GEOLOGIC, GEOMORPHIC, GEOTECHNICAL, AND DISPLACEMENT MAPS OF LAND AND BUILDINGS AT SELECTED SITES OF CHRISTCHURCH CITY COUNCIL OWNED REINFORCED CONCRETE STRUCTURES DAMAGED DURING THE 2010-2011 CANTERBURY EARTHQUAKES

CHRISTCHURCH SOUTH LIBRARY STUDY

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EXECUTIVE SUMMARY

The 2010-2011 Canterbury earthquake sequence (CES) in New Zealand's South Island caused extensive and recurrent damage to land and infrastructure within the Central Business District (CBD) of Christchurch. In this report we consider the effects of the CES on ground deformations and building deformations at the Christchurch South Library in southern Christchurch. We present geologic, geotechnical, geophysical and geomorphic data in the form of series of interpreted maps. We draw the following conclusions from the data presented herein: (1) the surface manifestation of liquefaction ejecta during the 22 February Mw 6.2 Christchurch earthquake occurred < 10 metres northwest of the northwest corner of the Christchurch South Library and was associated with lateral-spreading induced extensional failure of the cap sediments overlying the liquefiable layer and transport of the cap layer towards the Heathcote River, and (2) the distribution of surface ejecta correlates well with the vertical land displacements in the vicinity of the Christchurch South Library, implying cause and effect between earthquake-induced loading and observed ground failure.

1. SCOPE

The University of Canterbury (Dr. Mark Quigley) was commissioned by Christchurch City Council to (1) Produce detailed geologic, geomorphic, and geotechnical site maps for Council key assets, and (2) Produce earthquake-induced horizontal and vertical displacement maps for ground surface surrounding CCC key assets. The purpose of this project was to develop a geologic and geotechnical model for explaining the observed deformation field of land and buildings throughout the Canterbury earthquake sequence.

The seven key asset sites to be considered in this suite of reports are listed in Table 1, along with their approximate WGS84 coordinates and completion dates for the significant structures at each site.

Table 1 Key Christchurch City Council Assets

ASSET	LATITUDE	LONGITUDE	COMPLETION DATE
Christchurch Art Gallery	-43.530385	172.631448	2003
Manchester street carpark	-43.529597	172.640192	1964
Christchurch City Library	-43.529633	172.635131	1979
Lichfield Street carpark	-43.533845	172.635077	1965/1986 3 floors added to 1965 bldg in 1970's
Old Bus Exchange	-43.53387	172.637407	1999
Old Civic Building	-43.53503	172.637896	1939
Lancaster Park	-43.542031	172.654145	Dean's Stand 2010; Hadlee and Tui Stands 1995; Paul Kelly Stand 2002
Christchurch South Library	-43.561394	172.63805	2002

This study required the attainment and reproduction of a suite of previously produced maps (Geology Maps, Black Maps, DEMs), reinterpretation of a variety of datasets (CPT data, boreholes, auger data, differential LiDAR data, survey data), and production of a new suite of annotated maps and cross-sections for the CCC key assets.

The purpose of these studies was to (1) document geologic setting of council assets, document heterogeneity of surface and near-surface materials with variable engineering properties, and (2) document 2010-2011 earthquake-induced land elevation and position changes at CCC asset sites to document severity of ground deformation and document geologic/geotechnical controls on ground deformation. The primary purpose of these reports is to synthesize geologic, geomorphic, geotechnical, and geophysical data into a unified model that best explains the patterns and origin of land and building deformation in the 2010-2011 Canterbury earthquake sequence.

The focus of this report is CHRISTCHURCH SOUTH LIBRARY.

2. LOCATION AND PRIOR WORK

Christchurch South Library is located in Cashmere, Christchurch (Fig. 1). The central lat-long of the site is -43.561394, 172.63805.

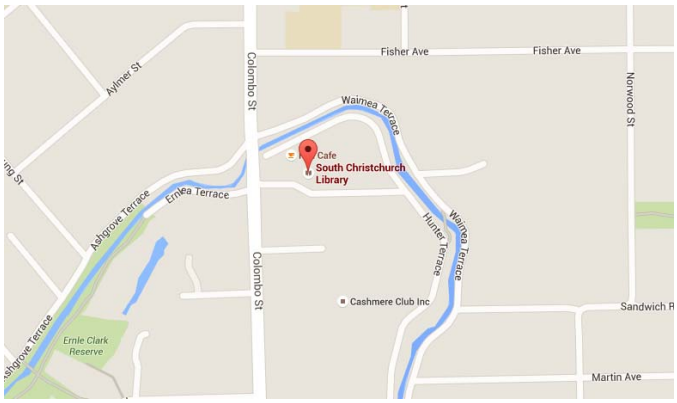

Figure 1. Location of Christchurch South Library shown on Google Maps.

