Damage to demolition – challenges and findings from inspection of damaged hollowcore floors

H.S. McKenzie
Holmes, Wellington, New Zealand.

P. Kakoty
University of Auckland, New Zealand

ABSTRACT

Findings over the last 30 years and more recently from the 2016 Kaikōura earthquake and the subsequent ReCast research programme highlighted the vulnerability of hollowcore flooring systems to earthquake damage. The recent demolition of the Civic Administration Building in the Wellington CBD has provided further opportunity to understand the level and extent of flooring damage, whilst highlighting the difficulties associated with the inspection and documentation of such damage. This paper seeks to provide a further data set in relation to building assessment, retrofit and observed hollowcore flooring damage, whilst reminding practitioners of the difficulties in observing such damage and the rigour needed to assess levels of damage after an earthquake event.

1 BACKGROUND

The former Wellington City Council (WCC), Civic Administration Building (CAB) in Te Ngākau Civic Square, Wellington, was a six-storey reinforced concrete frame building, designed in 1989 and constructed in the early 1990s as part of the major Civic Square redevelopment at that time. Lateral loads in the building were resisted by a perimeter reinforced concrete moment resisting frame with two internal "gravity only" concrete frames running through the centre of the building. Typical floors consisted of precast prestressed hollowcore units with an insitu topping spanning in the transverse ("short") direction of the building. The cladding system comprised precast concrete cladding panels, incorporating window penetrations, to all levels above Level 2, with the lower storeys comprising a glazed units set within the concrete frame. The building was founded on a series of bored reinforced concrete piles.

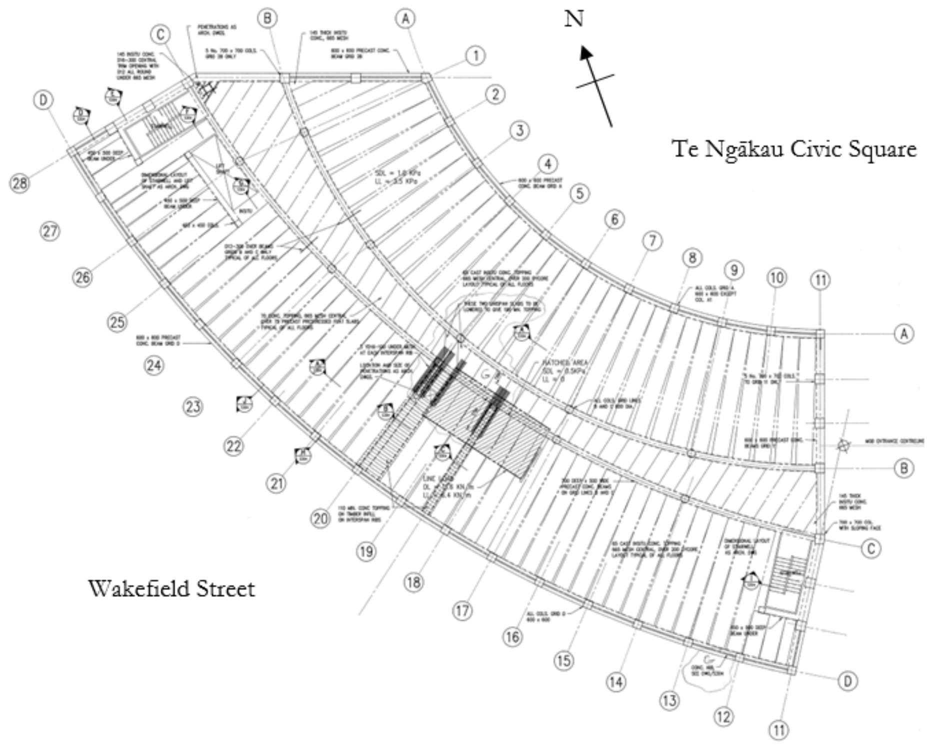


Figure 1: CAB structural plan (first floor)

