Christchurch City Council

Linwood Library & Service Centre Building
PRO 1982 001

Detailed Engineering Evaluation
Quantitative Assessment Report

OPUS

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Linwood Library & Service Centre Building

Detailed Engineering Evaluation

10 Cranley Street, Linwood

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Summary

Linwood Library
PRO 1982 001

Detailed Engineering Evaluation
Quantitative Report - Summary
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Background
This is a summary of the quantitative report for Linwood Library, and is based on the Detailed Engineering Evaluation Procedure document (draft) issued by the Structural Advisory Group on 19 July 2011.

Building Type
The building is single storey steel portal frame with tilt-up concrete cladding panels. It was constructed circa 1993.

Damage Observed
Earthquake damage comprised yielding of the roof bracing, minor to moderate cracking of concrete panels and collapse of the suspended ceiling. The building was further damaged in a fire in March 2012.

Critical Structural Weaknesses
There are no critical structural weaknesses.

Indicative Building Strength
The building is assessed to be 25%NBS based on the capacities of the steel portals and diagonal roof bracing. This is the as-designed rating prior to the earthquake damage and fire damage.

Contents

1 Introduction

Opus International Consultants Limited has been engaged by the Christchurch City Council (CCC) to undertake a detailed engineering evaluation of the Linwood Library & Service Centre building, located at 10 Cranley Road, Linwood, Christchurch.

A limited quantitative assessment was recommended in order to determine whether the building has a seismic rating of at least 67% NBS, which is the recommended performance standard for existing buildings [1].

The scope of the quantitative assessment is as follows:

1. An analysis of the seismic capacity of the precast walls on grids 1 and 3 for loads in the north-west to south-east direction for to determine the % NBS.
2. An analysis of the seismic capacity of the precast façade walls on the north-west elevation for seismic loads to determine the % NBS.
3. An analysis of the seismic capacity of the connections between the precast concrete walls and the portal frames for seismic loads to determine the % NBS.
4. An analysis of the seismic capacity of the roof bracing.
5. An analysis of the steel portal frames.

2 Building Description

The Linwood Library and Service Centre is a single level structure located with a street frontage to Cranley Street. Cranley Street is of short length with a 90 degree corner, and links with Linwood Ave to the south-west and Chelsea Street to the south-east. The building is located on the bend and is orientated perpendicular to the streets. For the purposes of this report we refer to the direction parallel to Chelsea St as the north-east to south-west direction and the direction parallel to Linwood Ave as the south-east to north-west direction.

The original building was constructed in 1993. Some minor internal office alterations took place in 2004.

The building is a single level hybrid steel portal frame and precast perimeter concrete wall building. The building is 29 metres long (south-east to north-west) by 28 metres wide (north-east to south-west) in plan dimension.

3 Seismic Load Resisting System

Loads and the existing structural layout have been assessed by referring to the 2008 record drawings by Christchurch City Council and the 1993 record drawings by O'Loughlin Taylor Spence.

Seismic forces in the north-west to south-east direction are generated by the response of the roof and external concrete wall panel masses. The load path is from the diagonal steel roof plane bracing located between grids B and C, into the concrete wall panels located on the grids 1 and 3, and into the foundations.

The roof bracing comprises small section 40x40x5mm steel angles and these are detailed on the drawings as being notched where they intersect, significantly reducing their strength.

There is no direct load path between the roof bracing and the panels, rather there is an indirect path via the purlins nearest to the portal knees to the portal columns and then via single M16 bolt inserts to the wall panels. The wall panels are anchored into an unreinforced floor slab thickening with threaded rods. The panels have large window openings forming deep beams/column frames that resist the in-plane shears.

There is a large concrete façade or colonnade on the north-west face which stands forwards of the main structure. The roof of the library extends to the façade creating an external sheltered area. The roof purlins are bolted to and retrain the tops of the façade panels for out-of-plane loads, with the exception of the two end bays which stand clear of the building and are not directly connected to it. These parts of the façade rely upon the rocking resistance of the end columns for stability. In plane forces are resisted by frame action between the colonnade beams and columns.

4 Seismic Forces

The following criteria from the earthquake loadings NZS 1170.5 [2] were used to determine the site loading spectrum:

Table 1: Earthquake Loadings Criteria

Parameter	Value	Comments
$C_h(T)$	3.0	Class D soil, $T_1 < 0.5$secs
Z	0.3	Increased seismic hazard factor for Christchurch
R	1.0	Importance level 2, normal building
N(T,D)	1.0	

For the purpose of the analyses carried out in this assessment it was assumed that the bracing wall panels were rigid in-plane so that the forces input to the roof diaphragm diagonal bracing were not amplified by the in-plane response of the walls. This is considered to be a reasonable assumption in the circumstances, although it may result in the bracing forces being somewhat under-estimated. The face-load forces on fixings of the panels to the bracing system were analysed as parts in accordance with NZS 1170.5.

