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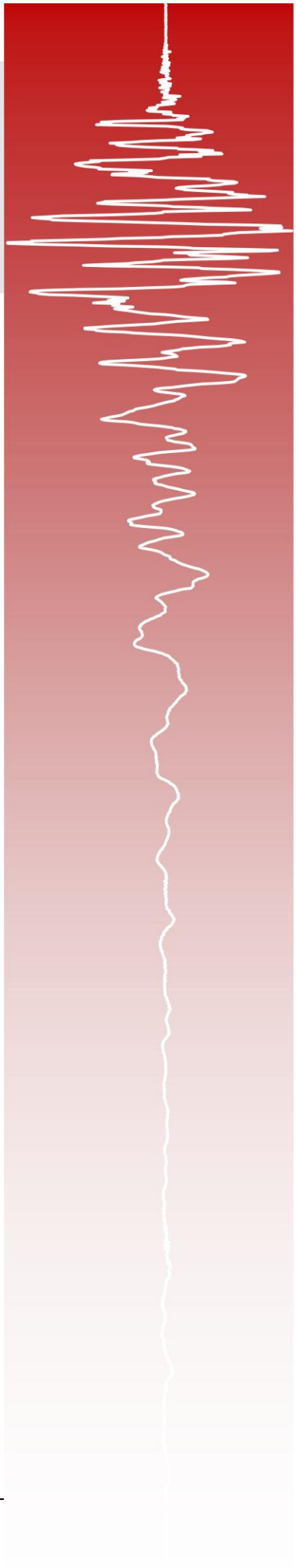

Victoria Square Apartments
100 Armagh Street, Christchurch

INDEPENDENT EARTHQUAKE PERFORMANCE ASSESSMENT

Ref: 11051-02

Revision 1

January 2012

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For: Canterbury Earthquakes Royal Commission
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Revision History

Revision number	Date of Issue	Report status
0	12/01/2011	Draft for review
1	20/01/2011	First release – revisions to account for RCF comments

Limitations

This report has been prepared for Canterbury Earthquakes Royal Commission, and the findings presented within the report are for their sole use. The findings are not intended for use by other parties, and may not contain sufficient information for the purposes of other parties or other uses.

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1. Introduction

Compusoft Engineering Limited have been engaged by the Canterbury Earthquakes Royal Commission to independently assess the performance of specified structures located in the Christchurch central business district (CBD) during the Canterbury Earthquakes of 2010 and 2011. These assessments are required by the Royal Commission to assist in fulfilling the requirement set out for them in their establishing terms of reference [1] to consider the performance of "a reasonably representative sample of buildings in the Christchurch City CBD". This report presents our independent assessment of the Victoria Square Apartments building located at 100 Armagh Street, Christchurch.

This report has been prepared based on documentation and reports provided by the Canterbury Earthquakes Royal Commission. Compusoft Engineering Limited had not inspected the Victoria Square Apartments building prior to publication of this report.

2. Location of building

The Victoria Square Apartments building is located at 100 Armagh Street, Christchurch as shown in Figure 1. This address places the structure to the north-west of the centre of Christchurch and close to the Avon River, which is approximately 65 m from the structure at its closest approach.