The building was curved in plan with non-orthogonal end frames contributing to the ill conditioned and flexible nature of the building, particularly in the transverse direction, parallel to the hollowcore span. This situation was further exacerbated by the addition of the Portico, at levels 4 to 6, to the northern end of CAB. The Portico was suspended above the Wakefield Street entrance to Civic Square, supported by the Central Library building to the north and CAB to the south. At the CAB end, the Portico was supported vertically on sliding bearings at Levels 4, 5 and 6 and was restrained against lateral/seismic actions at Level 5 only. At the Central Library end of the Portico sliding bearing supports, providing vertical support only, were provided under the Level 4 slab. A Detailed Seismic Assessment (DSA), undertaken by Holmes in early 2013 (Holmes 2013 a), showed that this eccentric distribution of seismic mass to the north end of the building meant that the building was prone to twisting under transverse loading, with maximum seismic displacement experienced along the northern frame on grid 28 (corresponding to 2.5% drift at 55%NBS load levels).

Figure 2: Portico connection to north end of CAB

The 2013 DSA also identified further building vulnerabilities associated with the Portico connections, lack of internal gravity beam connection to end frames, various hollowcore/diaphragm vulnerabilities (seating, alpha slabs, lack of column ties etc), precast panel connections (lack of seismic movement provision), and lack of internal gravity column displacement compatibility. Concept seismic strengthening/securing options were also prepared in parallel to the DSA at that time.

1.1 2013 Cook Strait Earthquakes

In mid-2013 Wellington experienced a series of minor-moderate earthquakes, most notably the Seddon Earthquake on 21 July and the Lake Grassmere Earthquake on 16 August. Rapid building assessments were conducted following these earthquakes and a more detailed damage report was prepared in September 2013 (Holmes 2013 b). The damage observed was not major, but moderate levels of non-structural damage was experience, especially at seismic joints between CAB and the neighbouring Municipal Office Building (MOB) and Central Library buildings. At the Portico to Central Library seismic joint 60-100mm of seismic movement was evident and the "sliding" pot-bearings were damaged due to the bearing puck freezing (not sliding as intended), leading to a failure of the bearing and an unintended steel-on-steel sliding interface.

The initiation of diaphragm cracking at key interfaces and junctions was also evident. Overall, the damage noted was consistent with and confirmed the findings of the DSA and the proposed seismic securing measures recommended as part of the DSA and Concept strengthening measures.

1.2 Seismic securing works and Portico removal

Following the Cook Strait Earthquakes, WCC agreed to progress with a staged seismic securing programme, with stage 1 including removal of the Portico structure and installation of positive tie connections between the internal gravity beams (on grid B, C and adjacent north end stair) and the end moment frames on grids 11 and 28. A plan of these north end frame connections at grid 28 are shown in figure 3. These stage 1 works were undertaken in a very timely and proactive way between November 2013 and March 2014.