The forces in the various components were calculated in accordance with the ductility criteria shown in Table 2 below:

Table 2: Ductility Factors

Component	Ductility Factor μ
Roof plane steel bracing	1.25 (NZS 3404 [4] category 3,
Steel Portal Frame (Flexure)	1.25 (NZS 3404 [4] category 3
Wall panels in-plane shear and flexure	1.25 (NZS 3101 [5], nominally ductile)
Fixing of wall panels to columns (welds and anchors)	1.25
Fixing of wall panels to columns (steel plate in flexure)	2.0
Rocking of façade end columns	2.0

While flexure in the wall panels is a potentially ductile mechanism, in this case the walls are lightly reinforced so that inelastic deformation is likely to be concentrated at one crack rather than spreading, leading to high reinforcement strains and potentially low-cycle fatigue fracture.

In some cases a higher ductility factor than 2.0 could be appropriate for rocking response. However this will result in increased rocking displacements, leading in this case to damage at the connection of the façade with the building.

5 Material Properties

The following material properties were used in the analyses:

Table 3: Material Properties

Material	Nominal Strength
Structural steel	f_y = 250MPa
Reinforcing steel	f_y = 430MPa
Concrete	f'_c = 40MPa

6 Analysis Results

The equivalent static load method was used to analyse the forces in the components of the north-south bracing system. The results of the analysis are reported in Table 4 below as %NBS, where for the components:

%NBS = the reliable strength ÷ new building standard force

Table 4: Summary of Seismic Performance

Component	Action	Seismic Rating % NBS
Steel Portal Frame	Flexure	24%NBS
Wall panels on grids 1 and 3 (force in-plane)	Flexure	>100%NBS
"	Shear	>100%NBS
"	Overturning	62%NBS
Wall panels on grids 1 and 3 (force out-of-plane)	Flexure	82%NBS
"	Shear	>100%NBS
Bolted fixing of grid 1 and 2 wall panels to portal frames	Tension (out of plane force)	60%NBS
"	Shear (in plane force)	>100%NBS
Façade panels (force in-plane)	Flexure	67%NBS
"	Shear	>100%NBS
Façade panels (force out-of-plane)	Flexure	>100%NBS
Façade panels (force out-of-plane)	Shear	>100%NBS
Façade and rear wall panel connections to roof bracing	Tension	>100%NBS
Façade end columns (forces out of plane)	Rocking	48%NBS
Diagonal roof bracing	Tension	25%NBS

7 Performance in the 22 February 2011 Christchurch Earthquake

There is a Geonet earthquake strong motion recording station (PRPC) in Pages Road approximately 1km from Linwood library (see Figure 1). It can be assumed that the ground motions recorded at the Geonet station were similar to those recorded at the library site. It is therefore possible to compare the loads applied to the building by this earthquake with the current code new building standard loads used for this assessment.