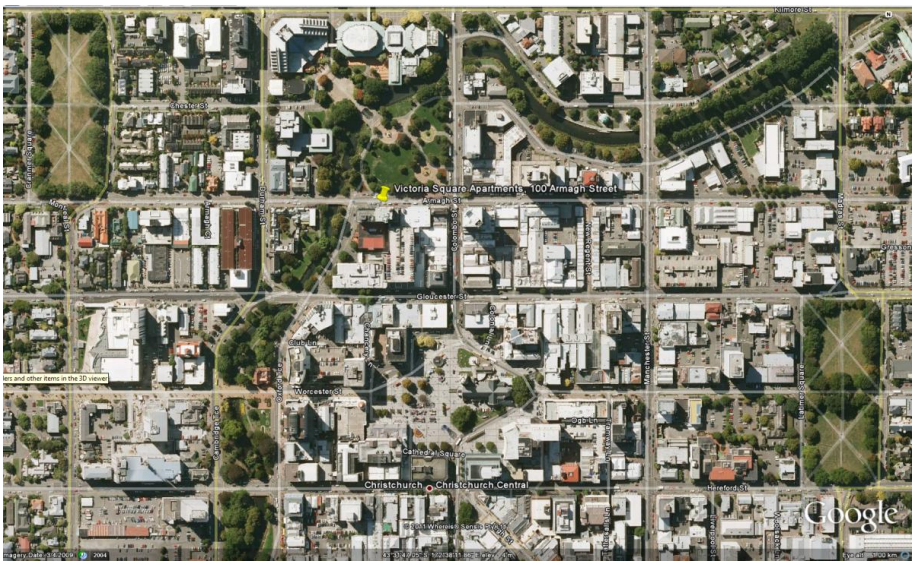

Figure 1: Plan showing location of Victoria Square Apartments

3. Description of building

The Victoria Square Apartments building is a fourteen storey reinforced concrete structure, which contains approximately 17 apartments. Figure 2 shows a view of the structure from Armagh Street. A ground floor plan of the structure is shown in Figure 3 (note that north is at the bottom of the plan). The floor plan of the structure reduces twice over the height of the structure from that shown in Figure 3, first at the fifth floor (see Figure 4), and then again at the eighth floor (see Figure 5). Structural design of the Victoria Square Apartments building was undertaken by Connell Mott MacDonald, and the architects for the project were The Buchan Group.

Figure 2: View of the Victoria Square Apartments building from Armagh Street[1]

[1] Victoria Square Apartment Building, 100 Armagh Street. Photo taken by Ross Becker, Licensed under Creative Commons Attribution 2.0 Generic