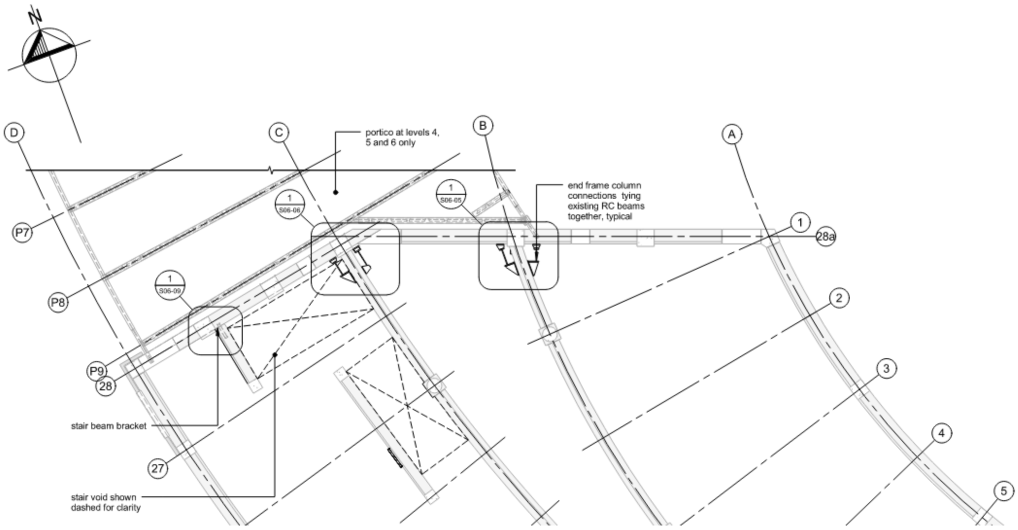


Figure 3: 2013-14 seismic securing frame connections – CAB north end

2 KAIKŌURA EARTHQUAKE

2.1 Rapid Building Assessment

Following the Kaikōura earthquake on 14 November 2016, Holmes undertook a Rapid Building Assessment (RBA) on the morning of 14 November, followed by a further visual inspection on the afternoon of 16 November 2016. A Level 2 RBA form was prepared, summarising the damage as moderate and assigning a yellow Y1 (restricted access to parts of the building only) designation. This was followed up with a more comprehensive site report on 23 November, confirming the findings of the Level 2 RBA assessment and recommending further intrusive Detailed Damage Evaluation (subsequently refined to a Targeted Damage Evaluation (TDE) approach) be undertaken. We also noted that a possible reduction in the buildings seismic capacity as a result of the Kaikōura earthquake could not be ruled out at this stage.

Whilst damaged observed as part of the RBA process was not excessive, findings from this initial visual inspection, evidence of significant seismic displacement (up to ~150mm at level 5 at MOB bridge joint, or ~0.8 – 1% inter-storey drift), combined with our prior knowledge of the building and DSA, and given the specific characteristics of the Kaikōura earthquake, we concluded that a more thorough inspection regime was warranted. We also advised that the yellow Y1 restricted access status should remain in place until that TDE process was undertaken. A selection of relevant photos from the RBA visual inspections are shown in figures 4-9.

Figures 4-9: A selection of photos taken during rapid building inspection(s)

2.2 Further inspection and Targeted Damage Evaluation

During early December 2016, Holmes prepared briefing document for further, more intrusive building investigations to allow a contractor to remove linings, sections of raised flooring and ceilings, to enable more comprehensive inspection of critical building components and junctions including:

- Critical beam and column potential plastic hinges and beam/column interfaces
- Critical diaphragm elements, especially adjacent end frames and around stair and lift voids
- Key hollowcore components including alpha slabs, seating, and zones of discontinuity
- A selection of precast panel connections

Soon after these more intrusive investigations got underway, far more extensive diaphragm and hollowcore flooring damage was discovered. This included large concrete cracks between hollowcore units (3-10mm wide) and fractured topping slab mesh reinforcing. This led to a recommended change in the buildings access status to yellow Y2, restricted access – short term only with engineering supervision. A temporary short term access management plan was also developed. A more comprehensive TDE process was also initiated with further inspections and documentation of damage undertaken through December 2016 and January 2017 and a final rev2 TDE (Holmes 2017) report issued in mid-February 2017. Damage was also categorised in accordance with the critical damage states outlined in the Engineering Guidelines for Targeted Damage Evaluation ver1.1 (NZSEE and SESOC 2017). A summary of critical damage observed included:

- Damage to a number of hollowcore flooring units
- Some minor beam hinging, typically concentrated as one single crack at the face of columns
- Movement of end frame relative to internal gravity beams and the effectiveness of recently installed securing beam-column brackets/ties.
- Minor precast panel damage and damage to precast frieze panel adjacent the Municipal Office Building seismic joint

Completion of the TDE report concluded the involvement of Holmes in this project, with further structural engineering input and involvement being undertaken by Aurecon on the back of a separate workspace strategy project also involving the Central Library building.

