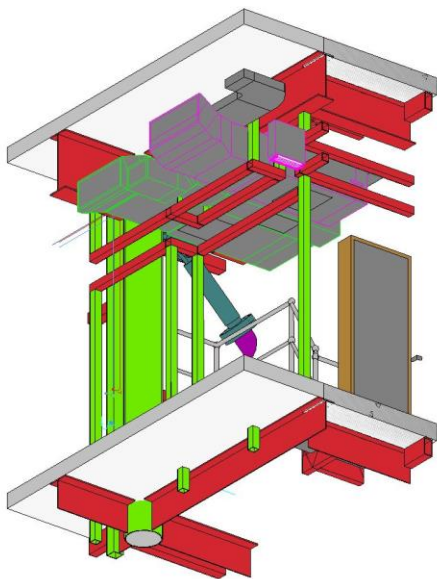
## 7 DETAILING

Once the ceiling and services zones were agreed, detailing was made as simple as possible by adopting consistent steel sections for partition restraint, and consistent movement joints. A typical seismic detail for vertical fire separation is shown in Figure 4.



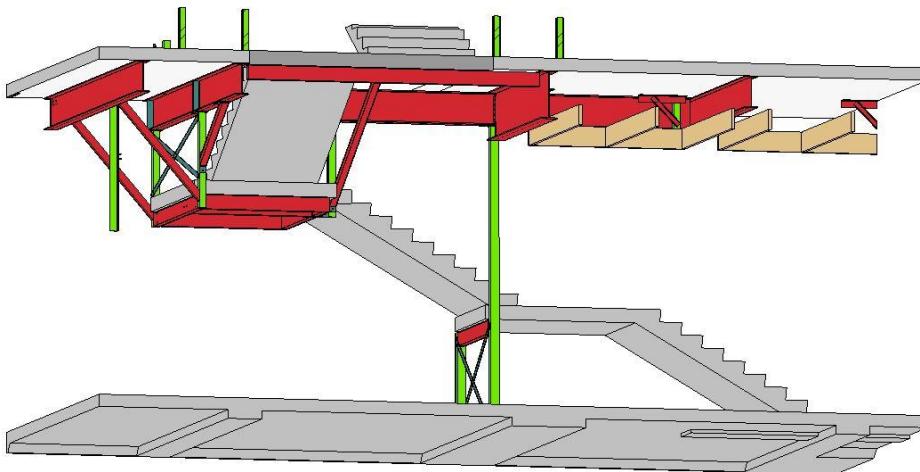
*Figure 4: Typical vertical fire separation prior and following lining*

The provision of defined horizontal building services zones in early stages generally worked very well. Considerable effort was required from all disciplines to carry out the detailing of the stairs, risers and façade elements to ensure these elements could be supported for their own gravity and seismic demands, while not impinging on the movement of the primary structure. An example is the ceiling services zone on level 3. During the detailed design of secondary steelwork, it was found to be impossible to accommodate all the services within the ceiling zone planned in the preliminary stages as larger ducts were required due to a change in user requirement. On this floor it was necessary to lower a section of the ceiling, and the partition support and movement joint with it. An extract of the Revit model and photo of this area are shown in Figure 4



*Figure 5: Revit model extract of a typical section of lowered ceiling to accommodate additional services*

The support of ceilings, partitions and bulkheads at ground floor level was more complex, partly due to the increased floor to ceiling height, increased displacement, a staircase with an extra right-angle section which needed to be hung from the first floor, and higher fire rating requirements. Refer to images in Figure 6 showing the ground floor stair being hung from the level 1 slab.



*Figure 6L Extra storey height at ground floor resulted in the stair landing being hung from level 1 to accommodate the necessary seismic movement*

## **8 BUILDABILITY**

The primary structure was fast to erect as the columns were full height. A lot of thought went into the erection sequence as every four-column segment of the steel frame had to be fully assembled before moving on to the next section.

The strength of the primary structural frame was a ‘contractors dream’ as Leighs could pour floor slabs top down without having the entire footprint complete. The concrete filled hollow section columns were not filled until the frame was complete, a concrete pump spigot was fixed to the column base during fabrication and the column filled in a continuous pour.

The steel moment frame was designed to take 70% of the design base shear, such that viscous dampers did not need to be in place to resist a construction level seismic event – a key consideration for a long lead time item (~30 weeks TBC). Viscous dampers and braces were simple to install and chained blocked into place after the floor slab was complete when the long lead time devices arrived from overseas.

The construction was procured as a traditional contract, however, due to the staged approach to tendering and consenting, the contractor, Leighs Construction was appointed before the design of secondary steelwork was completed. This meant that all the steelwork had to be designed before any contractor involvement, but there was ability to gain input through the shop drawings stages. In order to design the secondary steelwork connections, design assumptions needed to include anticipated construction sequence. For example, when designing steel access stairs in the service riser, would floor slabs be constructed before the secondary steel stair, therefore, would the stair fix to concrete or primary steelwork? These connection details were able to be agreed with Leighs to suit their adopted construction sequence.

There was extensive liaison with Leighs during the preparation of shop drawings, including, RFI's, exchanging sketches and weekly meetings at Leighs site offices, where Leighs team would navigate through the federated Revit model where details could be viewed, alternative options be discussed and evaluated rapidly.

## 9 BIM

The importance of a well-coordinated model was understood by the client at the briefing stage. Good coordination between disciplines including clash detection worked well and a federated model was created. The client appointed an independent BIM manager who held regular meetings with BIM leaders from each discipline. This approach resulted in a well-coordinated model.

Leighs developed the model further & used it extensively, for example the fire coatings were added and used for checking. The updated model was also used to develop the construction sequence and became a very useful tool to investigate and confirm options and details. Leighs also used the model to coordinate services.

## 10 LESSONS LEARNED

- Resilient design of buildings is a holistic design process involving the full design team.
- A clear definition and understanding of the client's performance brief is essential to set the requirements the design & construction team need to meet. Early clarification of responsibility for the non-structural element design and coordination is needed, both in design and during construction.
- The structural engineer needs to interpret this brief and ensure the design & construction team understand the implications for all components of a building. The structural engineer needs to clearly document the return brief, as it needs to be understood by the client, the design team, facade contractor, window supplier etc.
- Extensive interdisciplinary coordination and commitment is required to ensure that all components of a moderately heavily serviced building will be detailed and constructed to meet the specified performance objectives. This is important through the design stage, but also needs to be clearly understood by the contractor.
- Depending on building configuration to achieve a robust seismic performance additional secondary steel may be required beyond what is usual at a given importance level, however efficiencies in design can be made depending on building layout.

- The development of a well-coordinated and consistently detailed Revit model helps to support the interdisciplinary coordination and detailing necessary to meet the seismic performance objectives. This project demonstrates the benefit of a well-considered BIM Execution Plan and a dedicated BIM manager within the design team and should be considered as an example project which could assist in scoping future projects.
- Undertaking combined building services using the 3D model review was highly beneficial.
- Some aspects of design require contractor input to finalise details as they will depend on the contractor's choice of construction sequence.
- Achieving buy-in and commitment from all parties to create a resilient building is vital to ensure everyone working on the building has an understanding of how their inputs contribute to the overall building performance by successful implementation of resilient non-structural and secondary detailing.

## 11 REFERENCES

- Brown, U.T. 2016. Seismic and Financial Performance of Fluid Viscous Dampers Relative to BRBS: A Case Study, *NZSEE Conference*.
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