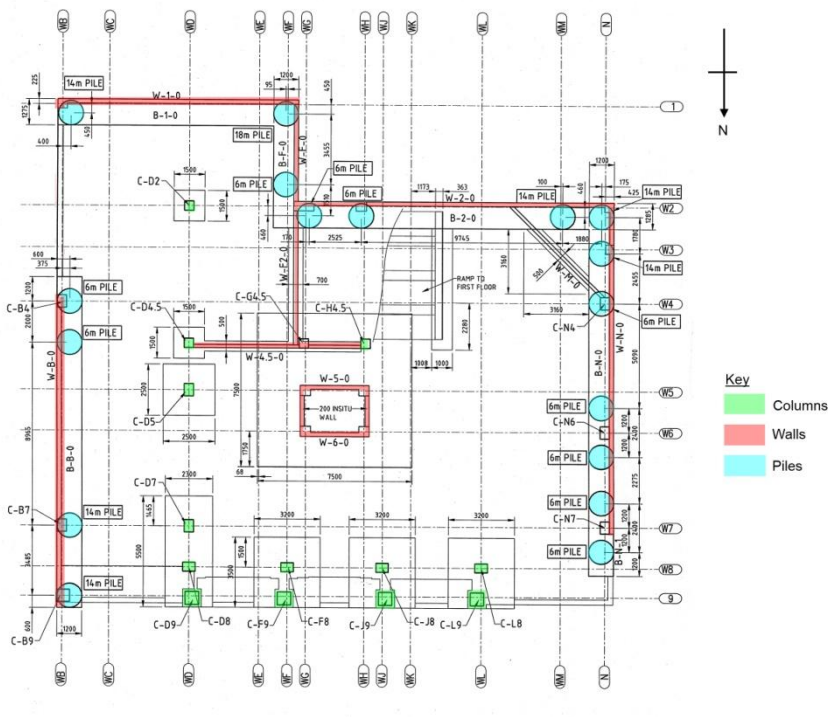

Figure 3: Ground floor plan of Victoria Square Apartments building

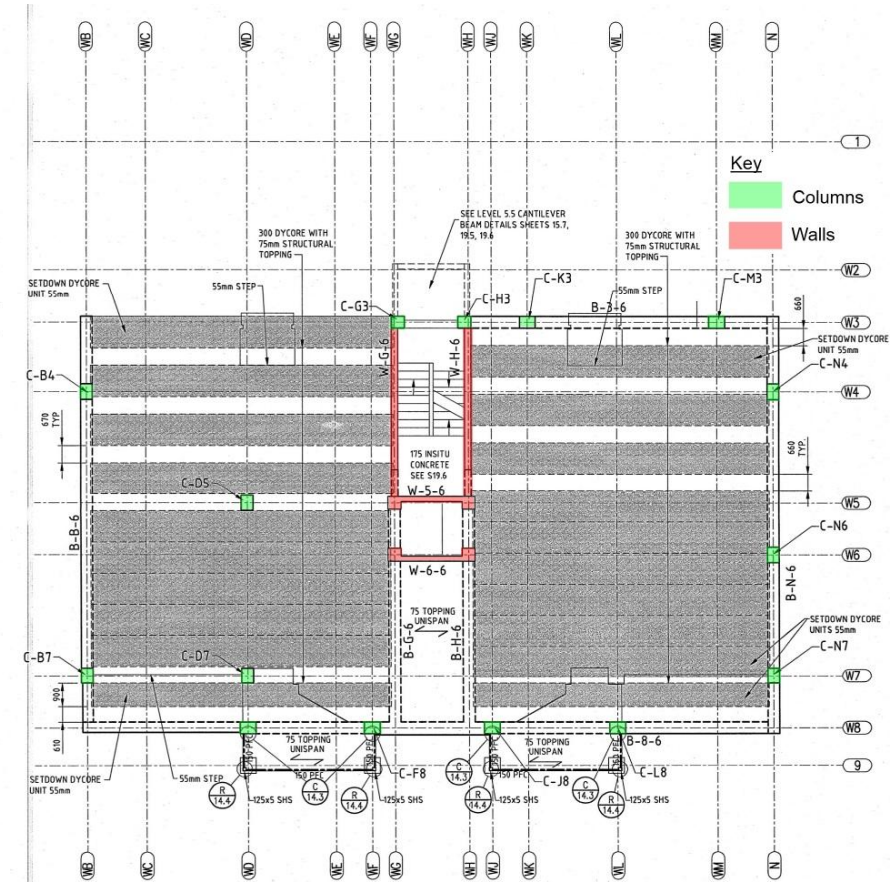

Figure 4: Sixth floor plan of Victoria Square Apartments building (fifth and seventh floors similar)

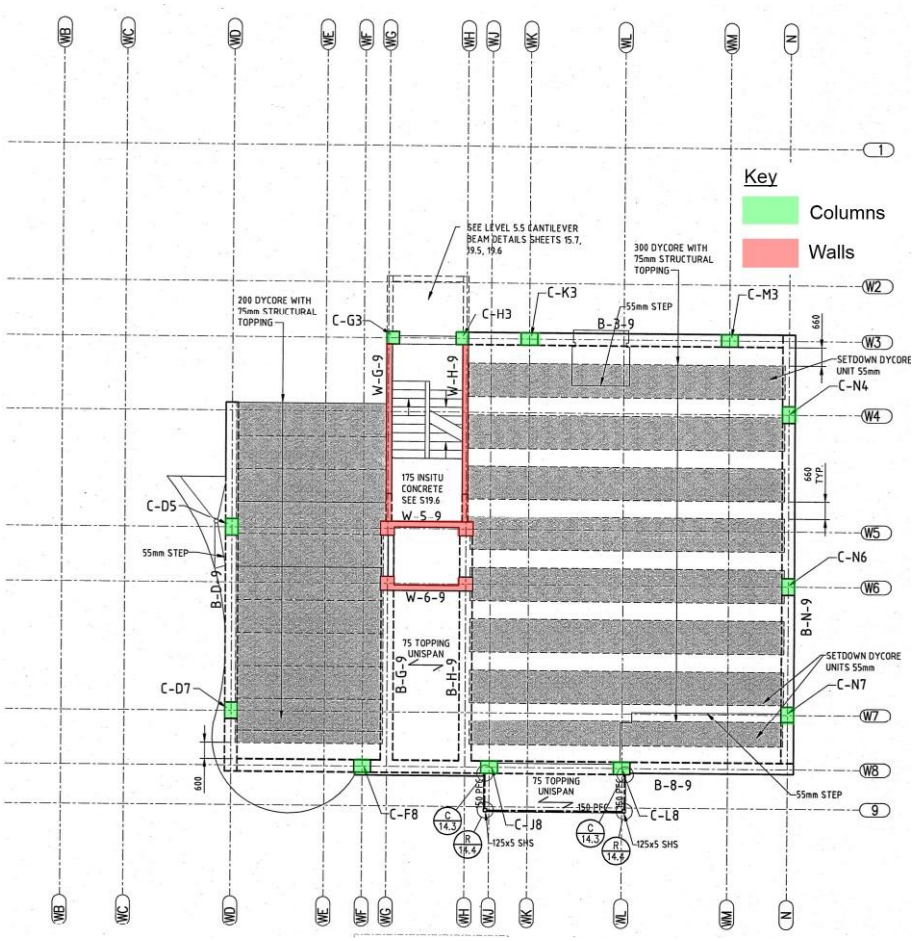

Figure 5: Ninth floor plan of Victoria Square Apartments building (eighth to thirteenth floors similar)

The Victoria Square Apartments building was constructed circa 2005/2006 based on drawings that were consented in August 2004. Based on these dates it can be assumed that the structure was designed using the New Zealand Loadings Standard NZS 4203:1992 [2] and the New Zealand Concrete Structures Standard NZS 3101:1995 [3]. NZS 3101:1995 was amended in March 2004 with the main subjects of the amendment being the incorporation into the standard of Grade 500E reinforcement and stricter requirements for support of precast floor systems. Without seeing original design documentation it cannot be stated with certainty whether this amendment was used during the design of the Victoria Square Apartments building.

