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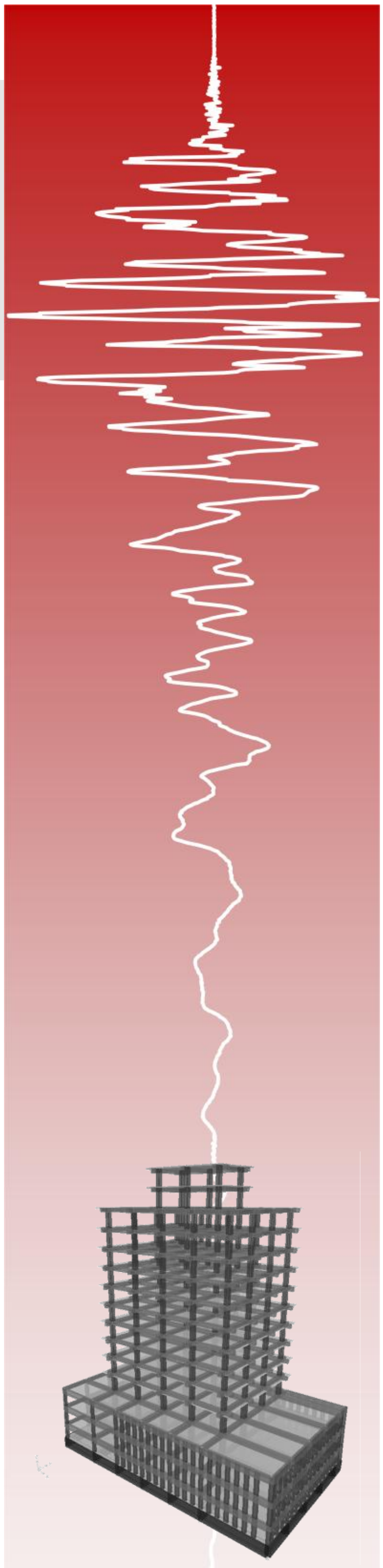

Central Police Station
48 Hereford Street, Christchurch

INDEPENDENT EARTHQUAKE PERFORMANCE ASSESSMENT

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Draft for Review R0

February 2012

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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 requirements set out for them in their establishing terms of reference [1]. This report presents our independent assessment of the Central Police Station building located at 48 Hereford 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 Central Police Station building prior to publication of this report.

2. Location of building

The Christchurch Central Police Station is located at 48 Hereford Street, Christchurch as shown in Figure 1. This location places the structure west of the centre of Christchurch and close to the Avon River, which is approximately 90 metres from the structure at its closest approach.

Figure 1: Plan showing location of Christchurch Central Police Station

3. Description of building

The Christchurch Central Police Station is a fifteen storey reinforced concrete structure, with its main function obviously being to provide office and other administrative functions for the New Zealand Police. Figure 2 shows a view of the structure from Cambridge Terrace looking west. Figure 3 shows a cross section (looking east) of the structure taken from the architectural drawings. This section is provided primarily to clarify numbering of levels within the structure. Two floor plans are shown in Figure 4 and Figure 5. These show the existence of a podium structure at the lower levels, with this podium having a floor area that is approximately twice the area of the tower structure. At the podium levels there is a structurally separate extension, which appears at the left side of Figure 4.

Figure 2: Central Police Station, 48 Hereford Street viewed from Cambridge Terrace [1]

[1] Central Police Station, 48 Hereford Street viewed from Cambridge Terrace. Photo taken by Ross Becker, Licensed under Creative Commons Attribution 2.0 Generic

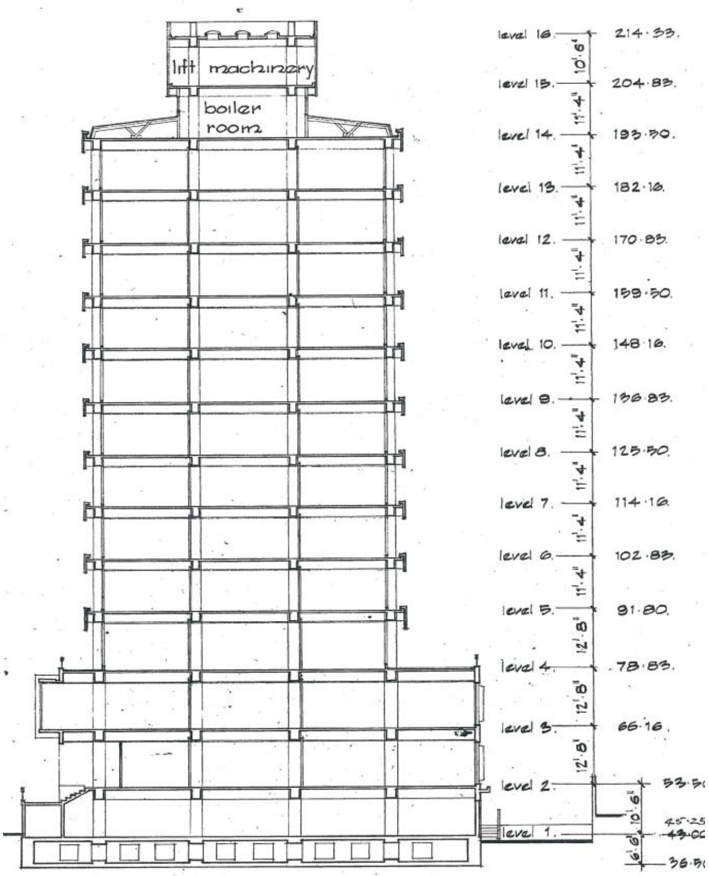

Figure 3: Section of Christchurch Central Police Station showing original designation of levels

