Report for

Detailed Seismic Analysis
Colonial House
258 Stuart St

Spectra Limited
PO Box 613
Dunedin 9054

Job No: 13700
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HANLON & PARTNERS Ltd.

CONSULTING STRUCTURAL & FIRE ENGINEERS
BI Chisholm BE MIPENZ IntPE CPEng (Civil & Structural)

219 HIGH STREET, DUNEDIN
Ph: 03 4777-475   Fax: 03 479 2597
email: office@hanlons.co.nz

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Report Compiled:
Lyndsay McGrannachan
Structural Engineer
BE(Hons) Civil, BSc, PG Dip, CPEng 242279, MIPENZ

Section A Executive Summary

Detailed seismic analysis of Colonial House, 258 Stuart St has shown that the building components have sufficient capacity to resist the forces generated in the building by the design earthquake for Dunedin from the Earthquake Actions New Zealand Standard 1170.5 2004.

Consequently Colonial House qualifies for a Percentage New Building Standard (%NBS) of 100%

Section B Building and Analysis

Our review is based on copies of the original 1985 Building Consent drawings. The geotechnical conditions at the site have been taken as Type C (that is neither rock nor deep and soft) in accordance with NZS1170.5 New Zealand Earthquake Loadings Standard. The choice for using Type C soils is from experience of foundation construction in this area and bore logs from construction drawings of other buildings in the area. The GNS geological map describes the geology for the area as ‘Olivine basaltic rock and flows from the second main eruptive phase of the Dunedin Volcano.

The building is a 5 storey combined shear wall and transverse concrete moment frame with a steel frame roof. The internal columns are supported on 2.2m x 2.2m square concrete foundation pads, the exterior wall and pilasters are supported on a foundation ground beam. The carpark floor is cast in-situ concrete slab, the remaining floors are prestressed rib beams with a 75mm reinforced slab overlay.

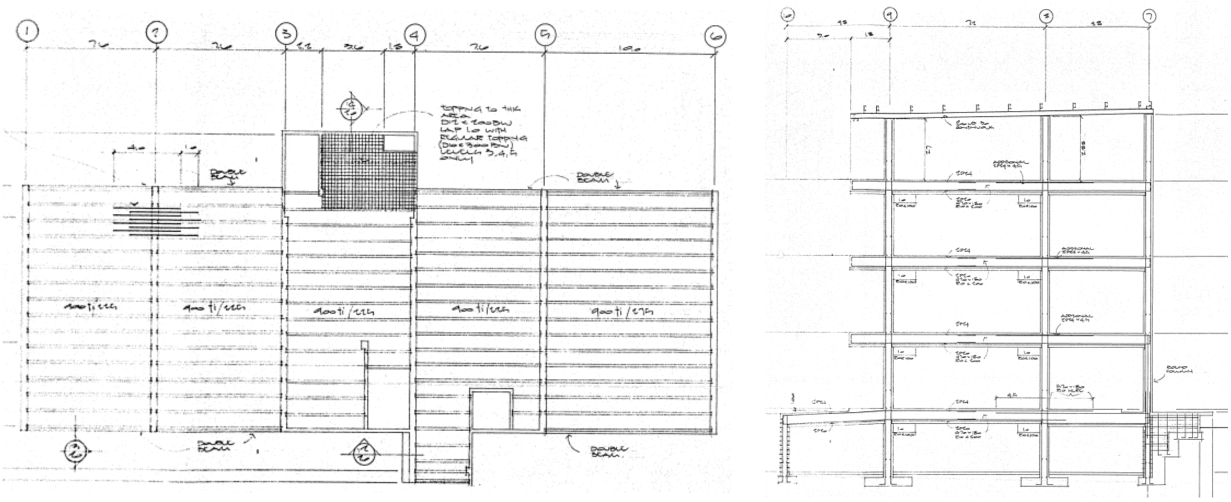

Figure 1 : Left; 3nd floor plan showing the building grid layout referred to in the analysis results and the locations of the lift and stair service cores within the building and external stairs at the western end of the building.

The structure was modelled using structural analysis software called ETABS and subjected to the loading regimes set out in AS/NZS1170, which is the current New Zealand design loadings Standard.