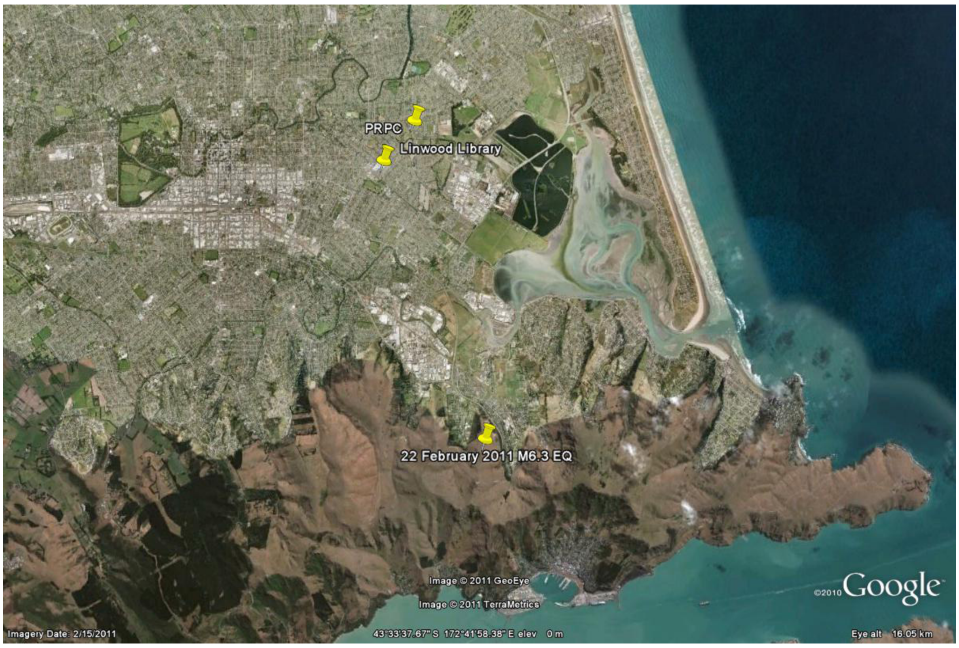

Figure 1: Relative locations of the Linwood Library and Service Centre, Geonet station PRPC and the epicentre of the Christchurch earthquake

Figure 2 shows the 5% damped response spectra for ground motions from the 22 February magnitude 6.3 Christchurch earthquake recorded at the PRPC station, along with the current design standard spectrum.

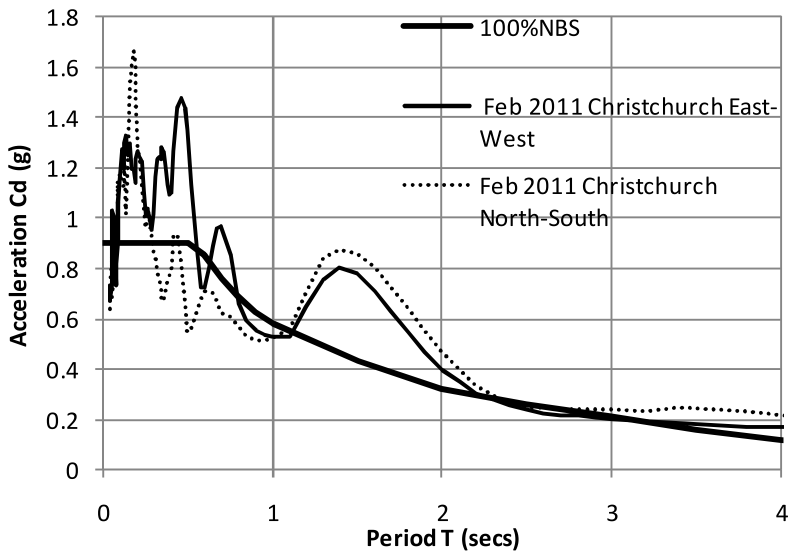

Figure 2: Acceleration response spectra from ground motions recorded by Geonet station PRPC near to Linwood Library, compared with the current design standard 100%NBS acceleration spectrum for the site

The north-south natural period of vibration of the building is in the 0.15 to 0.25 second range. It can be seen from Figure 2 that the loads experienced were similar to or in excess of the code loads in this period range.

The building sustained moderate structural damage in the Christchurch earthquake, and total collapse of suspended ceilings. The structural damage included tension yielding of the roof bracing and cracking of concrete wall and colonnade panels.

8 Geotechnical Information

A desk study was carried out to assess the site at 10 Cranley Street, Linwood, Christchurch. No geotechnical investigations were undertaken for this assessment. The building is located on flat-lying ground in the eastern Christchurch suburb of Linwood. The area is underlain by marine/estuarine silts and sands of the Christchurch Formation, which are underlain by Riccarton Gravels (Brown and Wilson, 1998; IGNS, 1992; IGNS, 2008; Environment Canterbury well database).

Deep boreholes in Christchurch show the alluvial and estuarine deposits exceed 200 metres depth (Brown and Wilson, 1988). The site is therefore classified as subsoil Class D (deep soil) in accordance with NZS 1170.5:2004.

The closest known active fault to the site is the Port Hills Fault; however this lies approximately 4 km to the south of the site and although it ruptured during the Christchurch earthquake on 22 February 2011 it did not rupture the ground surface. Therefore the fault rupture hazard at the site is considered to be very low.

The liquefaction hazard at the site is high, as the area around the building is underlain by at least 20 metres of silt and fine sand (Tonkin and Taylor, 2011a; Environment Canterbury, 2004).

However strong ground shaking during the Christchurch earthquake in February did not cause liquefaction (Tonkin and Taylor, 2011a; Environment Canterbury, 2004).