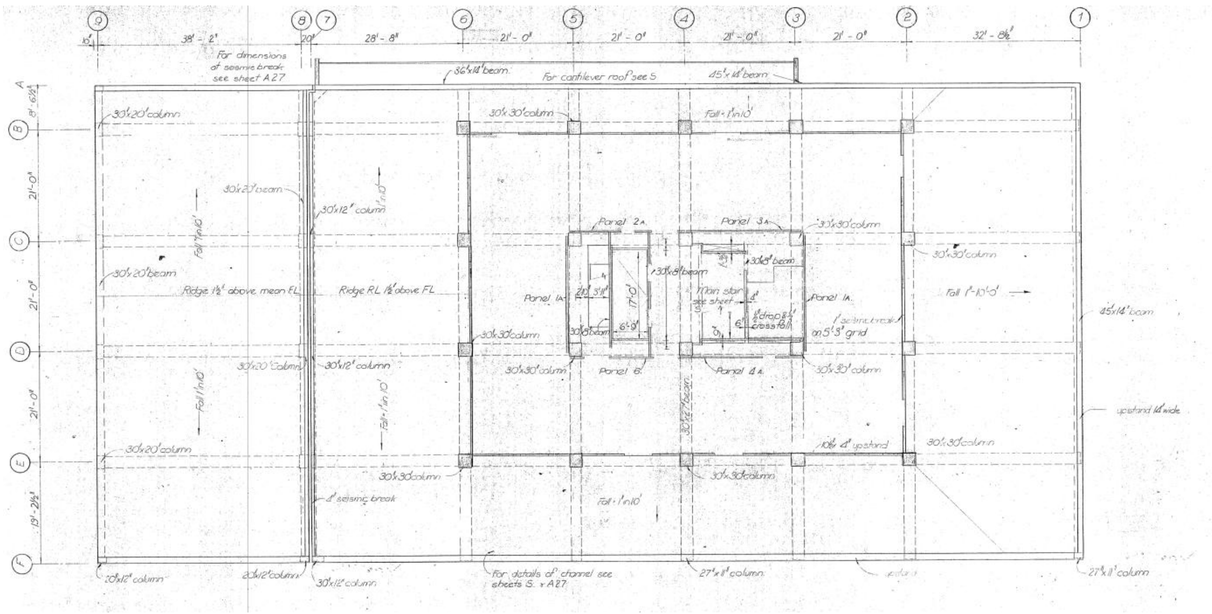

Figure 4: Level 4 floor plan (Levels 1-3 similar)

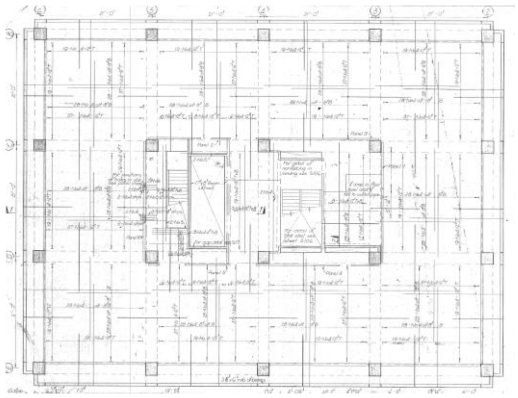

Figure 5: Typical floor plan applicable for levels 5-13

Design of the Christchurch Central Police Station was undertaken by the Ministry of Works, with the structure drawn in mid 1968 and reportedly constructed over the following two years [2]. Based on the drawing date it is probable that the structure was designed using the New Zealand Standard Model Building By-Law [3, 4]. The structure was designed prior to the first known publication [5] outlining the principles that became known as “capacity design”.

3.1. Gravity and lateral force resisting systems

The gravity and lateral force resisting systems of the Christchurch Central Police Station rely on the same structural elements, and hence both are discussed together in this section.

The Christchurch Central Police Station is a reinforced concrete moment resisting frame structure. The frames are arranged on a two-way grid, with all beam and column members being of similar dimensions and having full moment connections. Typical member dimensions are summarised in Table 1.

Table 1: Typical beam and column dimensions

Area of structure	Beams		Columns	
	depth	width	depth	width
Lower levels (podium)	762 mm	686 mm	762 mm	762 mm
Upper levels (tower)	686 mm	610 mm	686 mm	686 mm

The floors of the Christchurch Central Police Station consist of reinforced concrete flat slabs. These slabs are typically 152 mm thick, and there are no thickenings at columns. The slabs are uniformly orthogonally reinforced for positive bending, with reinforcement for negative bending provided only at beams. The reinforced concrete slabs are also required to function as diaphragms.