Figures 10-17: A selection of photos documented in the TDE report

2.3 Further damage assessment and insurance settlement

In early 2020 Aurecon undertook further visual inspection of the underside of the Level 2 floor slabs, from the Level 1 floor slab level. No access equipment was used and crack widths/lengths were not measured. Crack map plans and descriptions were summarised in Aurecon correspondence dated 13 March 2020 (Aurecon 2020). This visual mapping was consistent with and built on the findings of the earlier TDE report. This information, together with further floor assessment and damage repair documentation formed the basis for the insurance settlement for the building which was concluded in November 2020.

Figure 18: Photo from the Aurecon L2 soffit mapping adjacent northern stair void (grid 27)

3 CAB BUILDING DEMOLITION 2024

3.1 Initial external observations

Demolition of the CAB only commenced in 2024 without further involvement from either Aurecon or Holmes. However, as part of a chance encounter whilst passing the demolition site on 13th September 2024 the first author noticed significant horizontal web splitting in a hollowcore flooring unit being craned from the building as part of the demolition process. A photo of this unit was taken through the site perimeter fence and is shown below in figure 19.

Figure 19: Chance view of hollowcore web splitting during demolition removal, 13 Sept 2024

3.2 Limited hollowcore damage mapping during demolition

During the demolition process, it was arranged with the project manager (RCP) and demolition contractor LT McGuinness, for limited visual inspection and mapping of specific hollowcore flooring units at third floor level and this was undertaken by the second author on 24th September 2024. The floor demolition process of this floor was undertaken using a cut and crane method, removing two adjacent hollowcore units together (refer Figure 20). Units were lowered to ground by mobile crawler crane, secured by chains. Once lowered to the ground, four pairs of hollowcore units (8 units total) were visually surveyed for obvious observable crack damage. Due to the nature of the demolition process, distinguishing the origin of the cracks posed a challenge. Significant damage to the ends of units, due to the demolition process was evident, making it difficult to attribute damage specifically to earthquake shaking. Similarly, cracks that originated during the earthquake could have been elongated or widened due to the forces exerted during demolition.

3.2.1 Specific third floor hollowcore unit observations

The floor panel 7, made up of hollowcore units 7.1, 7.2, and 7.3, exhibited varying degrees of damage across its those units. In unit 7.1, nominal web splitting cracks across the ends of the broken hollowcore webs were observed on End B as annotated in Figure 21, while a crack approximately 500mm long was noted along the side web of End A (in Figure 21), which was only partially accessible. The sides of unit 7.1 were inaccessible for further inspection.

Unit 7.2 showed more extensive damage, with cracks observed both along the side webs and across both broken ends of the hollowcore unit. Unit 7.3 displayed the most significant damage, with cracks along and across the hollowcores on both ends and cracks along the web exceeding 150mm in depth. The exposed side (towards panel 7) was heavily damaged, featuring cracks running across the web and an angular crack forming on End B, where the damage was notably more severe than on End A.