The building was analysed using the ‘modal response spectrum method’ as set out in NZS1170.5 Earthquake Actions. The design actions were established using a structure ductility of $\mu = 1.5$ in accordance with the NZSEE document “*Assessment and Improvement of the Structural Performance of Buildings in Earthquakes”* The post elastic deformation of the frames was a 'mixed‘sidesway’ mechanism where plastic hinges form only at the faces of the exterior columns, at the top and bottom of the interior columns and at the column bases. The vulnerability of this configuration to ‘soft storey’ collapse means the building can only be classed as ‘nominally ductile’ and needs to be able to resist the almost the full design earthquake load and remain in the elastic state to achieve 100%NBS.

The building model was provided with material properties based on expected strength, which is higher than dependable or specified strength. This is the accepted procedure when analysing an existing building for resisting earthquake induced forces.
The expected strength of concrete was assumed to be 50% higher than the specified strength. The concrete stiffness used for design was increased by 30% to match the expected stiffness. Reinforcing steel expected yield strengths were taken as being 8% higher than specified strengths as per standard practice.

The concrete member stiffness properties were modified to account for cracking. The effective stiffnesses for beams, columns and walls were taken as defined in the New Zealand Standard; NZS3101 Concrete Structures Table C6.6 considered to be 40%, 50 % and 45% of gross sections, respectively.

Transfer of the horizontal forces to vertical load resisting components is determined by the stiffness of the floor and its consequent ability to act as a diaphragm. Diaphragm stiffness was reduced to 40% of that calculated from the gross section and concrete properties to represent the stiffness of the diaphragms after flexural cracking occurs.

Springs with stiffness representative of the soils to be found at the corresponding depth at the site were applied to the base and sides of the foundation pads to model the vertical and horizontal resistance of the subsoils respectively.

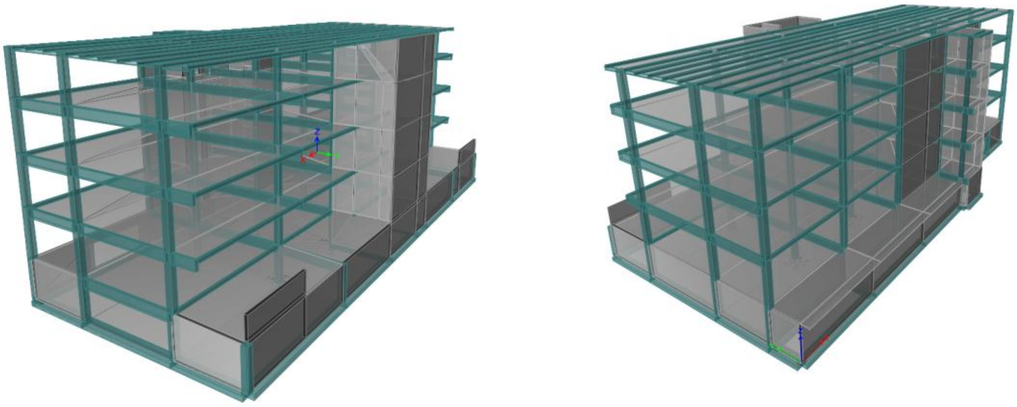

Figure 2: Model of building from ETABS structural analysis software

Dunedin has a low earthquake risk when taken in a New Zealand context with approximately one third of the risk associated with a building in Wellington. All buildings in New Zealand are required to be designed to a 500 year return period earthquake, unless modified for buildings that may contain crowds or particularly important or unimportant buildings. A five hundred year return period earthquake in Dunedin is significantly less severe than the 500 year return period earthquake in more at risk parts of New Zealand. This is reflected in the earthquake induced forces that are required to be applied to buildings in Dunedin.

The minimum code requirements are to preserve life and to prevent collapse rather than to ensure further use of the building. It is possible that even if the structure remains standing, that there may be a large amount of damage and the structure may be on a lean and require demolition after the earthquake. Design according to current codes is to ensure “life-safety” rather than to protect the building for further use.

258 Stuart St is a relatively low building and as such will not sway significantly under earthquake loading. The full height structural walls provide the only resistance to lateral forces in the building longitudinal direction. In the building transverse direction lateral forces are resisted by a combination of structural walls and moment resisting frames.