A seismic assessment of the Christchurch Central Police Station was undertaken by Lewis Bradford Consulting Engineers in 2010 [2]. This review was first issued in May 2010, but had a revised executive summary added in July 2010. In the revised summary it was concluded that the building was not earthquake prone if classified as an Importance Level 2 (IL2) structure according to AS/NZS 1170.0 [6], but would be earthquake prone if classified as an Importance Level 4 (IL4) structure. The basis for finding that the building was not earthquake prone with respect to IL2 requirements is not clear, as the original (May) report had found the building to be earthquake prone for IL2 loads and no revised details were provided to support the altered conclusion.

3.2. Foundation System

The foundations of the Christchurch Central Police Station consist of a deep reinforced concrete cellular raft system. The base slab of the raft is 457 mm (18 inches) deep, and the top slab (also the Level 1 floor slab) is 305 mm (12 inches) deep. The top and bottom slabs are separated by a clear distance of 1829 mm (72 inches). Support between the two slabs is provided by a grillage of 914 mm (36 inch) wide reinforced concrete beams. These beams contain significant penetrations in some areas (see Figure 6 for example), but are generally well reinforced.

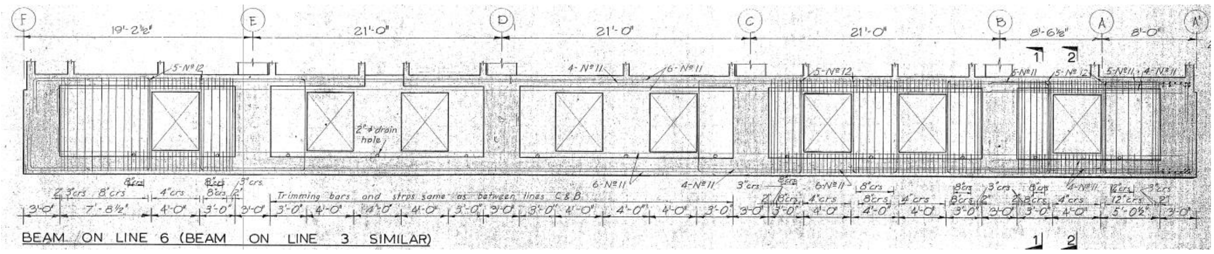

Figure 6: Example elevation of foundation beam

3.3. Non-structural elements

The Christchurch Central Police Station contains a large number of precast concrete wall panels located in the vicinity of the stair/lift core. These panels are typically 102 mm to 152 mm (4” to 6”) thick, and are separated from the primary structural elements by 25 mm

(1”) seismic gaps between the top of the panels and the storey above. Figure 7 shows the detailing of a typical precast panel.

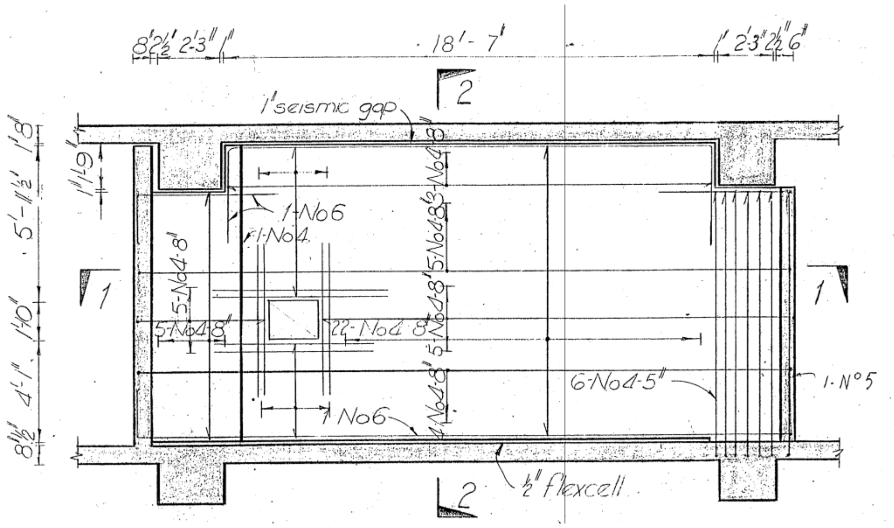

Figure 7: Typical detail of precast non-structural wall panel

There are two full height stairs in the Christchurch Central Police Station, described as the main and emergency stairs. Both are constructed from in-situ concrete, and their positions within the structure can be seen in both Figure 4 and Figure 5. The main stair is arranged with two flights per storey, meeting at a mid-storey landing, while the emergency stair has a single continuous flight per storey. The detailing of the main stairs indicates that the upper flight of each storey is isolated at the mid-storey landing, but that the lower flight is not isolated from the structure (see Figure 8). The emergency stairs are isolated at the bottom end of the flight of stairs using a similar detail to that shown in Figure 8.