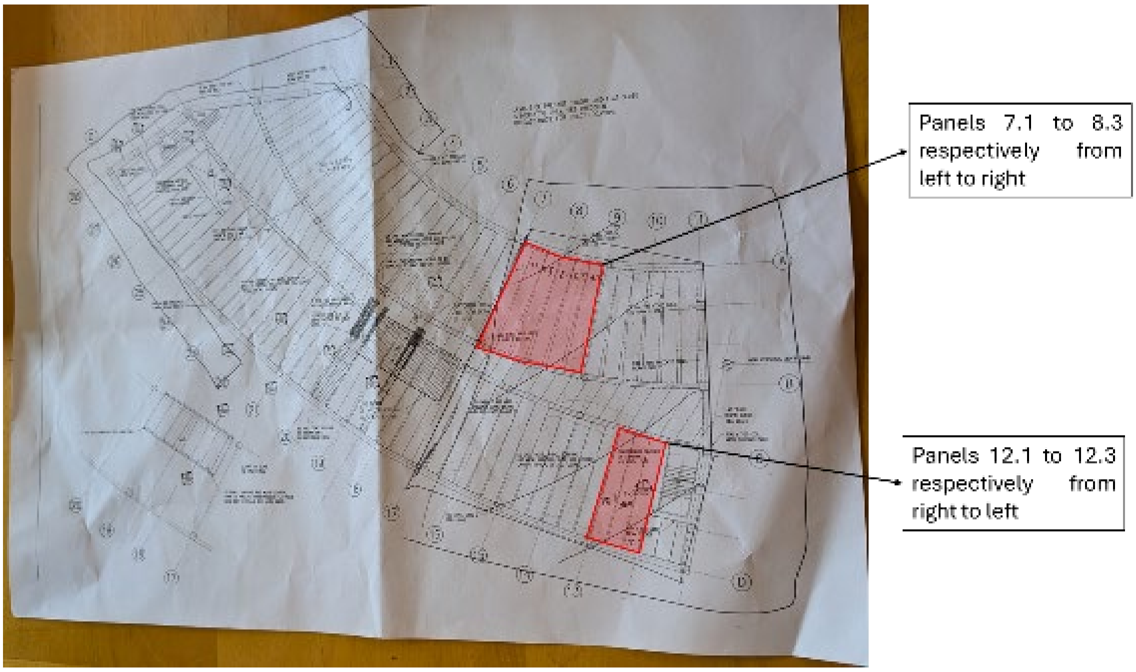


Figure 20: Annotation of the panels surveyed for observable damage following the demolition of CAB. There are three hollowcore units between each grid line (for example, three units between grid line of 7 and 8, and referred to as 7.1, 7.2, and 7.3 respectively).

The floor panel 8, divided into units 8.1, 8.2, and 8.3, showed considerable damage across all sections. In unit 8.1, cracks were observed along and across the hollowcores on both ends, while the exposed side (towards panel 9) was completely damaged, featuring two cracks running across the web on the top and bottom, spaced 80–90mm apart (top and bottom of web). These two cracks converged at an angle 220–240mm from End A as annotated in Figure 22. Unit 8.2 also displayed cracks along and across the hollowcores on both ends, with cracks along the web forming angular patterns at a depth of approximately 80–100mm. Although the sides of this subpanel were inaccessible for measurement, significant damage was evident. Subpanel 8.3 experienced severe damage, with cracks along and across the hollowcores on both ends. Concrete spalling was noted from End A on the exposed side (towards panel 9), where cracks extended approximately 600mm, accompanied by an angular crack forming at a depth of 280mm and 60mm from the top.

(a)

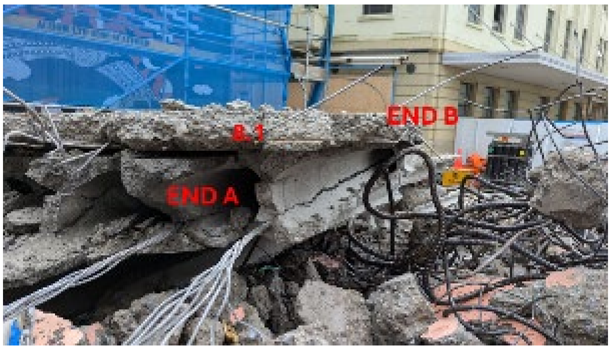
(b)

(c)

(d)

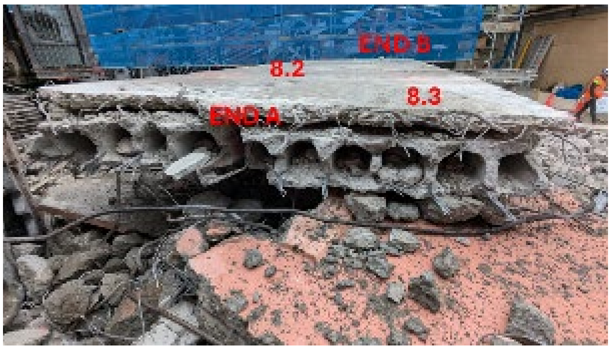
Figure 21: Damage observation and annotations of units 7.1, 7.2, and 7.3