3.1. Lateral force resisting system

The Victoria Square Apartments building relies on a combination of walls and moment resisting frames for lateral force resistance. The distribution of walls and frames varies up the building. In summary:

- At the lower levels of the structure there are structural walls on three sides of the structure and a moment resisting frame on the fourth (north) side of the building. These structural walls generally terminate at fourth floor level to coincide with the change of floor plan that occurs at this height. The relative stiffnesses of the walls and frames at the lower levels indicate that the contribution of the north face moment resisting frame to lateral resistance would have been minor.
- Full height walls surround the central lift core. Substantial columns exist at the corners of the lift core. These columns would function as boundary elements for the lift core walls.
- Two additional walls exist on grids WG and WH that extend to the roof of the structure. The wall on gridline WH does not extend to ground level, and hence cannot be seen in Figure 3.
- At the upper levels of the structure torsional resistance is provided by moment resisting frames around the perimeter of the structure. These frames would also contribute to the lateral resistance of the structure.

Diaphragms in the Victoria Square Apartments building consist of structural toppings reinforced with conventional deformed (i.e. not mesh) reinforcement. The thickness of the topping varies between 75 mm and 150 mm. Reinforcement size and spacing varies depending on the location of the diaphragm, and additional "drag" bars are indicated on the drawings. The structural topping is supported by hollowcore planks spanning to beams or walls as discussed in section 3.2.

3.2. Gravity system

Gravity load carrying capacity in the Victoria Square Apartments building is provided by the same elements that comprise the lateral load resisting system.

The floor system of the Victoria Square Apartments building consists of precast concrete units with an in-situ topping. The type and size of precast unit and topping used varies through the structure depending on the span and usage of an area. The majority of the flooring consists of 200 mm and 300 mm deep hollowcore ("Dycore") planks topped with 75 mm to 150 mm of in-situ concrete. Smaller areas of the floors are constructed from solid

precast planks ("Unispan"). Precast units generally span along the east-west axis to beams or walls.

3.3. Foundation system

The foundation system for the Victoria Square Apartments building consists of a mix of piles and shallow foundations.

A total of seventeen piles are provided under the perimeter walls on the south, east, and west sides of the structure. The majority (ten) of these piles are detailed with a length of 6 m. The remaining seven piles are either 14 m or 18 m long. These longer piles are largely located at the corners of the structure. Notably, all piles in the north-west corner of the structure are the shorter 6 m items. Piles are linked together by foundation beams with dimensions of 1200 mm width by either 750 mm or 1200 mm depth.

Shallow foundations are provided under isolated columns along the north face of the structure and at the interior, and also under the lift core walls and other internal walls.

4. Geotechnical site assessment

Parts of a geotechnical investigation report for the Victoria Square Apartments building have been provided by the Canterbury Earthquakes Royal Commission. The information provided consists of the results of nine borehole logs published by Geotech Consulting Ltd. Due to the significance of geotechnical effects on the performance of the Victoria Square Apartments building; further discussion of the geotechnical investigation received is presented in section 7.

5. Compliance

A building consent application (ABA10045722) was submitted on 17th May 2004. The consent was issued on 29th September 2004, and the code compliance certificate for the building was issued on 21st April 2006.

6. Effects of earthquakes on building

Three reports on the effects of the Canterbury earthquakes on the Victoria Square Apartments building have been provided to Compusoft Engineering Limited by the Canterbury

Earthquakes Royal Commission. The first of these was produced by Structex [4] and relates to the effects of the September 4th earthquake on the structure. The remaining two reports were produced by Aurecon [5, 6], and relate to the effects of the 22nd February earthquake on the structure. The Structex report indicates that no structural damage occurred during the September earthquake, and that only minor non-structural cracking was observed. The Aurecon reports indicate that the 22nd February 2011 earthquake caused only minor structural damage to the Victoria Square Apartments building. Damage described included minor cracking of concrete shear walls, spalling of concrete at stair landings, and damage to (non-structural) Hebel cladding panels.

Although the structural damage resulting from the February earthquake was minor, the earthquake caused a significant, permanent overall displacement of the Victoria Square Apartments building. The magnitude of this displacement was reported by Aurecon as being approximately 450 mm at the "top" of the building, or approximately 0.8% drift. This displacement is clearly visible in photos of the structure taken from appropriate angles. Aurecon survey results (reproduced in Figure 6) indicate that the total displacement/drift can be attributed to settlement of the foundations. The structure was found to have settled by 220 mm at the north-west corner and 160 mm at the north-east corner, both levels taken as relative to the south-east corner.