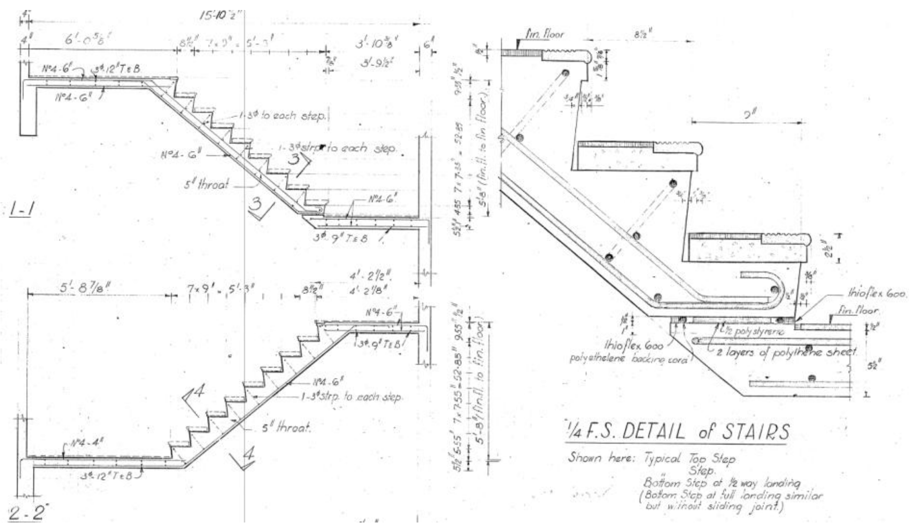

Figure 8: Sections and detail for main stair of Christchurch Central Police Station

4. Geotechnical site assessment

No geotechnical information specific to the Christchurch Central Police Station has been provided to Compusoft Engineering Limited. Some information is available from more generic sources. Figure 9 shows the geotechnical cross section along Hereford Street originally published by Elder and Macahon [7] and more recently published in the Canterbury Earthquakes Royal Commission Interim Report [8]. This shows the Christchurch Central Police Station to be founded on a layer of sandy gravel, with sands and other materials at depth. The recent Tonkin & Taylor geotechnical study [9] does not include sections for the streets adjacent to the Christchurch Central Police Station; however, the plans presented in the appendices to the report largely agree with the geology shown in Figure 9.

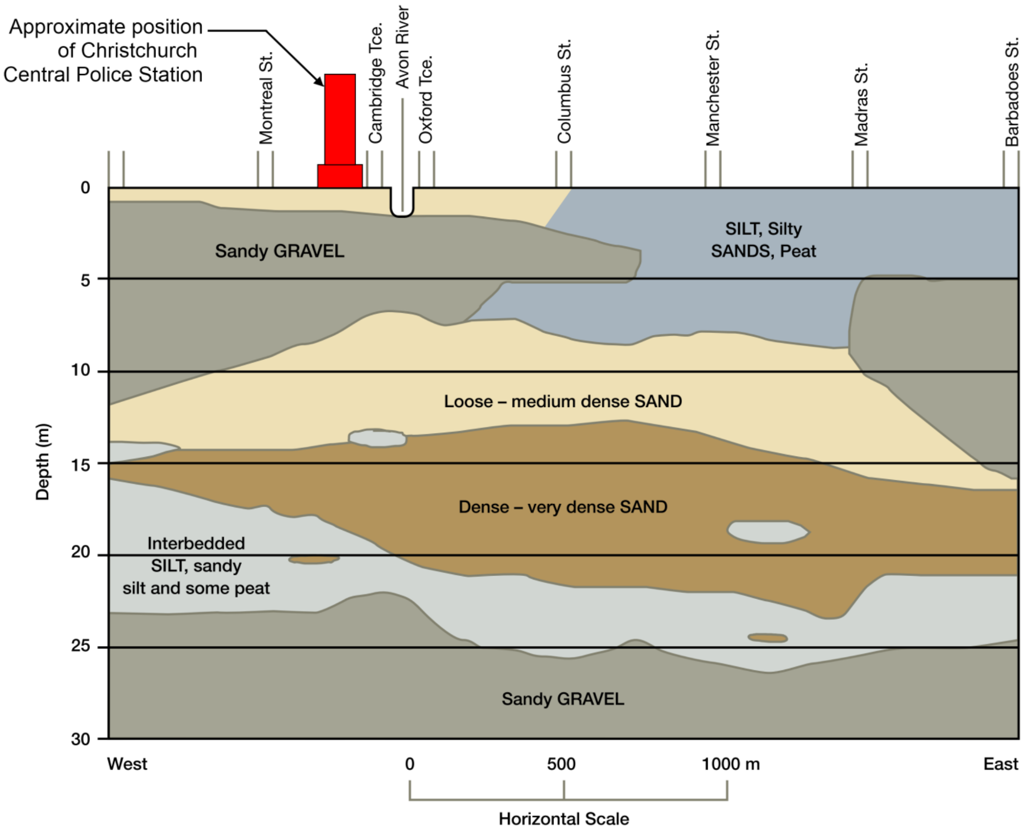

Figure 9: Subsurface cross section of Christchurch CBD along Hereford Street (adapted from [8])

5. Compliance

To be completed by David Hutt

6. Effects of earthquakes on building

Reports by Lewis Bradford Consulting Engineers describing damage inflicted on the Christchurch Central Police Station during the 4th September 2010 [10] and 22nd February 2011 [11] have been provided to Compusoft Engineering Limited by the Canterbury Earthquakes Royal Commission. Review of these two reports form the basis for the description of earthquake performance presented in this section. Additional reports were received from the Canterbury Earthquakes Royal Commission, but these dealt primarily with non-structural damage issues.