Two unites of floor panel 12, namely 12.1 and 12.2, were inspected and they exhibited varying levels of damage across its sections, as annotated in Figure 23. In unit 12.1, cracks were observed along and across the hollowcores on both ends, as well as through the web. Although all sides of the panel were inaccessible for measurements, the extent of the cracks along the web appeared to be consistent with other panels, approximately 80–100mm from the top of the hollowcore panel and projecting into the core. Unit 12.2 had cracks along and across the hollowcores on both ends, with the exposed side (towards panel 13) completely damaged, possibly exacerbated by the manner in which it was lowered. Longitudinal cracks spanning the length of the panel were also observed. Unit 12.3 experienced significant damage, with cracks along and across the hollow cores on both ends. The cracks along the web ranged from 500–800mm deep, and angular cracks through the web of the hollow cores extended 500–600mm deep, forming angles approximately 150mm from the top.



(a)

(b)

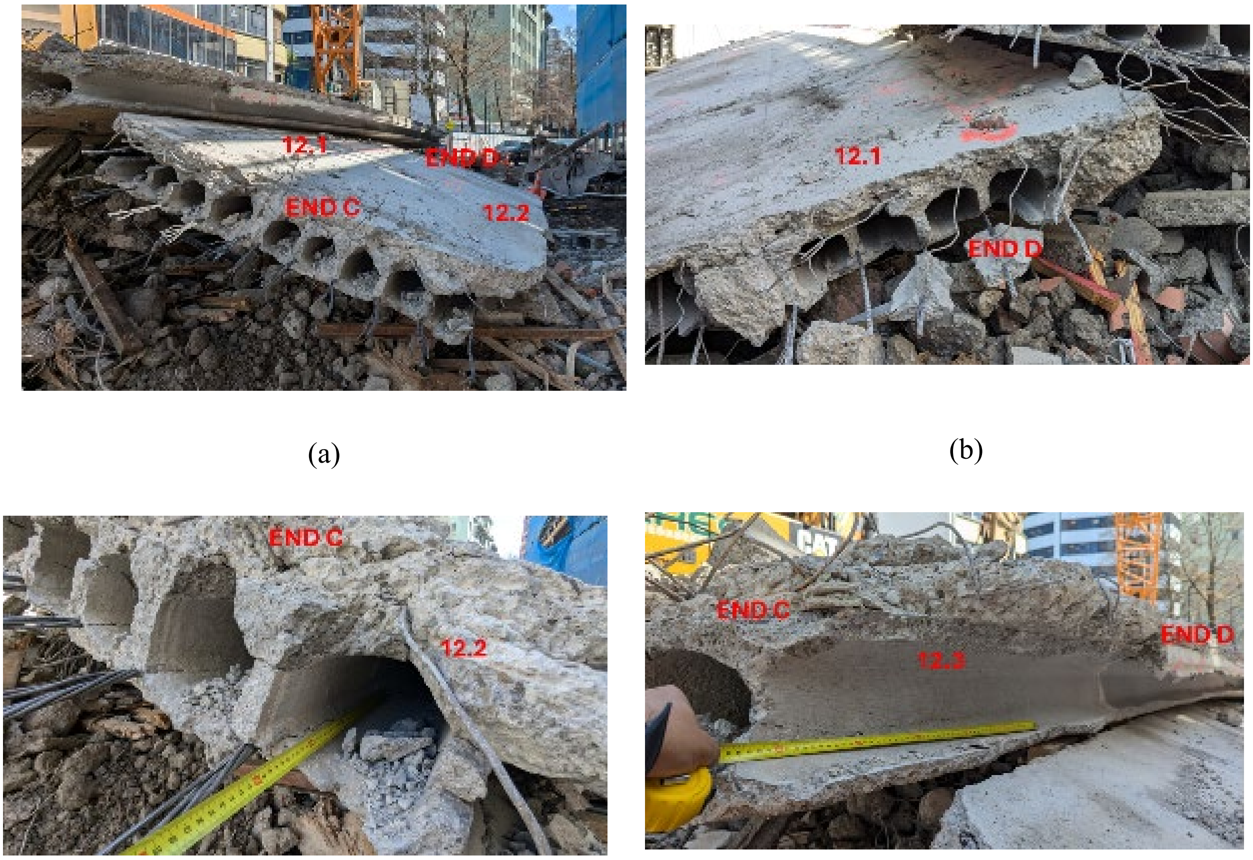


(c)