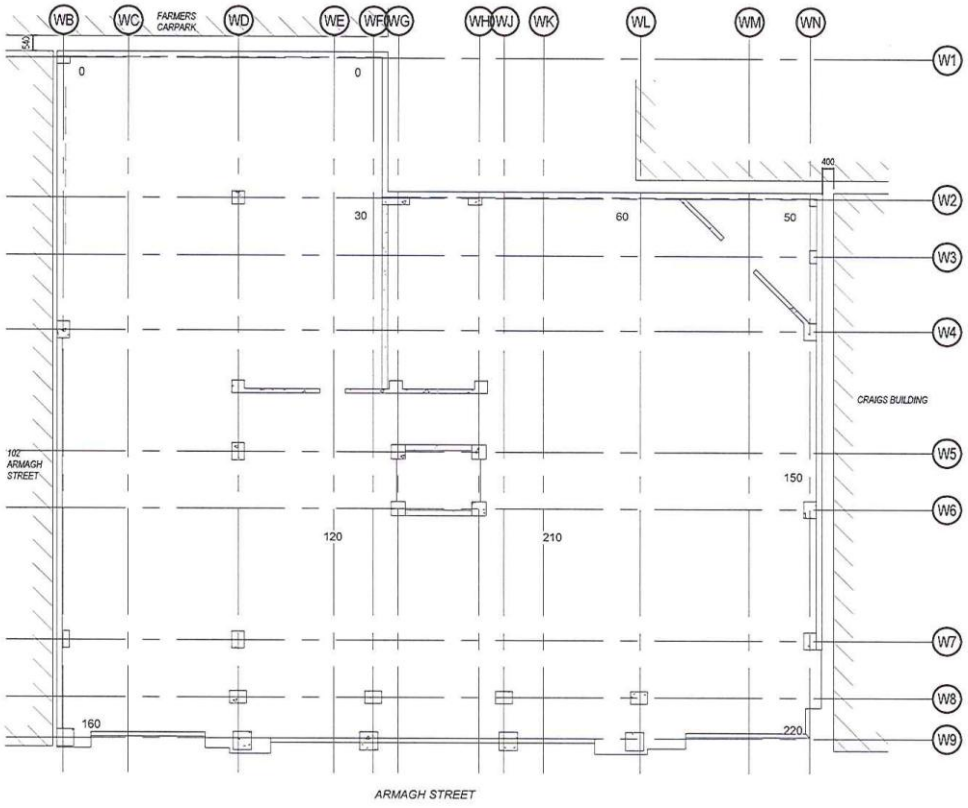

Figure 6: Aurecon surveyed foundation levels

7. Discussion of structural performance

As noted in the previous section, the major effect of the February earthquake on the Victoria Square Apartments building was to cause a permanent (rigid body) rotation of approximately 0.8% drift towards the north-west. The assertion made in other reports that the rotation was due to differential foundation settlement appears correct, and the reasons for the required pattern of foundation settlement appear to be readily explainable. Two different factors contributed to the differential settlement:

- The layout of different types of foundation element under the structure.
- The distribution of soil liquefaction in the vicinity of the structure during the earthquake.

Compusoft Engineering Limited are not geotechnical engineers, and no detailed analyses of the Victoria Square Apartments foundations have been undertaken for this report. The comments made here are therefore qualitative in nature.

Figure 7 shows the preliminary map of liquefaction in areas surrounding the Christchurch CBD that was presented in the Royal Commission Interim Report [7]. The location of the Victoria Square Apartments Building has been marked on this map. It can be seen that the boundary of the zone of severe liquefaction lies approximately at the north side of Armagh Street. Later revisions of this map [8] in fact show the zone of severe liquefaction extending to the south side of Armagh street, i.e. directly adjacent to the front face of the Victoria Street Apartments. Victoria Square, a prominent park directly north of the apartments, has also been identified by Tonkin & Taylor as an area where lateral spreading occurred [9]. Based on available geotechnical information [6, 9] it is most likely that liquefaction at the north side of the Victoria Square Apartments building would have occurred at depths between 8 m and 14 m below the surface, with some possibility of liquefaction from 16 m to 20 m below the surface.

A ready explanation for the residual displacement of the Victoria Square Apartments building is provided by the occurrence of severe liquefaction and lateral spreading at one side of the structure in conjunction with the mixed foundation layout. The failure of the ground at the north side of the building would have resulted in the significant rotation towards the north. The structure also has a less significant rotation to the west. The principal cause of this rotation is likely to have been structure-soil-structure interaction as suggested elsewhere [10]. Specifically, the existence of a second large structure immediately to the west of the Victoria Square Apartments building would have resulted in both structures influencing the stress state in the soil in the vicinity of the boundary line. A secondary contribution may have been the provision of piles of only 6 m length at the north-west corner of the structure. Such short piles are unlikely to have penetrated below the liquefiable material under this region of the structure (see Figure 8).

The apparent rigid body rotation of the Victoria Square Apartments building indicates that the structure possesses significant stiffness, without which the differential foundation settlement would have resulted in structural deformations. Consideration of the structural drawings and estimation of structural period using simple formulae [11, 12] does not indicate that the tower itself would be unusually stiff. However, the lower levels of the structure would be significantly stiffer due to the presence of longer (approximately 15 m) walls on three faces in conjunction with substantial ground beams spanning between the piles.