Lewis Bradford Consulting Engineers concluded that the 4th September earthquake inflicted only minor damage on the Christchurch Central Police Station [10]. No damage to the primary structure was reported. It was also stated that the foundations and ground under the building were undamaged, although this statement was qualified based on only limited inspections having been undertaken. It was reported that significant cracking and cosmetic damage had been inflicted on non-structural elements.

Lewis Bradford Consulting Engineers similarly concluded that the damage inflicted on the Christchurch Central Police Station by the 22nd February 2011 earthquake was minor [11]. As was the case during the September earthquake it was noted that significant damage to non-structural elements of the building had occurred. Lewis Bradford reported that minor liquefaction had occurred at the north-west corner of the site. Differential settlement between the main structure and the adjacent podium was noted, and surveys showed that a 100 mm differential settlement existed between the two ends of the main structure. The main report indicates that damage to the primary structure was limited to hairline cracks that may have been caused by long term effects rather than the earthquake. However, Appendix D to the report suggests that cracks of the order of 2 mm wide occurred in beams at the face of beam-column joints. This appendix was produced by Goleman Exterior Building Care to present the results of an abseil inspection of the exterior of the structure. Photographs referred to in this appendix are discussed further in section 7.

7. Structural performance

The performance of the Christchurch Central Police Station during the Canterbury earthquakes was significantly better than would have been expected based on the results of the pre-earthquake structural assessment [2]. The focus of this section is to attempt to identify why this was the case.

In order to provide a better understanding of the behaviour of the Christchurch Central Police Station, a model of the structure was developed by Compusoft Engineering Limited using the software package “Etabs” [12]. This model was not intended to be as complete as would be used for design of a structure, but is sufficiently accurate to provide information about the distribution of forces and deformations within the building. A screenshot showing the model is shown in Figure 10. A key output from the model is the finding that the first mode periods for the structure are 2.15 seconds and 2.0 seconds for north-south and east-west vibration respectively.

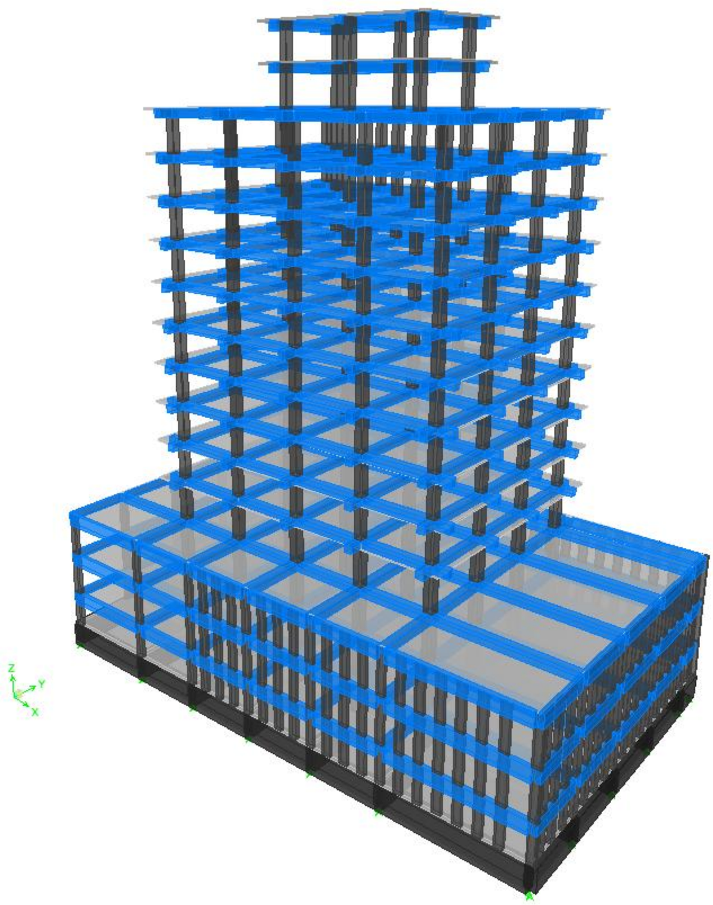

Figure 10: Screenshot of Christchurch Central Police Station Etabs model

Several factors are likely to have contributed to the apparent disparity between the expected and actual performance of the Christchurch Central Police Station. These include:

- The regularity and proportioning of the structure

- The existence of relatively stiff "non-structural" elements around the stair/lift core
- Possible under-estimation of structural capacity
- Apparent under-estimation of the ductility demands placed on the structure by the 22nd February earthquake

The Christchurch Central Police Station largely comprises a two-way moment resisting frame arranged on a regular grid. The detailing of the structure is sufficient to provide a significant level of robustness despite not being fully compliant with modern detailing requirements. Of particular importance is the fact that the structure is dimensioned and reinforced in a manner that would provide a high degree of protection against formation of column sway (soft storey) mechanisms. This is due to the ratio of beam to column moment capacities (sometimes referred to as the sway index) for the typical storey being approximately 0.5. The columns are also detailed in a manner that would allow them to sustain plastic rotations if required. Beam detailing is less consistent with current standards. The main deficiency is that beam longitudinal reinforcement is inadequately restrained by transverse reinforcement in the potential plastic hinge regions, which could lead to buckling of longitudinal reinforcement if large plastic deformation demands were imposed on the hinges.