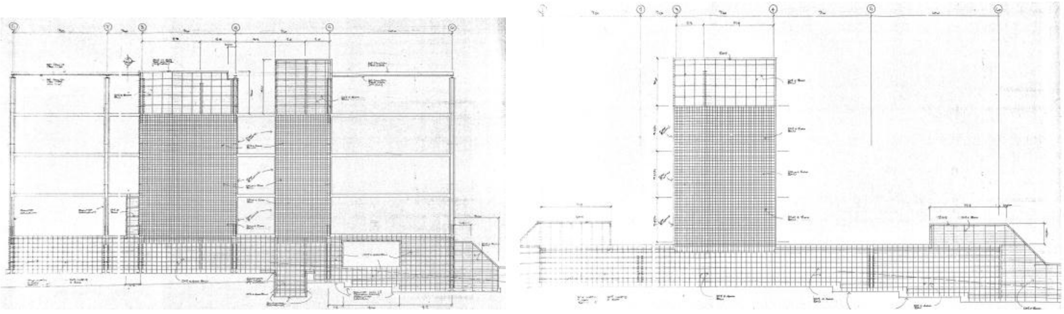

Figure 3: Showing the concrete structural walls that resist building lateral forces.

Section C Results

Analysis results on the model indicate the most stressed representatives of repeated members throughout the building under the two earthquake loading directions. Capacity demand ratios have thus only been calculated for the most 'at risk' building elements not for every element in the structure. The exception to this is evaluation of column and wall flexural capacity where axial load enhances the ability of the component to resist flexure and tension reduces it. Analysis of every member at every level under worst case loading was thus necessary.

The capacity to demand ratio (c/d ratio) of the various members throughout the building gives an indication of which members will fail before the others under a set loading, eg the 1170.5 design earthquake loading. A capacity/demand ratio greater than 1 means the member will not fail under that loading and less than 1 means that failure will occur. Members with a lower c/d ratio will fail before those with a higher c/d ratio.

Table 1: Building Element Capacity to Demand

Element	**Failure mode**	**Capacity**	**Demand G+0.3Q+EQ**	Cap/Demand
Frame beam B-28 Levels 4 & 5	Flexure	192 kNm	187 kNm	1.03
Structural wall-Pier 8	In plane flexure	15754 kNm	10281 kNm	1.5
Structural wall-Pier 1	In plane shear	913.6 kN	582.03	1.6
Foundation pad	Flexure	481 kNm	289 kNm	1.7
Foundation pad	Shear	752 kN	419 kN	1.8
Frame beam 15 Level 2	Shear	250 kN	140 kN	1.8
Floor slab ties into beams	Shear	368 kN/m	187kN/m	2.0
Beam column joint	Shear	1973 kN	324 kN	3.4
Column C110	Shear	65.2 kN	289 kN	4.8
Exterior Column C98 level 5	Flexure	116.7 kNm	22.9 kNm	5.1
Foundation pad	Bearing	500+ kPa	325 kPa	> 1

1. Inter-story drift is the difference in lateral deflection between two adjacent stories of a building subjected to lateral loads.

The accurate estimation of inter-story drift ratio and its distribution along the height of the structure is very critical for seismic performance evaluation purposes since the structural damage is directly related to the inter-story drift ratio.

The current provisions in NZS1170.5 limit inter-story drift to 2.5% of the storey height between any two adjacent floor levels.

The maximum interstorey drifts in 258 Stuart St under current Standard earthquake loading are around 0.4%; well within the 2.5% limit between any two adjacent floor levels from NZS1170.5. This is a reflection of the low height of the building and Dunedin's low earthquake demand.

Table 2: Displacement and interstorey drift in building transverse (y direction) earthquake.