T&T conducted mapping (Fig. 2), and CPT investigations (Fig. 3) in close proximity to these sites.

Horizontal and vertical displacement data was derived using differential lidar and airphoto interpretations throughout the Canterbury earthquake sequence (Fig. 4,5) and plotted on digital elevation model underlays. From these data, the tectonic component of displacement was removed (using tectonic displacements inferred geodetic seismic source models presented in Beavan et al., 2012), with the residual displacements interpreted to reflect shaking-induced permanent ground displacements relating to liquefaction and ground failure. See "Evaluation of Building Settlements during the Canterbury Earthquake Sequence using LiDAR" (T&T Ref # 53841) (see References) for further detail on how horizontal and vertical land displacements were obtained from differential LiDAR. Ecological maps (pre-development vegetation and waterways) were reproduced by T&T for Christchurch area (Fig. 6) from historic "Black Maps".

Initial mapped liquefaction distributions (Fig. 2) do not cover the site of interest in detail. However, in general, liquefaction severity appears highest in this map in areas most proximal to (i.e. within 50 m) the Heathcote River. The Christchurch South Library is proximal to the river.

Mapped horizontal displacements (Fig. 4) tend to show west to northwest directed movement. Displacements tend to be highest in low elevation areas close to the Heathcote River, consistent with increased density of liquefaction ejecta. The correlation with topography in the southern part of the map area suggests that the lateral displacement field is driven by a shallow mechanism; liquefaction-induced lateral spreading is the most feasible mechanism for this. The absence of 3-d cross-sectional data for this area precludes interpretation of spreading data in the context of subsurface variations in the distribution of liquefiable strata. Horizontal displacements in the Christchurch South Library are ~160-170 mm north towards the Heathcote River. This is consistent with predicted lateral spreading towards the nearest free-face.

The permanent vertical land displacement field (Fig. 5) is challenging to interpret in the vicinity of the Christchurch South Library. We expect that a component of the vertical displacements (uplift > 1m on eastern end and >0.1m on southern end) probably relates to pre-earthquake construction activities in 2003 during building completion around the periphery of the building. We attribute the subsidence to the northwest corner of the building to liquefaction-induced land subsidence and lateral spreading because it overlaps well with the location of mapped surface ejecta (Fig. 7). Other areas of maximum subsidence in the southwest corner of the map area overlap with the edges of paleochannels (terrace risers) and areas where we consider extensional strains to be largest, providing further evidence for the relationship between ground subsidence and liquefaction during the CES in this location.

The paleo-ecology map simply shows the Heathcote River was proximal to the Christchurch South Library site in the past, as it is currently.

Figure 2: Area reconnaissance mapping of liquefaction and lateral spreading in the vicinity of Christchurch South Library following the 22 Feb 2011 Christchurch Mw 6.2 earthquake (mapping by Tonkin and Taylor Ltd). More detailed mapping (this report) is presented in Fig. 11

Figure 3: Location of CPT, borehole, and other geotechnical sampling sites in the vicinity of Christchurch South Library.