7.1. Earthquake demand

Figure 11 and Figure 12 show the north-south and east-west components of the February 2011 Christchurch earthquake recorded at three stations in the vicinity of the Christchurch CBD. Both figures also show the current design spectrum for a typical CBD site (i.e. NZS 1170.5 [13], class D soil, Z = 0.3). These plots indicate that the demands imposed on the Christchurch Central Police Station by the February earthquake would have been similar to those that would be used to design an equivalent new structure. The actual forces imposed on the structure could in fact have been somewhat less than those suggested by the NZS 1170.5 spectrum due to the observation made by Carr that the force reduction factors for ductile structures during the 22nd February earthquake exceeded the ductility factor in most cases [14].

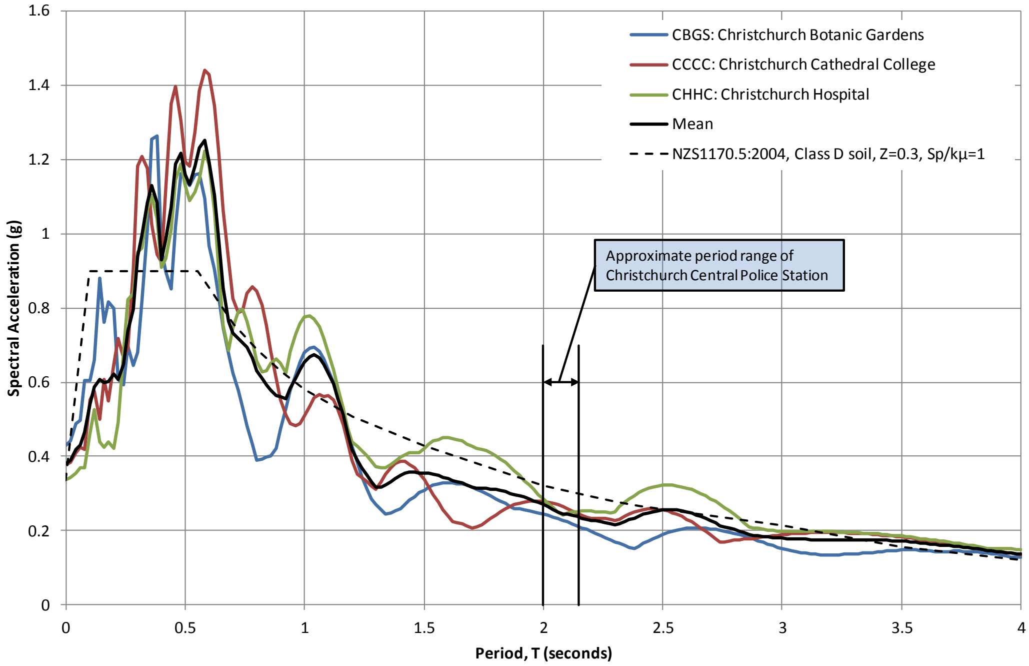

Figure 11: 22nd February 2011 N00E earthquake components for Christchurch CBD compared to NZS 1170.5 design spectrum

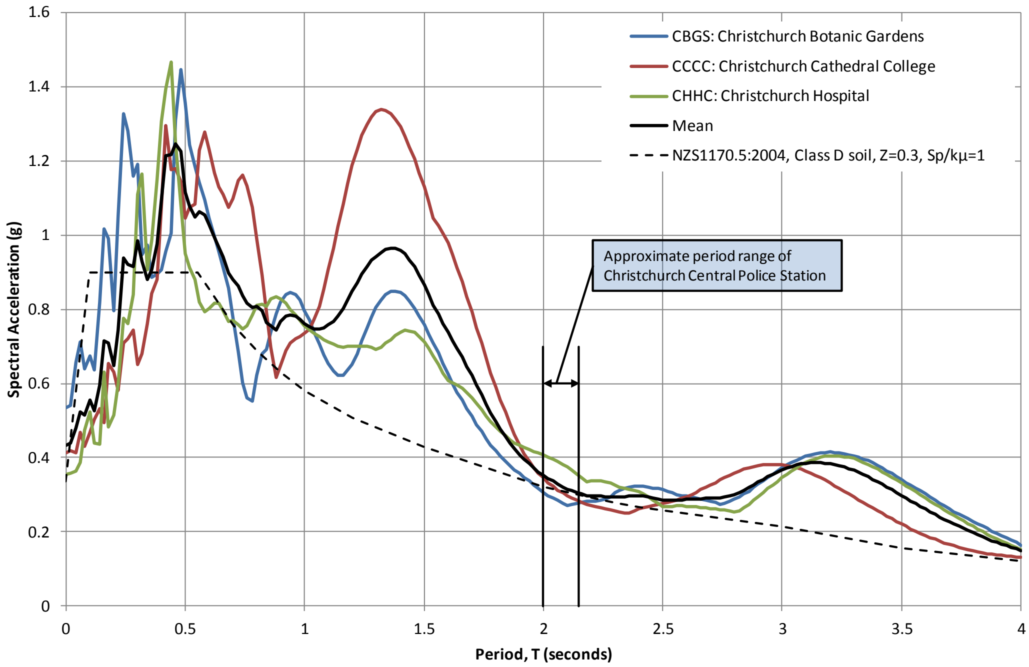

Figure 12: 22nd February 2011 N90E earthquake components for Christchurch CBD compared to NZS 1170.5 design spectrum