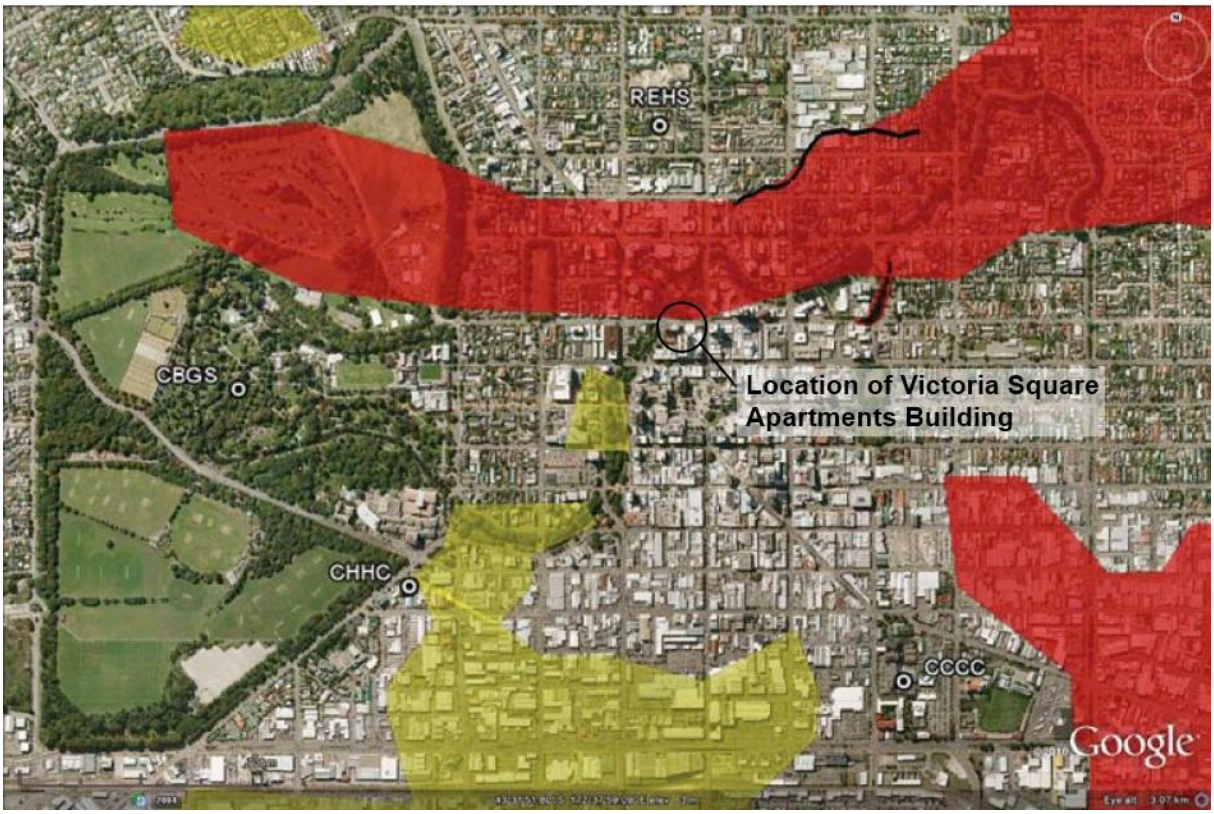

Figure 7: Preliminary map indicating moderate (yellow) and severe (red) liquefaction in areas surrounding the Christchurch CBD (reproduced from [7])

