Assessing the effect of liquefaction on residential land

May 2013

Introduction

One of the key features of the Canterbury Earthquake Series was the unprecedented land and building damage caused by liquefaction. This has highlighted the need to better understand the vulnerability of land around Canterbury to liquefaction effects in future earthquakes because:

1. A better understanding of liquefaction vulnerability will assist with the residential recovery process in Canterbury
2. Land that has become more vulnerable to future damage as a result of the ground surface subsidence caused by the Canterbury Earthquakes may be covered by the Earthquake Commission (EQC), depending on the degree of increased vulnerability.

Tonkin & Taylor has undertaken a study for EQC to determine a suitable method for quantifying the degree of vulnerability of land to liquefaction-related damage from earthquakes. The study considered the degree of vulnerability to damage from very strong earthquake shaking as experienced during the main Canterbury earthquakes, as well as vulnerability from moderate or small earthquakes (which have a higher likelihood of occurring). The full Liquefaction Vulnerability Study is technical and is intended for engineers, scientists and researchers. This paper is a simplified, non-technical summary of that report prepared for the general public.

What is liquefaction?

Liquefaction occurs where soils below the groundwater level temporarily lose substantial strength and stiffness when shaken. This can cause the soil to temporarily behave like a liquid and often result in the ejection of soil and water to the ground surface, leaving a silt and fine sand residue. The surface of the ground often subsides as a result of liquefaction, usually in an uneven manner. After the earthquake the soil slowly starts to regain its strength and stiffness effectively back to the condition it was in before the earthquake occurred.

Some of the main factors contributing to the liquefaction vulnerability of land include:

1. The nature of the subsurface materials (i.e. soil type)
2. The strength, intensity and duration of shaking
3. The depth to groundwater
4. The nature and thickness of the crust (the uppermost non-liquefying materials).

Study objectives and methodology

The Liquefaction Vulnerability Study assesses three different methods used to predict the effect of liquefaction based on the results from the geotechnical investigation (“drilling”) which has been undertaken, and compares the results with the land damage observations. Drilling has been undertaken at
more than 8,000 locations by the end of January 2013. This investigation and testing was supplemented by monthly monitoring of groundwater levels at more than 800 locations.

The geotechnical investigation and groundwater monitoring information was combined with the measured strength of shaking during the earthquake series (measured by a network of seismic sensors throughout Canterbury) and analysed using various internationally recognised vulnerability indicators. These were then compared to the observed damage around Canterbury to see which provided the best match. The observed damage included:

1. Observations of liquefaction discharge (i.e. silt) and lateral spreading made after each significant earthquake
2. Observed damage to foundations of individual homes
3. Liquefaction related ground subsidence (measured using LiDAR* aerial survey data corrected for tectonic effects).

Key conclusions

Of the liquefaction vulnerability indicators considered, a method known as the Liquefaction Severity Number (LSN) best matched the observed damage and was found to be the most suitable indicator for assessing vulnerability of land in Canterbury to liquefaction related damage. The LSN indicator focuses on liquefaction related damage such as the ejection of silt and building settlement. It does not address vulnerability to lateral spreading (such as might occur near waterways or sloping ground). Therefore, EQC have examined land damage due to lateral spreading as a separate part of the land damage assessment process.

The study identified that most of the land in the residential Red Zone is highly vulnerable to damage from future possible earthquakes. In general, land in TC2 and TC3 areas is identified as considerably less vulnerable compared to the residential Red Zone land for any earthquake shaking intensity.

How does LSN work?

The LSN is a number indicating the likelihood of land suffering liquefaction related damage for a particular level of earthquake shaking. The number depends on the soil and groundwater conditions at the property and increases with shaking intensity. Sites for which a high LSN is calculated are more likely to experience damage from liquefaction compared with sites for which a low LSN is calculated.

The LSN is calculated based on the results at each geotechnical investigation location. It works by adding together the contribution of damage from each soil layer which may liquefy. Shallow layers which liquefy provide a greater contribution of damage at the ground surface and are therefore more heavily weighted, compared with deeper layers of liquefying material which contribute less to the damage. This is illustrated in Figure 1.

<table>
<thead>
<tr>
<th>LSN Range</th>
<th>Typical Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-20</td>
<td>Little or no expression of liquefaction, minor sand boils, minor damage to homes</td>
</tr>
<tr>
<td>20-40</td>
<td>Moderate expression of liquefaction, undulation and cracking of ground surface (there are occasional instances of severe damage)</td>
</tr>
<tr>
<td>40+</td>
<td>Widespread severe damage, extensive liquefaction expression, severe settlement of buildings and damage to services</td>
</tr>
</tbody>
</table>

* LiDAR stands for Light Detection and Ranging. It is effectively an aerial survey using a combination of laser sensors and global positioning systems to determine ground surface elevation.
Example application of LSN analysis

To illustrate how LSN can be applied, the performance of areas around the Avon River in Christchurch have been assessed using the available datasets.

The LSN results presented in Figure 3 below show the calculated LSN for a shaking intensity representing a 1 in 100 year earthquake combined with the design groundwater model. The 1 in 100 year shaking intensity is similar to that experienced by a large proportion of Greater Christchurch in the 4 September 2010 earthquake. In a future 1 in 100 year earthquake, the areas with low LSN (blue colours) in Figure 3 are expected to have little to no expression of liquefaction whereas the areas with high LSN values (orange to red colours) are expected to have extensive expression of liquefaction.

The areas with high LSN closely match those areas that experienced severe liquefaction damage in the 4 September 2010 earthquake. Areas around the Avon with high LSN generally experienced severe liquefaction related effects, while areas with low calculated LSN generally experienced low to moderate liquefaction related effects.

Figure 3 - Predicted LSN for Eastern Christchurch City for a 1 in 100 year earthquake based on available geotechnical investigations and post December 2011 ground surface levels.