The capacity of the Christchurch Central Police Station has been investigated by applying equivalent static load distributions based on the current design spectrum for the site (NZS 1170.5 [13], class D soil, Z = 0.3). Application of the full elastic loads corresponding to this spectrum (i.e. $\mu = 1$, $S_p = 1$) indicates that the probable nominal capacity of the beams is approximately 30% of the elastic demand. This implies a ductility demand of between 2.25 and 3.0 depending on the value of the structural performance (S_p) factor that is applied to the structure. The figures discussed here exclude the influence of flanges to the beams, which increase the negative moment capacity by approximately 20% and would somewhat reduce the ductility demand. It is important to note that the similarity of demands between the current design spectrum and the recorded earthquake spectra suggests that the Christchurch Central Police Station should have experienced a ductility demand of the order of $\mu = 2.0$ during the February earthquake.

7.2. Structural response

Returning to the aforementioned reports of damage inflicted on the Christchurch Central Police Station, it appears that the level of damage that occurred is of the same order as would be expected based on the ductility demands estimated in section 7.1. As noted an appendix describing an exterior survey of the building reported cracks at beam-column interfaces of greater than 2 mm width in multiple locations. Figure 13 shows an elevation of the north face of the structure adapted from this appendix, while Figure 14 and Figure 15 show associated photos of beam cracking. It is difficult to draw precise conclusions regarding the deformation demands indicated by these cracks due to the imprecise nature of the information. However, moment-curvature analysis confirms that the occurrence of a 2 mm wide crack would coincide with a curvature of approximately 12 rad/km (see Figure 16). The yield curvature of the beam would be approximately 4.5 rad/km, and hence the curvature ductility in the beam would be of the order of $\mu_\phi = 3$. This is likely to correspond to a structural displacement ductility of approximate $\mu = 1.5$ [15].

7.3. Influence of other structural aspects on performance

The minor discrepancy between the expected ductility demand on the structure ($\mu \approx 2.0$) and the ductility demand estimated from damage ($\mu \approx 1.5$) is most likely due to the additional damping (through damage) that would have been provided by the “non-structural” precast elements positioned around the stair/lift core of the Christchurch Central Police Station. The 25 mm separation provided between these elements and the primary structure is sufficient to allow approximately 0.75% interstorey drift, which is approximately equal to the yield drift of the frame but not sufficient to accommodate ductility. The initial stiffness of the structure is therefore likely to have been largely unaffected by the presence of the non-structural components, but the large displacement response of the structure would have been reduced by contact between the precast panels and the primary structure.

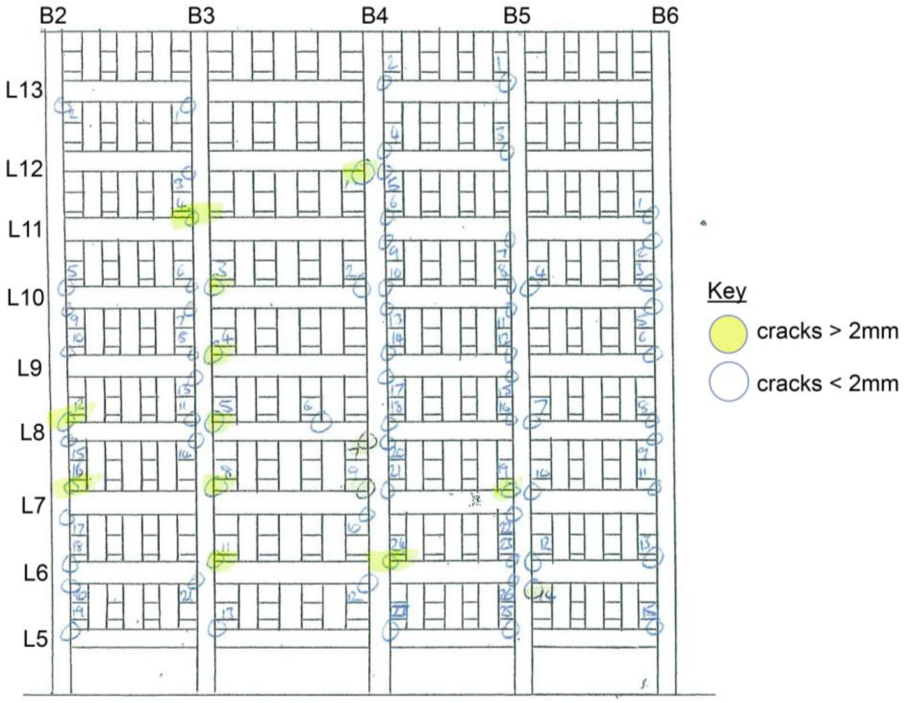

Figure 13: North elevation showing locations of cracking (adapted from Appendix D [11])

Figure 14: Example of beam cracking (Grid B3 Level 6, from [11])

Figure 15: Example of beam cracking (Grid B2 Level 7, from [11])