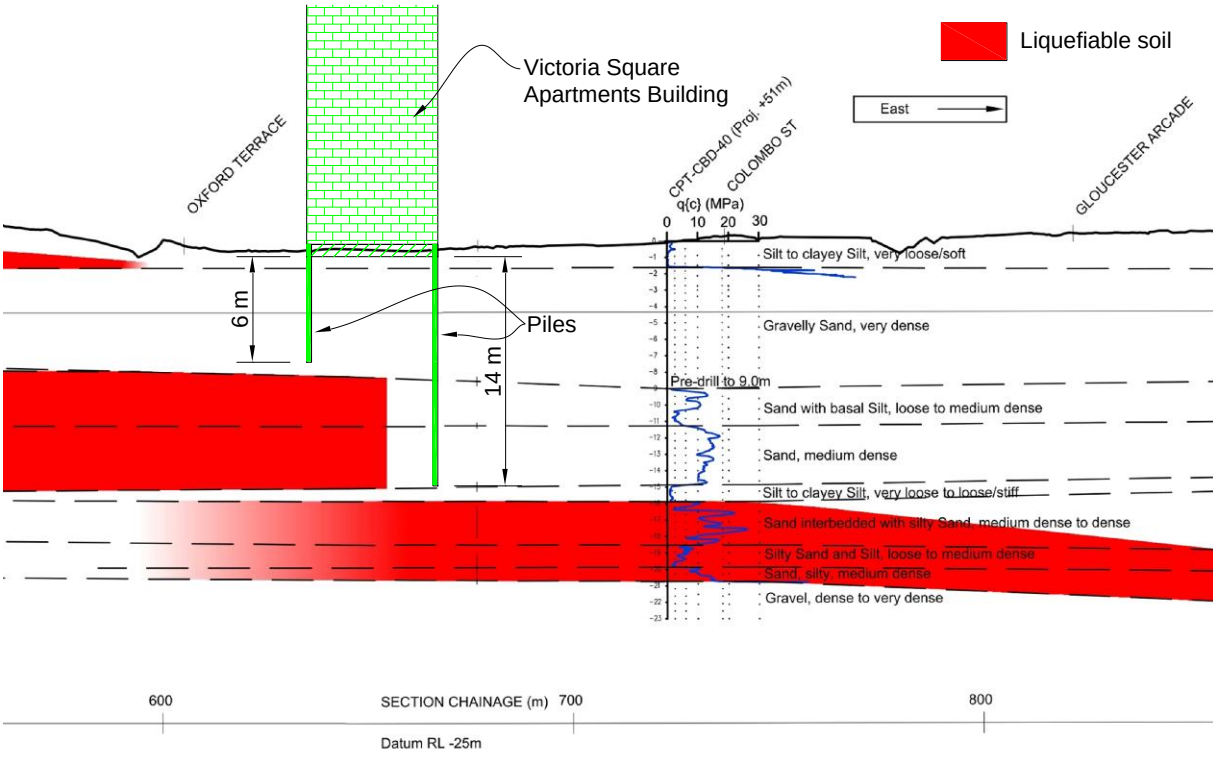

Figure 8: Schematic showing approximate position of Victoria Square Apartments Building in relation to zones of liquefiable soil (adapted from [9])

It is not known to what extent the liquefaction potential of the area was understood by the original designers or why the selected foundation scheme was chosen. The original geotechnical investigation (provided to Compusoft Engineering by the Royal Commission) shows that the ground conditions under the site were known, and not apparently susceptible to liquefaction. However, it is not known whether the likelihood of liquefaction under the adjacent Victoria Square was known or considered. The 1990 Christchurch shallow foundation hazard map (see Figure 9) does not identify the area around the Victoria Square Apartments building as being susceptible to liquefaction, although commonly referred to ground profiles [13] show that Victoria Square is underlain by sandy deposits that can be liquefiable. Given the known susceptibility of Christchurch soils to liquefaction and the proximity of the Avon River to the site, it is reasonable to state that the possibility of adjacent land liquefying should have been considered, which may have lead to a more regular foundation scheme being selected.

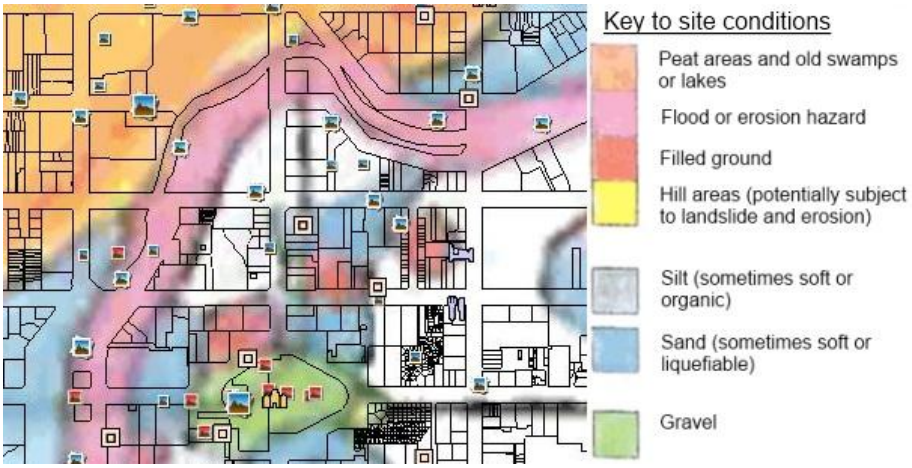

Figure 9: Excerpt from Christchurch shallow foundation hazard map 1990

Inspection of structures affected by the Christchurch earthquakes has in many instances indicated that the structure has been subjected to reduced seismic actions due to foundation behaviour (i.e. soil-foundation-structure interaction). While this has most often been the case for structures with shallow foundations, it is possible the low structural damage to the Victoria Square Apartments was due in part to protection provided by foundation deformation.