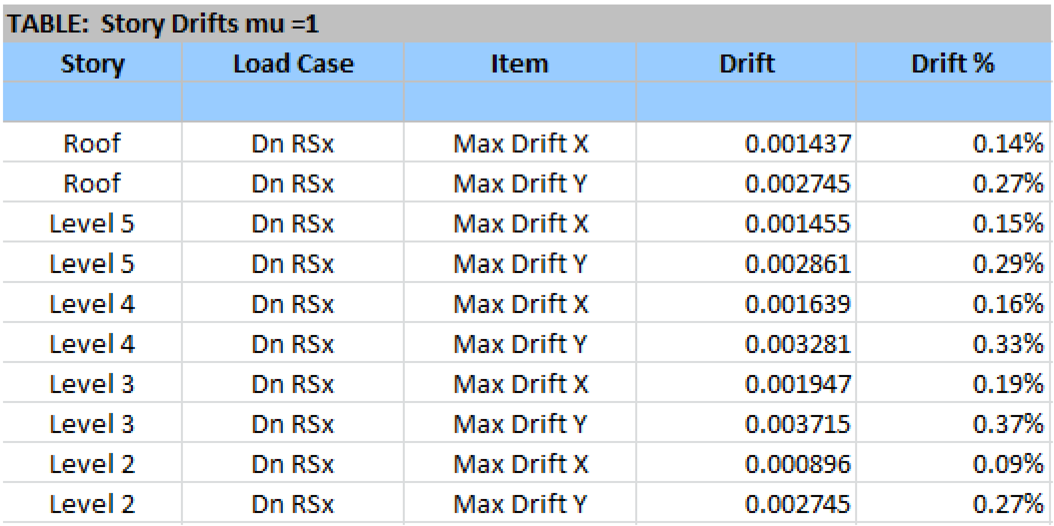

TABLE: Story Drifts mu =1

Story	Load Case	Item	Drift	Drift %
Roof	Dn RSx	Max Drift X	0.001437	0.14%
Roof	Dn RSx	Max Drift Y	0.002745	0.27%
Level 5	Dn RSx	Max Drift X	0.001455	0.15%
Level 5	Dn RSx	Max Drift Y	0.002861	0.29%
Level 4	Dn RSx	Max Drift X	0.001639	0.16%
Level 4	Dn RSx	Max Drift Y	0.003281	0.33%
Level 3	Dn RSx	Max Drift X	0.001947	0.19%
Level 3	Dn RSx	Max Drift Y	0.003715	0.37%
Level 2	Dn RSx	Max Drift X	0.000896	0.09%
Level 2	Dn RSx	Max Drift Y	0.002745	0.27%

Table 3: Displacement and interstorey drift in building longitudinal (x direction) earthquake.

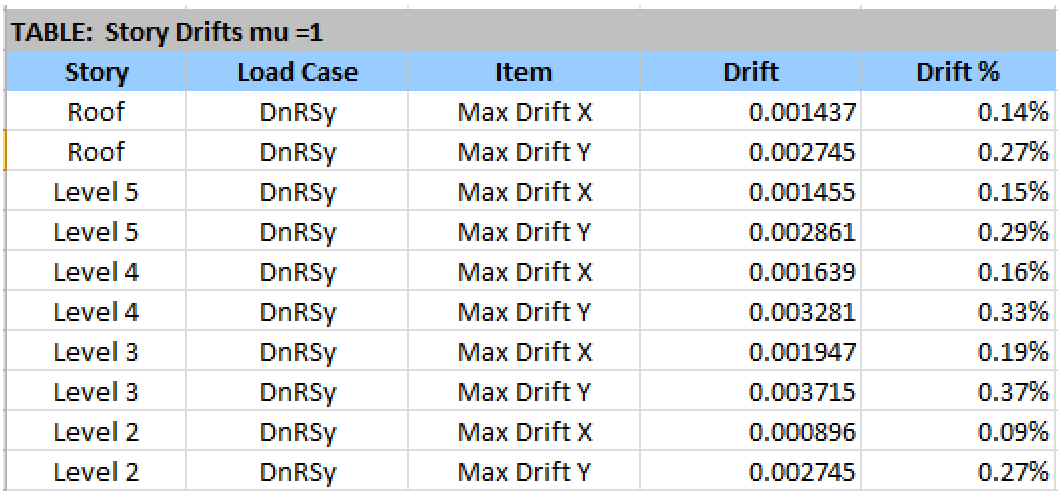

TABLE: Story Drifts mu =1

Story	Load Case	Item	Drift	Drift %
Roof	DnRSy	Max Drift X	0.001437	0.14%
Roof	DnRSy	Max Drift Y	0.002745	0.27%
Level 5	DnRSy	Max Drift X	0.001455	0.15%
Level 5	DnRSy	Max Drift Y	0.002861	0.29%
Level 4	DnRSy	Max Drift X	0.001639	0.16%
Level 4	DnRSy	Max Drift Y	0.003281	0.33%
Level 3	DnRSy	Max Drift X	0.001947	0.19%
Level 3	DnRSy	Max Drift Y	0.003715	0.37%
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Level 2	DnRSy	Max Drift Y	0.002745	0.27%

2. Provision and maintenance of load paths for internal forces within a diaphragm are a principal concern in earthquake resistance. The performance of the vertical lateral force resisting structural system is dependent on the continuing function of the floor diaphragms during prolonged or extreme seismic loading. Ineffective and brittle connections between floor diaphragms and the service core were in part responsible for the collapse of the CTV building in the February 22 Christchurch earthquake.