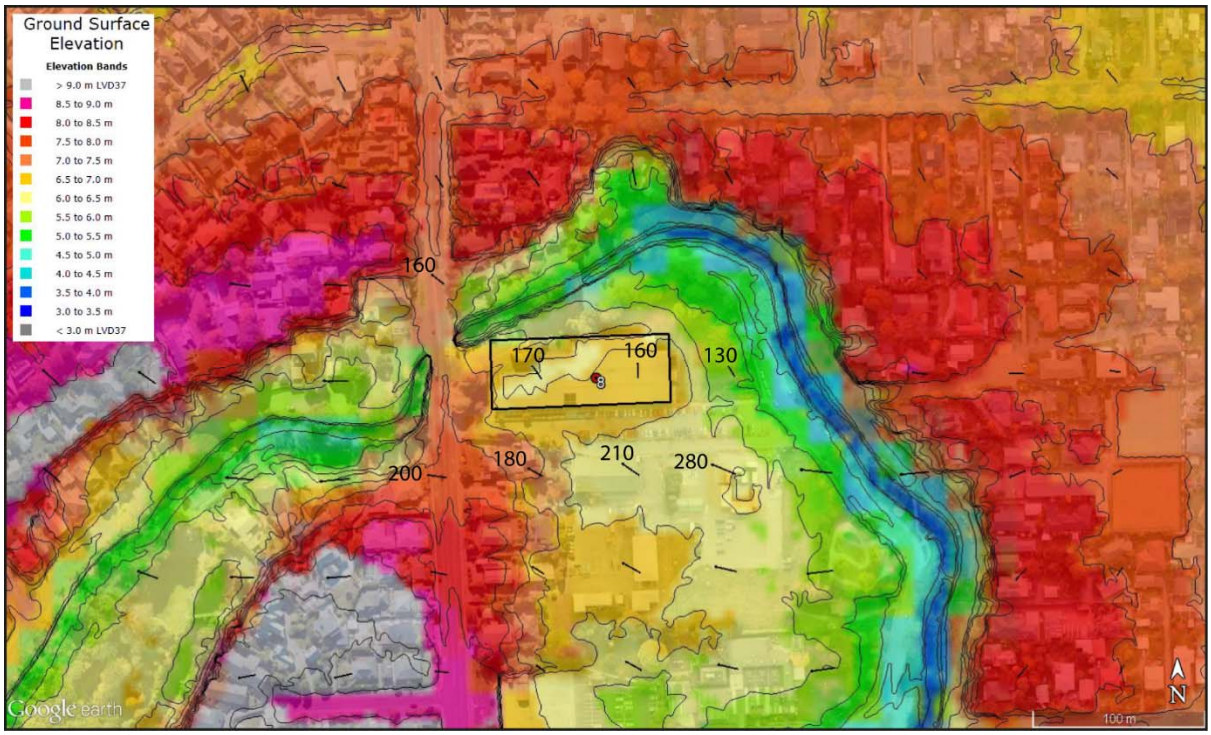

Figure 4: Cumulative horizontal permanent land displacements in mm with tectonic component removed for the South City Library area, superimposed on DEM underlay. Location of MASW surveys and geologic cross-sections shown

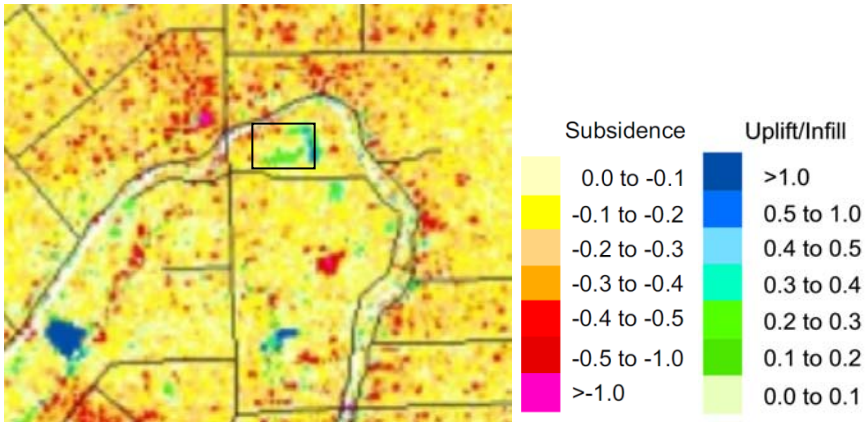

Figure 5: Permanent vertical land displacements from 2003 to December 2011 in metres for the Christchurch South Library area. Image from Hughes et al. (2015)

Figure 6: Paleo-ecology of the Christchurch South Library site.

3. THIS WORK

3.1. MAPPING OF LIQUEFACTION EJECTA

The new map of liquefaction surface ejecta using airphotos obtained immediately following the 22 February earthquake is presented in Fig. 7 in order to better quantify the extent of liquefaction surface ejecta. Distributions of liquefaction were characterised as definite or inferred.

Figure 7: Map of liquefaction surface ejecta in the Christchurch South Library area following the 22 February 2011 Mw 6.2 Christchurch earthquake.

The map presented in Fig. 7 provides higher resolution and improved accuracy compared to previously published maps (Fig. 2), which were undertaken at the suburb-scale for general land-damage and liquefaction severity purposes. The following conclusions can be drawn from the mapping.