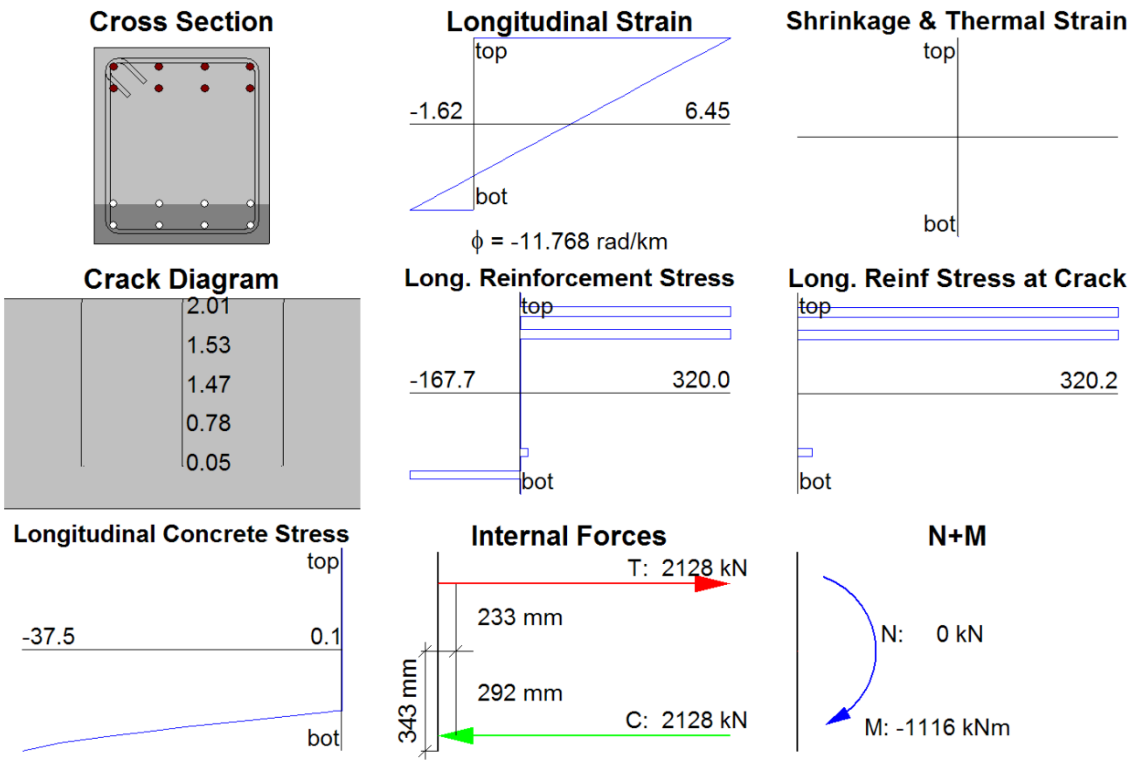

Figure 16: Moment-curvature results for a typical beam obtained using Response 2000 [16]

It is felt worthy to note that at the outset of this review it was anticipated that the existence of the deep stiff waffle raft slab may have aided the performance of the Christchurch Central Police Station by lifting and hence relieving tension forces in the columns supporting the tower. However, during assessment it became evident that this effect would not have had a significant effect on the structure. The existence of the continuous raft slab is likely to have enhanced the performance of the structure with respect to preventing or minimising differential settlement due to liquefaction in the vicinity of the structure.

8. Issues arising from review

There do not appear to be any structural or geotechnical issues arising from the review of the Christchurch Central Police Station.

A pre-earthquake structural assessment of the building [2] indicated confusion amongst practicing structural engineers regarding the manner in which existing buildings should be assessed. The review initially concluded that the Christchurch Central Police Station was “earthquake prone” with respect to design requirements for “ordinary” structures (using the pre-earthquake “Z = 0.22” earthquake loads for Christchurch). However, in a revised summary the conclusion was changed to find that the building was not earthquake prone. The revised summary is brief and does not give an indication of the performance level expected. The confusion noted by the authors of the assessment suggests attention should be paid to enhancing the clarity of requirements for assessment and retrofit of existing structures.

9. Conclusions

The performance of the Christchurch Central Police Station during the 22nd February 2011 earthquake was approximately as would have been expected based on the assessment of the structure presented in this report. This assessment showed that the structure was highly likely to behave in a desirable “strong column, weak beam” manner, and that the ductility demand placed on the structure by current (Z = 0.3) design earthquake loads would be approximately $\mu = 2.25$ to $\mu = 3.0$. It was further concluded that the demands placed on the structure by the 22nd February 2011 earthquake would be approximately equal to the current design loads, and that the performance of the structure during the earthquake was indicative of a ductility demand of approximately $\mu = 1.5$. The discrepancy between the expected and actual ductility demands was concluded to have been the result of non-structural precast concrete elements providing additional damping to the structure during large displacement cycles.

The satisfactory performance of the Christchurch Central Police Station lead to the conclusion that no structural or geotechnical issues arose from this review. However, it was noted that previous assessors of the structure had noted that the current requirements for assessment of existing structures were unclear and lead to confusion. It is recommended that these procedures be clarified to ensure consistent assessment of existing structures is achieved.

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