Prediction of Liquefaction Damage in Christchurch, New Zealand and Rebuilding with Increased Resiliency

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Acknowledgements

Tonkin + Taylor Colleagues

Prof. Misko Cubrinovski
Prof. Brendon Bradley
Prof. Jonathan Bray
Prof. Russell Green
Prof. Tom O’Rourke
Prof. Ross Boulanger

Dr. Hugh Cowan (EQC)
Worst Observed Liquefaction Land Damage for the CES (observations at each residential property)

51,932 Properties with Observed Minor to Severe Liquefaction Related Land Damage
Worst Observed Liquefaction Land Damage for the CES
(observations at each residential property)
Worst Observed Liquefaction Land Damage for the CES (observations at each residential property)
Worst Observed Liquefaction Land Damage for the CES
(observations at each residential property)

**Moderate to Severe Land Damage**
- Aerial photo showing liquefaction ejecta on Seabreeze Close
- Liquefaction ejecta in turning circle of Seabreeze Close
- Outside of dwelling showing level liquefaction ejecta reached on brickwork and windows
- Large amounts of liquefaction ejecta
- Large amounts of liquefaction ejecta and tilting dwelling
- Large amounts of liquefaction ejecta around property

**LEGEND**
- None to Minor
- Minor to Moderate
- Moderate to Very Severe
The Liquefaction Related Consequences from the 2010 - 2011 CES

- Observed Liquefaction Land Damage
- Liquefaction Related Subsidence (m)
- Differential Foundation Settlement
- Building Repair Costs ($NZ exc GST)
The Liquefaction Related Consequences from the 2010 - 2011 CES

- **Observed Liquefaction Land Damage**
- **Liquefaction Related Subsidence (m)**
- **Differential Foundation Settlement**
- **Building Damage Ratio**

Legend:
- None-to-Minor
- Minor-to-Moderate
- Moderate-to-Severe
- -1.0
- -1.0 to -0.5
- -0.5 to -0.4
- -0.4 to -0.3
- -0.3 to -0.2
- -0.2 to -0.1
- -0.1
- 0 - 0.2
- 0.2 - 0.5
- 0.5 - 0.75
- > 0.75

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City Map Area
Residential Building Damage Ratio
(repair cost ÷ building replacement cost)
Residential Building Damage Ratio (repair cost ÷ building replacement cost)
Correlation of Total Liquefaction Related Ground Surface Movement (Vertical + Horizontal) with Land Damage

- None-to-minor
- Minor-to-moderate
- Moderate-to-severe

Total Liquefaction Related Ground Surface Movement (m)
Correlation of Total Liquefaction Related Ground Surface Movement (Vertical + Horizontal) with Building Damage Ratio

Total Liquefaction Related Ground Surface Movement (m)

- < 0.2
- 0.2 to 0.5
- > 0.5
Residential Building Floor Level Surveys

Max Differential = [+14] + [-28] = 42 mm

Address: 15 T+T Lane

Scale 1:50
Residential Building Floor Level Surveys
(differential settlement and angular distortion)

Max Differential = [+14] + [-28]
= 42 mm

Slope associated with max. differential
= (42/6720) x 100
= 0.63 % (2 d.p)

Maximum angular distortion
= (20/4000) x 100
= 0.5 %

Address: 15 T+T Lane

Scale 1:50
Residential Flat Land Building Foundation Types

Type A: Timber floor on piles
Type B: Timber on internal piles with perimeter concrete footing
Type C: Concrete slab on grade
Mixture

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Kaiapoi & Northern Suburbs
Using the 4,000 Boreholes and 22,000 CPT in Christchurch can the Liquefaction Damage be Predicted?
Using the 4,000 Boreholes and 22,000 CPT in Christchurch can the Liquefaction Damage be Predicted?

<table>
<thead>
<tr>
<th>Test Date</th>
<th>Location</th>
<th>Bintry</th>
<th>Operator</th>
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<tr>
<td>4 Nov 2010</td>
<td>EQC</td>
<td>EQC</td>
<td>EQC</td>
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<tr>
<td>Pre-Test (m)</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
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<tr>
<td>Assumed GMR (m)</td>
<td>1.5 (m)</td>
<td>1.5 (m)</td>
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<td>CPT No.</td>
<td>20528</td>
<td>20528</td>
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**Diagram:**
- **Legend:**
  - CPT Location
  - MBIE Technical Category:
    - TC1
    - TC2
    - TC3
  - N/A - Port Hills & Banks Peninsula
  - N/A - Rural & Unmapped
  - N/A - Urban Nonresidential
  - CERA Residential Zone
  - Red Zone

**Graphs:**
- **Gore Resistance (MPa):**
  - Depth (m): 0 to 20
  - Shear Friction (Pa):
- **Friction Ratio (%):**
  - Depth (m): 0 to 20
  - Pore Pressure (kPa):
  - Depth (m): 0 to 20
The Liquefaction Triggering Assessment Process