Following the Canterbury earthquake sequence, land in the green zone was divided into three technical categories. Each category describes the level of land damage (liquefaction induced subsidence) predicted in future earthquakes, and guidance is given for the repair and rebuild of structures (Department of Building and Housing, Nov 2011). This guidance has been used primarily for residential properties, therefore in accordance with the revised guidelines this site is classified as being Urban Nonresidential. However, based on the assessment of the surrounding properties, it can be assumed that this site would be Technical Category 2 (TC2). This means that enhanced foundation solutions are required in the rebuild and repair of buildings; standard NZS 3604 solutions are no longer viable to satisfy Building Code requirements.

A more detailed evaluation will be required at detailed design stage.

9 Evaluation of Results

The major deficiencies relative to the new building standard are the strength of the roof bracing (25% NBS), the rocking resistance of the end façade columns (48% NBS), the rafters of the portal frames require braces to prevent lateral torsional buckling (24%NBS) and the effectiveness of the wall panels (62%NBS). These deficiencies have contributed to the damage that was observed following the Christchurch earthquake, i.e. loose, yielded roof bracing, and cracking in the colonnade concrete panels. It should be noted that that yielding of the bracing and foundation rocking are expected and acceptable response mechanisms given the magnitude of shaking experienced at the site. However it is probable that the amount of damage to the building would have been less if it had complied with current design standards.

The building design and detailing generally gives the impression of having been targeted at the minimum code requirements of the day. As an example, the floor slab is unreinforced and the thickening foundation has only limited reinforcement in places. A detailed inspection of the floor slab for damage has not yet been carried out.

Although the wall panels in the longitudinal direction could provide the capacity required, the foundations will not provide the stability between gridlines D and E for the panels to be effective. Therefore a separate analysis was carried out to account for these panels overturning. The panels within the steel frame will provide more overturning resistance because they are fixed to the concrete encased steelwork but will pick up more stress as a result. However, the fixing of the wall panels on grids 1 and 3 to the steel framing lack robustness in view of their role in supporting both out of plane and in plane forces. A braced bay in the longitudinal direction is strongly recommended given the unreinforced slab and foundations. The options for this are steel cross braces, a panel thickening or window infills combined with angle connectors for the panels and concrete encased stanchions.

A continuous eaves member connected to the panels is required to improve the out of plane capacity.

The roof bracing has become elongated and cannot be considered as having load bearing capacity. Replacement of the roof bracing is required in all cases.

10 Conclusions

We conclude as follows:

1. The seismic rating of the building is approximately 24% of current building code new building standard.
2. The following improvements are required to improve the rating to at least 67%NBS:
    - Strengthen the roof plane diagonal bracing;
    - Provide a braced bay panel to grids 1 and 3;
    - Provide tie members at the eaves between the portal frames connected to the wall panels on grids 1 and 3;
    - Increase the rocking resistance of the two colonnade end columns;
    - Include lateral torsional buckling braces to portal frame rafters.

11 References

[1] *Guidance on Detailed Engineering Evaluation of Earthquake Affected Non-residential Buildings in Canterbury, Part 2 Evaluation Procedure*, draft prepared by the Engineering Advisory Group, Revision 5, July 2011.

[2] *NZS 1170.5:2004, Structural Design Actions, Part 5 Earthquake Actions New Zealand*, Standards New Zealand.

[3] *NZS 3404:1997, Steel Structures Standard*, Standards New Zealand.

[4] *NZS 3101:2006, Concrete Structures Standard*, Standards New Zealand.

Appendix A – CERA DEE Spreadsheet

Detailed Engineering Evaluation Summary Data V1.14

Location

Building Name:	Linwood Library	Reviewer:	Robert Davey
Unit / No: / Street		CPEng No:	17912
Building Address:	Cranley St	Company:	Opus International Consultants
Legal Description:		Company project number:	6-QUCCC.22
		Company phone number:	03-3635400
GPS south (Degrees / Min / Sec):	43 / 32 / 2.20	Date of submission:	Sep-13
GPS east (Degrees / Min / Sec):	172 / 40 / 32.40	Inspection Date:	1-Jun-11
		Revision:	Final V3
Building Unique Identifier (CCC):	PRO 1982-001	Is there a full report with this summary?	yes

Site

Site slope:	flat	Max retaining height (m):	
Soil type:	silty sand	Soil Profile (if available):	
Site Class (to NZS1170.5):	D		
Proximity to waterway (m, if <100m):		If Ground improvement on site, describe:	
Proximity to clifftop (m, if < 100m):			
Proximity to cliff base (m,if <100m):		Approx site elevation (m):	12.00