7.1. Stairs

Little information is provided in the assessment reports regarding the nature or extent of stair landing damage. The only elaboration regarding the nature of the damage is in the form of a photo reproduced here as Figure 10.

Figure 10: Photo of stair landing damage (reproduced from [5])

The limited information available about the damage makes it difficult to draw conclusions about the cause of the damage. However, review of the structural drawings indicates that the typical stair detailing provides no isolation of the stairs from the structure (see Figure 11). This lack of isolation would allow the stair units to act as struts able to transfer forces between floors in a manner they are unlikely to have been designed for.

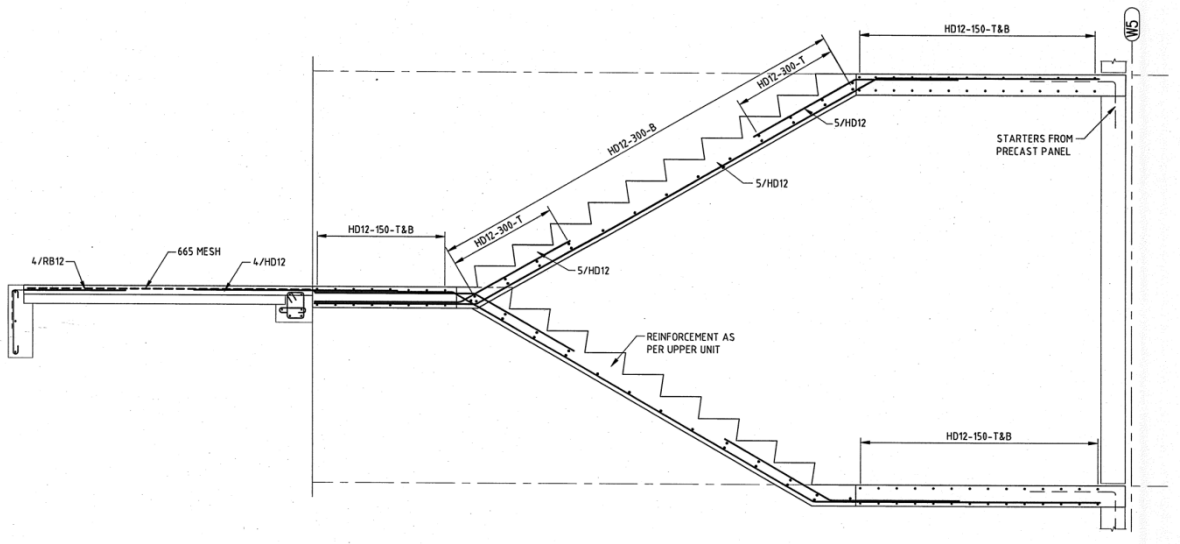

Figure 11: Typical stair detailing in Victoria Square Apartments building

8. Issues arising from review

As noted previously, only minor structural damage was inflicted on the Victoria Square Apartments building by the 2010 and 2011 Canterbury earthquakes. However, it appears probable that stair landing damage occurred due to the inadequate isolation of the stairs from the structure.

Considering the foundation behaviour of the Victoria Square Apartments building, with hindsight it is clearly unfortunate that the selected foundation arrangement placed those elements least able to accommodate soil liquefaction (isolated pad foundations) adjacent to the area in which liquefaction occurred. The behaviour of the Victoria Square Apartments building indicates that the ground conditions in the vicinity of a structure should be considered as carefully as the ground conditions directly beneath the structure. It is further suggested that designers should be wary of "hybrid" foundations, irrespective of whether these consist of combined shallow and deep foundations or piles of differing length. It is probable that the performance of the Victoria Square Apartments building would have been significantly improved if an adequate number of deep piles had been installed on the north side of the structure.

9. Conclusions

This report has considered the performance of the Victoria Square Apartments building during the 2010 and 2011 Canterbury earthquakes. Review of reports by other consultants showed that the earthquakes caused minimal structural damage, but that the February earthquake resulted in a significant overall rotation of the structure. This rotation was determined to be caused by the occurrence of severe liquefaction immediately to the north of the structure in combination with the provision of shallow foundation elements at the north side of the structure. From the information available it could not be determined whether the potential for liquefaction to occur to the north of the structure was known to the designers of the structure, and nor was it clear why the selected foundation arrangement was chosen. It was concluded that two design issues arose from this review. The first was inadequate isolation of the stairs from the structure, which apparently lead to stair landing damage due to "jamming". It was secondly concluded that designers should take care to understand the geotechnical conditions in the vicinity of a structure as well as directly under the structure,

and that designers should take particular care before specifying hybrid foundations for a structure.

10. References

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