Geotechnical Investigation Data (22,000 CPT) → Liquefaction Triggering Assessment

<table>
<thead>
<tr>
<th>Project</th>
<th>Core No.</th>
<th>Sample Type</th>
<th>Stress State</th>
<th>Seed Stress</th>
<th>Maximum Seed Stress</th>
<th>Liquefaction Probability</th>
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<tbody>
<tr>
<td>CPT-2892</td>
<td>Core 10</td>
<td>SLS</td>
<td>PGA 0.19g, MW 6.0</td>
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<td>0.19g</td>
<td>10%</td>
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<td>Core 11</td>
<td>ILS</td>
<td>PGA 0.30g, MW 6.0</td>
<td>0.30g</td>
<td>0.30g</td>
<td>20%</td>
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<td></td>
<td>Core 12</td>
<td>ULS</td>
<td>PGA 0.52g, MW 6.0</td>
<td>0.52g</td>
<td>0.52g</td>
<td>50%</td>
</tr>
</tbody>
</table>
Liquefaction Prediction Across Christchurch

- Liquefying soils
- Non-liquefying soils

Legend:
- Crust
- Liquefying soils
- Non-liquefying soils

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Liquefaction triggering is not predicted
Liquefaction triggering is predicted
Prediction of Liquefaction Damage

Depends on:

- Crust thickness, strength, integrity
- Liquefaction triggering susceptibility
- Relative density of the liquefying layers
- Thickness of the liquefying materials
- Location of the liquefying materials
- Topography
- Foundation type
- Surface penetrations
- Interaction with structures
- Earthquake shaking characteristics
- Geological transitions
- Void redistribution, trapped water layers, pore pressure migration & unravelling
- Foreshocks & aftershocks
- Site response & base isolation from deeper liquefaction
- Whether the neighbor left the sprinkler running
- Murphy’s law
CPT-based Prediction of Liquefaction Vulnerability using the LSN Liquefaction Vulnerability Parameter

Sept 2010 event M7.1

Feb 2011 event M6.2

Observed Land Damage
- None to Minor
- Minor to Moderate
- Moderate to Severe

LSN
- 0-10
- 10-20
- 20-30
- 30-40
- 40-50
- 50+
Correlation of Predicted Liquefaction Vulnerability with Land and Building Damage

Land Damage Observation
- None to Minor
- Minor to Moderate
- Moderate to Very Severe

Building Damage Ratio
- BDR < 0.2
- 0.2 < BDR < 0.5
- BDR > 0.5
Residential Building Damage Ratio
(15,000 houses which need to be rebuilt)
New Residential Flat Land Building Foundation Types
(on land without liquefaction vulnerability)
New Residential Flat Land Building Foundation Types (on land with assessed liquefaction vulnerability)

**Type A**
- timber floor with piles

**Type B**
- timber floor with perimeter footing

**Type C**
- slab-on-grade
Driven Timber Poles

Rammed Aggregate Piers

Soil Cement Rafts and Gravel Rafts

‘Cleared Land’ Ground Improvement Methods
5 Years on from the 2010-2011 Canterbury Sequence the Rebuild was Well Underway and Then....

14 February 2016 $M_w$ 5.7 Christchurch Earthquake
Conditional Mean PGA Contours (from Prof Brendon Bradley)

PGA = 0.2g
Liquefaction Observations (T+T, Prof Russell Green, GNS)
Comparison Between the Observed Liquefaction and CPT-based Predicted Liquefaction Vulnerability

14 Feb 2016 Land Damage

LSN based on IB-2008
Comparison Between the Observed Liquefaction and CPT-based Predicted Liquefaction Vulnerability

14 Feb 2016 Land Damage

LSN based on BI-2014
Comparison of 4 September 2010 Building Damage with Areas of Liquefaction Land Damage

4 Sept 2010 Land Damage

Building Damage Repair Cost ($)

Legend:

PGA Contours
Major
Minor

Land Damage Observation
None to minor ground cracking but no observed liquefied material
Moderate to severe quantities of ejected material and/or moderate to severe lateral spreading

Minor to moderate quantities of ejected material but no observed lateral spreading

Histogram Bar Series
None to Minor Land Damage
Minor to Moderate Land Damage
Minor to Severe Land Damage
Moderate to Severe Land Damage

Total Repair Cost
< 10,000
10,000 to < 50,000
50,000 to < 100,000
100,000 +
TC1, TC2, TC3 and Residential Red Zone properties with either no building claim or repair costs unknown

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Comparison of 14 February 2016 Building Damage with Areas of Liquefaction Land Damage
Conclusions

• Liquefaction greatly increases building damage

• Liquefaction damage can be predicted..... but there is lots of room for improvement

• Affordable mitigation methods can be incorporated

• Money spent on mitigation pays back ten fold