Building

No. of storeys above ground:	1 (single storey = 1)	Ground floor elevation (Absolute) (m):	12.30
Ground floor split?	no	Ground floor elevation above ground (m):	0.30
Storeys below ground	0		
Foundation type:	pads with tie beams	if Foundation type is other, describe:	Ties in one direction only
Building height (m):	4.00	height from ground to level of uppermost seismic mass (for IEP only) (m):	
Floor footprint area (approx):	800		
Age of Building (years):	20	Date of design:	1992-2004
Strengthening present?	no	If so, when (year)?	
		And what load level (%g)?	
Use (ground floor):	public	Brief strengthening description:	
Use (upper floors):			
Use notes (if required):			
Importance level (to NZS1170.5):	IL2		

Gravity Structure

Gravity System:	frame system		
Roof:	steel framed	rafter type, purlin type and cladding	Steel UB, steel pulins, steel cladding
Floors:	other (note)	describe sytem	concrete slab on ground
Beams:	steel non-composite	beam and connector type	530UB, welded connection
Columns:	structural steel	typical dimensions (mm x mm)	530UB concrte encased
Walls:	non-load bearing	0	125

Lateral load resisting structure

Note: Define along and across in detailed report!

Lateral system along:	single level tilt panel		note total length of wall at ground (m):	15
Ductility assumed, μ:	1.25			
Period along:	0.40	0.00	estimate or calculation?	estimated
Total deflection (ULS) (mm):	50		estimate or calculation?	estimated
maximum interstorey deflection (ULS) (mm):	50		estimate or calculation?	estimated
Lateral system across:	welded and bolted steel moment frame		note typical bay length (m)	
Ductility assumed, μ:	1.25			
Period across:	0.40	0.00	estimate or calculation?	estimated
Total deflection (ULS) (mm):	50		estimate or calculation?	estimated
maximum interstorey deflection (ULS) (mm):	50		estimate or calculation?	estimated

Separations:

north (mm):		leave blank if not relevant
east (mm):		
south (mm):		
west (mm):		

Non-structural elements

Stairs:			
Wall cladding:	precast panels	thickness and fixing type	125mm, weld plates
Roof Cladding:	Metal	describe	steel profile
Glazing:	aluminium frames		
Ceilings:	light tiles		
Services(list):			

Available documentation

Architectural	full	original designer name/date	CCC, 1992
Structural	full	original designer name/date	O'Loughlin, Taylor, Spence 1993
Mechanical	none	original designer name/date	
Electrical	none	original designer name/date	
Geotech report	none	original designer name/date	

Damage

Site: (refer DEE Table 4-2)

Site performance:	Slight damage	Describe damage:	Minor settlement
Settlement:	0-25mm	notes (if applicable):	
Differential settlement:	0-1:350	notes (if applicable):	
Liquefaction:	0-2 m³/100m²	notes (if applicable):	
Lateral Spread:	none apparent	notes (if applicable):	
Differential lateral spread:	none apparent	notes (if applicable):	
Ground cracks:	none apparent	notes (if applicable):	
Damage to area:	slight	notes (if applicable):	

Building:

	Current Placard Status:	red		
Along	Damage ratio:	28%	Describe how damage ratio arrived at:	
	Describe (summary):	Minor to moderate cracking in concrete panels, yeilding and buckling of roof bracing		
Across	Damage ratio:	25%		
	Describe (summary):	Minor to modetrate cracking in concrete panels		
Diaphragms	Damage?:	no	Describe:	
CSWs:	Damage?:	no	Describe:	
Pounding:	Damage?:	no	Describe:	
Non-structural:	Damage?:	yes	Describe:	Collapsed suspended ceiling

$$Damage\_Ratio = \frac{(\% NBS\,(before) - \% NBS\,(after))}{\% NBS\,(before)}$$

Recommendations

Level of repair/strengthening required:	significant structural	Describe:	Crack repairs and improved roof bracing, wall bracing and foundation ties. The building was extensively fire damaged in March 2012.
Building Consent required:	yes	Describe:	
Interim occupancy recommendations:	do not occupy	Describe:	

Along	Assessed %NBS before e'quakes:	25%	##### %NBS from IEP below	If IEP not used, please detail assessment methodology:	Quantitative
	Assessed %NBS after e'quakes:	18%			
Across	Assessed %NBS before e'quakes:	24%	##### %NBS from IEP below		
	Assessed %NBS after e'quakes:	18%			

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