1. Surface manifestation of liquefaction is heavily concentrated around southern bank of the Heathcote River with a linear array that is parallel to the river channel. This implies liquefied material was ejected through the surface via lateral spreading cracks resulting from extensional land failure towards the river channel. Isolated small pockets of surface ejecta are also inferred from mapping to have formed to the southeast of the library. This implies that liquefaction at the study site was controlled by local topography and geomorphology.
2. The liquefaction ejecta distributions to the northwest side of the library similarly correspond with increased vertical subsidence (~0.3-0.5 m) at that location.

We note also that cumulative lateral spreading vectors (Fig. 4) show local variations in orientation and displacement superimposed on an overall north to northeast trend of displacement. We argue that this regional displacement results from liquefaction-induced lateral displacements towards a Holocene embayment north of the study site (Fig. 8). Observed ground displacements at the study site thus show regional and site-specific components, consistent with widespread ground failure induced by the 2010-2011 Canterbury earthquakes.

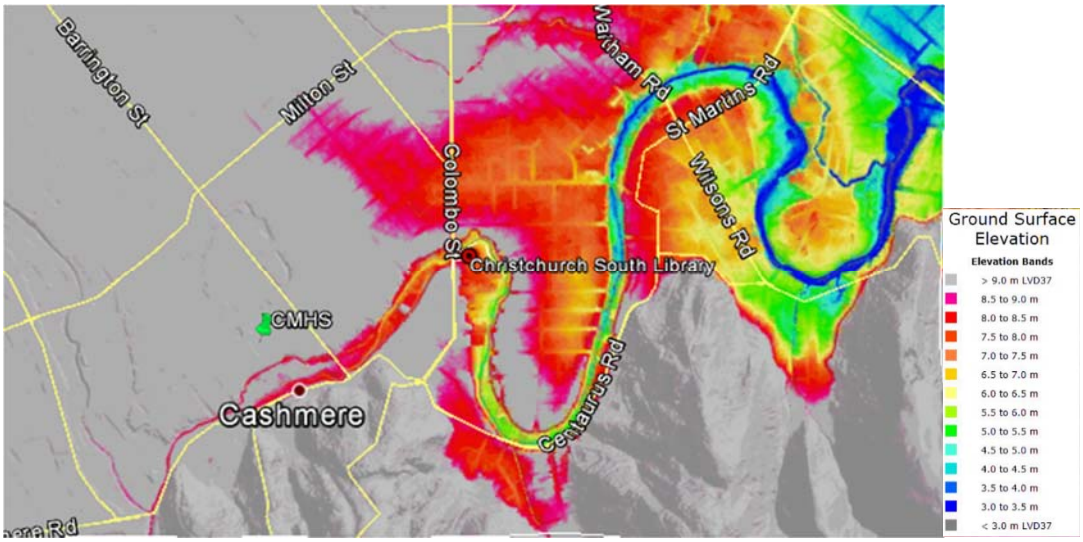

Figure 8: Regional DEM for the study site.

4. CONCLUSIONS

Differential lidar analysis (Deam, 2015) shows negligible vertical deformation of the roof of the Christchurch South Library through the CES. However, the vertical and horizontal displacements of the land surrounding the Christchurch South Library are consistent with liquefaction-induced lateral spreading. The surface manifestation of liquefaction ejecta during the 22 February Mw 6.2 Christchurch earthquake occurred < 10 metres northwest of the northwest corner of the Christchurch South Library and was associated with lateral-spreading induced extensional failure of the cap sediments overlying the liquefiable layer and transport of the cap layer towards the Heathcote River. The distribution of surface ejecta correlates well with the vertical land displacements in the vicinity of the Christchurch South Library, implying cause and effect between earthquake-induced loading and ground failure.

5. REFERENCES

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6. APPLICABLILITY

This report has been prepared for the benefit of Christchurch City Council with respect to the particular brief given to us and it may not be relied upon in other contexts or for any other purpose without our prior review and agreement.

Important Notice

Some of the maps and data presented herein were prepared and/or compiled for the Earthquake Commission (EQC) to assist in assessing insurance claims made under the Earthquake Commission Act 1993 and/or for the Canterbury Geotechnical Database on behalf of the Canterbury Earthquake Recovery Authority (CERA). It was not intended for any other purpose. EQC, CERA, their data suppliers and their engineers, Tonkin & Taylor, have no liability to any user of this map and data or for the consequences of any person relying on them in any way. Each Canterbury Geotechnical Database (https://canterburygeotechnicaldatabase.projectorbit.com/) map and data is made available solely on the basis that:

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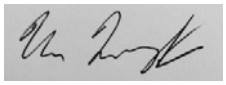

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