The floors in the building above ground level are precast, prestressed rib beams with timber plank infill between the beams and a 75mm topping slab over. The topping slab is tied into the walls and beams with deformed bar starters that lap with the topping reinforcement which is D10 bars at 300mm each way. This type of floor has been shown to be susceptible to loss of composite action between the precast ribs and topping slab because of delamination between of the topping slab as a result of the transfer of diaphragm horizontal forces to the vertical lateral force carrying components of a building.

There are two reasons why this building should be safe from floor delamination and consequent loss of gravity support for the floors:

- The building will respond elastically when subjected to forces up to the Dunedin design earthquake load, meaning the beams will not elongate as they form plastic hinges and 'unzip' the floors as the topping buckles.
- The topping slab reinforcing is deformed rod rather than the hard-drawn brittle reinforcing mesh typically found with this type of floor which is more susceptible to breaking as it laps with the starter bars from the beams or the walls as occurred in the CTV building in the Christchurch earthquake.

There was a recognition from the designers of this building that the protruding floors on the north-east side of the building containing a stairwell and service duct would be subject to large diaphragm shear flow concentrations around the openings. Figure 4 above shows the increased reinforcing density required to resist the diaphragm shear forces concentration shown on the right from the analysis software.

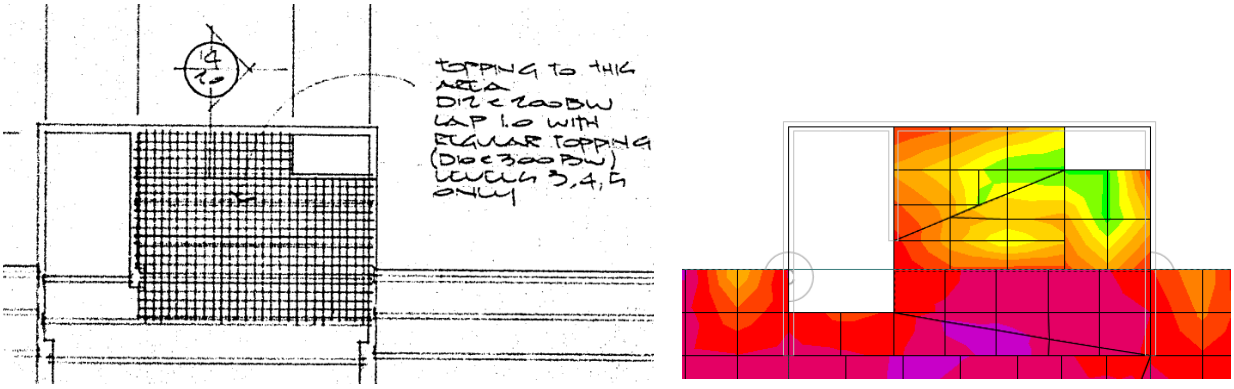

Figure 4: Showing increased reinforcement density, placed to resist diapragm shear foce concentrations around openings, shown on the right.

3. The main lateral force resistance system in this building is via the stiff structural walls. In resisting the inertial forces the building diaphragms and vertical lateral load resisting structures must deform. As the walls deform the stiff diaphragms move with them and being connected to the columns via the beams the columns must also displace to accommodate the interstorey drift. This displacement induces flexural and shear forces in the columns and beams. Analysis of beams and columns capacity compared to earthquake demand shows that they will remain in an elastic state as they deform, that is the reinforcing steel in the beams and columns will not yield and the beams and columns will remain serviceable post earthquake.

4. Being separated on all sides from surrounding buildings means that the building is not at any risk of damage from pounding between buildings responding differently to earthquake induced forces.

5. A potential critical structural weakness that buildings may possess, that has been brought to the forefront by the Christchurch earthquakes, is the vulnerability of the stairs to collapse preventing egress from the building even though it may remain standing post-earthquake.