(d)

Figure 22: Damage observation and annotations of units 8.1, 8.2, and 8.3

The floor panel 12, divided into units 12.1, 12.2, and 12.3, exhibited varying levels of damage across its sections, as annotated in Figure 23. In unit 12.1, cracks were observed along and across the hollowcores on both ends, as well as through the web. Although all sides of the panel were inaccessible for measurements, the extent of the cracks along the web appeared to be consistent with other panels, approximately 80–100mm from the top of the hollowcore panel and projecting into the core. Unit 12.2 had cracks along and across the hollowcores on both ends, with the exposed side (towards panel 13) completely damaged, possibly exacerbated by the manner in which it was lowered. Longitudinal cracks spanning the length of the panel were also observed. Unit 12.3 experienced significant damage, with cracks along and across the hollow cores on both ends. The cracks along the web ranged from 500–800mm deep, and angular cracks through the web of the hollow cores extended 500–600mm deep, forming angles approximately 150mm from the top.



(a) (b)

(c) (d)

Figure 23: Damage observation and annotations of units 12.1, 12.2, and 12.3

4 CONCLUSIONS AND ACKNOWLEDGMENTS

4.1 Conclusions

The Civic Administration Building serves as an example of the challenging and complex nature of seismic assessment, retrofit and damage assessment processes. This is a relatively rare example of a building that has undergone assessment, retrofit/securing, earthquake damage and subsequent demolition. Through this journey it seems clear that:

- The conclusions of the original DSA were well founded. The building was very flexible and had a number of vulnerabilities that warranted attention.
- The seismic securing measures implemented in 2013-14 were warranted and timely. The demolition of the Portico structure removed critical connection vulnerabilities and helped mitigate the torsional building response (and overall displacement in the subsequent Kaikōura earthquake). The end frame column connections helped provide a critical building tie, to limit adverse building displacement and separation, where subsequent building movement was apparent.
- The RBA and subsequent TDE process after the Kaikōura earthquake was crucial in identifying initial concerns about the building and leading to further investigation that led to further, more intrusive action

and significant floor damage findings. However, on it's own the RBA process was not conclusive, and was only further informed by specific knowledge of the building given previous DSA understanding.

- Hollowcore floors are susceptible to damage – yet establishing a concise and thorough understanding of the extent and nature of that damage is very difficult. Unfortunately, comprehensive research findings in relation to this building were limited, due to the timing and nature of various inspections and the lack of comprehensive crack mapping or any borescope inspections into hollowcore cells prior to demolition.

4.2 Acknowledgements

The authors would like to thank the following parties for their involvement with or contribution to this paper including:

- Wellington City Council
- Aurecon
- RCP – demolition project managers
- LT McGuiness – demolition contractor to facilitate site access
- Ken Elwood and Lucas Hogan for their interest and assistance in making the damage inspections and documentation of the hollowcore, during demolition possible

References

Aurecon (2020). *"WCC Civic Administration Building, earthquake damage assessment crack mapping to the underside of level 2, 13 March 2020."*

Holmes (2013 a). *"WCC Civic Administration Building, Detailed Seismic Assessment Report."*

Holmes (2013 b). *"WCC Civic Administration Building, Seddon Earthquakes, Detailed Damage Report."*

Holmes (2017). *"Civic Administration Building, Targeted Damage Evaluation, Post-earthquake November 2016.*

NZSEE and SESOC (2017). *"Engineering Guidelines for Targeted Damage Evaluation following the November 2016 Kaikōura Earthquakes, ver 1.1 25 January 2017."*