We have assessed the performance of the stairs as recommended by the Department of Building & Housing in accordance with the Report to the Royal Commission on Stairs and Access Ramps between Floors in Multi-storey Buildings.

The stairs are steel section construction and are attached to the concrete floor topping slap and service core walls at the stair landings with 6mm cleats that are anchor bolted to the concrete members. The 6mm cleats shown in Figure 5 below will flex and possibly yield in a ductile manner when subjected to displacements between the floors in the order of the interstorey drift displacements at Dunedin design earthquake levels.

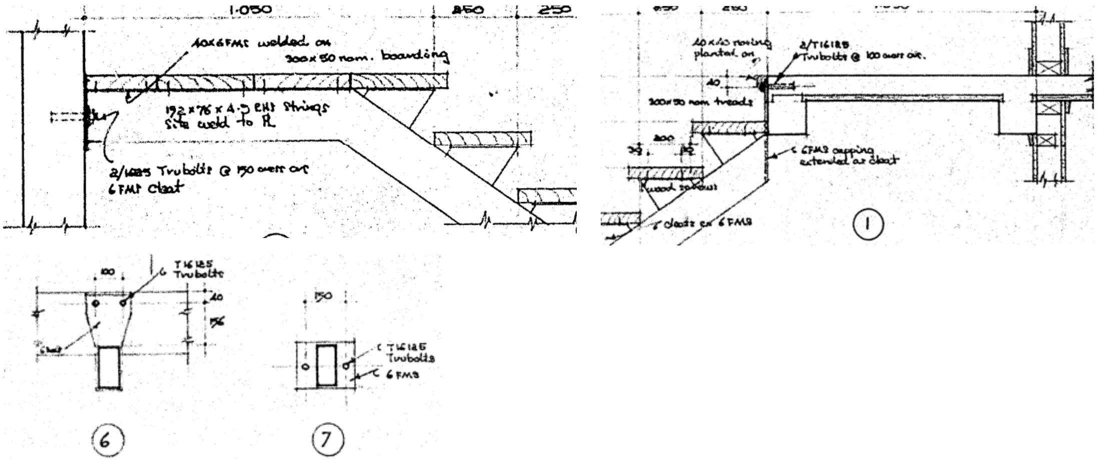

Figure 5: Sections of the steel RHS stairs and their attachment method to the main structure of the building. Displacement ductility will be provided by flexure and yielding of the attachment cleats.

The steel stairs will be ductile enough to allow distortion without collapse and allow egress from the building in the event of emergency.

Section D Glossary

Critical Structural Weakness (CSW): a possible collapse hazard in a building. A significant vulnerability feature.

Plastic Hinge: used to describe the deformation of a section of a beam where plastic bending occurs. Plastic bending is the deformation of a material undergoing non-reversible changes of shape (yielding) in response to applied forces.

Ductility: a measure of a material's ability to undergo appreciable plastic deformation before fracture and thus to continue to carry load after yield and before fracture..

Bending moment: The product of a force and a lever arm. A force acting at a distance e.g. torque is a moment force as is a lever arm over a fulcrum

Shear: to deform or fracture as a result of excess torsion or transverse load

In-plane, Out-of-plane: bending or shearing motions which are respectively in the plane of the element and perpendicular to the plane.

Flexure: The act of bending

Mechanism: A system of elements whose connections are hinges and therefore cannot resist any loads applied to it.

Fundamental period of vibration: The elapsed time, in seconds, of a single cycle of oscillation. The inverse of frequency.

Out of Phase: The state where a structure in motion is not at the same frequency as the ground motion; or where equipment in a building is at a different frequency from the structure.

Spectra: A plot indicating maximum earthquake response with respect to natural period or frequency of the structure or element.

Cast in situ: Concrete cast in its intended location.

Balustrade: An architectural barrier that is designed to provide building occupants with safety from falling.

%NBS: (Percentage New Building Score): Lesser of all the Capacity to Demand ratios of building elements that constitute Critical Structural Weaknesses for a building. The Capacity of a building element is evaluated in accordance with the appropriate current New Zealand Standard for the element material. The Demand is the earthquake induced force or displacement on the element ascertained from analysis in accordance with NZS1170.5 2004 the current New Zealand earthquake loadings Standard.

Section E Bibliography

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