Geological engineering study of liquefaction after the 2010 Darfield earthquake in an area of complex fluvial geology


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ABSTRACT: The liquefaction potential of an area of southwest Christchurch was assessed following the September 4 2010 Darfield earthquake. Site investigations were carried out where sand boils were observed, and on adjacent areas where no indication of liquefaction was found. At the site with sand boils, the path of ejected material was followed downwards to the source along thin (<5mm) dykes that cut the near surface confining layers. The ejected material had followed an irregular path to the surface. Despite the fluidised material passing through dry, high porosity sands there did not appear to be any migration of fluid into the adjacent sands. Trenches at locations without sand boils also showed sands of low density and high pore pressures. This suggested that liquefaction may have occurred but near surface confining conditions did not allow migration of the liquefied material to the surface. Particle size analysis indicates grain sorting processes may have occurred during liquefaction. Analysis of existing topographic (LIDAR) and subsurface geological data has enabled us to determine which parts of the study area are likely to be susceptible to liquefaction.

1 INTRODUCTION

Liquefaction resulting from the September 4th 2010 Darfield earthquake was widespread throughout Christchurch City. While some eastern areas of the city were significantly affected, there was also extensive liquefaction in the southwest of the city, extending around the suburbs of Oaklands and Halswell. Immediately west of these suburbs, land covering 161 ha has been designated as a future urban growth area, known as the Awatea Block (Figure 1). Liquefaction features are restricted to the southeast corner of the Block, and damage to structures was minimal with no lateral spreading. The pavement of Halswell Junction Road was disrupted, and adjacent drains were silted up. At the request of Christchurch City Council (CCC), IRBA Geosciences has undertaken an initial assessment of liquefaction potential for the Awatea Block, in order to understand why this area appears to have performed better than adjacent areas (IRBA Geosciences 2010). The assessment used available topographic and subsurface data, supplemented by limited site investigation.

1.1 Geological Setting

The Awatea Block is located across the watershed between Halswell (south) and Heathcote (north) river catchments. Both river systems are geologically young drainage features developed on the distal post-glacial floodplain of the Waimakariri River. The mapped geological unit in the area is the Yaldhurst Member of the Springston Formation, which is believed to be c.3000 years old (Brown & Weeber 1992). Sediments in the area are all fluvial (river channels and floodplains).

The area is bisected by the south branch of the Islington Channel, which is the southernmost of a number of incised, erosional flood channels derived from the Waimakariri River. Prior to stopbank construction along the Waimakariri River, historically recorded flood flows went down the Islington Channel into the Heathcote River (Brown & Weeber 1992). While the gross elements and their associated groundwater systems are well known (Brown & Weeber 1992), the internal details of the fine-grained systems are less well described, with published sedimentological studies available only...
for the estuaries and coastal areas (e.g. McFadgen & Goff 2005).

Figure 1. Location map, Awatea Block, southwest Christchurch. Scale = 1:50,000, LINZ sheets BX23 and BX24. Study area outlined in yellow, trenching site denoted by a red dot. Residential properties with liquefaction damage outlined in green (from Tonkin & Taylor 2010). Liquefaction damage to rural areas mapped off Tonkin & Taylor (2010, Figure B 27) outlined in purple.

1.2 Geomorphology

The Awatea Block is an area of low relief which has been modified by gravel extraction, placement of fill, drainage works, road construction, agricultural activities, and minor construction of houses and commercial facilities (Figure 2). A drainage retention basin system is presently being constructed on the north side of the study area along Awatea Road. The LIDAR data used here predates that work.

Superimposed on the generally gently sloping landscape is an incised pattern of river terraces and abandoned river channels with steeper slopes on channel margins. Across the north of the block, the Heathcote River occupies a depression on the north flank of the Islington Channel, bounded to the north by older fan or river surfaces. Elevation generally increases to the southwest away from the Heathcote River channel, until a further terrace edge is reached at approximately the northeast boundary of the gravel pits. This represents the youngest phase of erosion and infill along the Islington Channel. The south flank of the Islington Channel (south of the gravel pits), though marked as a sharp boundary by Brown & Weeber 1992, appears to be gradational on the LIDAR data (Figure 3).

The surface through the Islington Channel has a pattern of low-relief braided stream channels superimposed on it. These channels are aligned parallel to the Islington Channel, and were generated by flow along that channel at times of flood. Crossing the southeast end of the Islington Channel is an abandoned high sinuosity meander loop with a channel oriented generally perpendicular to the Islington Channel. Within the meander loop are typical point bar deposits. This meander loop does not appear to connect to other meandering channel stream patterns to the southwest of the Awatea area. It appears probable that the meander loop is related to a former Halswell River tributary which flowed through the area at some time after the last pulse of gravel deposition along the Islington Channel.

Urban and rural drainage development in the area has probably obscured landscape evidence for the original configuration of streams in the area.
Figure 2. Pre-September 2010 LIDAR image for the Awatea Block (outlined in black) and adjacent areas. Scale = 1:10,000, grid = NZTM. IC = Islington Channel, C = channels along Islington Channel, G = gravel pits, HT = Heathcote River headwaters, HW = Halswell River headwaters, M = cutoff meander loop.
2 TRENCHING INVESTIGATION

Two trenches were dug by hydraulic excavator in adjacent areas of paddocks on the northwest corner of Wigram Road and Halswell Junction Road (see Figure 2 for location). Trench 1 was completed in an area with no surface expression of liquefaction, and Trench 2 was excavated through a small sand boil. The trenches were 63m apart and both trenches were excavated a small distance (300 mm) below the water table. Recorded lithologies are described in Tables 1 and 2.

Table 1. Trench log, IRBA-1

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Description</th>
<th>PSA Sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>0–0.28</td>
<td>Silty topsoil</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Medium greyish brown silty very fine sand coarsening</td>
<td></td>
</tr>
<tr>
<td>0.28–0.48</td>
<td>Medium olive grey to brownish grey slightly clayey silt, slightly plastic, slightly moist, firm.</td>
<td></td>
</tr>
<tr>
<td>0.48–0.7</td>
<td>Light olive grey to brownish grey silty clay, moderately firm, minor iron mottling.</td>
<td></td>
</tr>
<tr>
<td>0.7–1.33</td>
<td>Silty clay as above grading down to very fine sand, muddy, minor mottles. Sharp base.</td>
<td></td>
</tr>
<tr>
<td>1.33–1.53</td>
<td>Dark olive grey to brownish grey very fine sand, slight iron mottling and lamination, moist, soft, grading downwards.</td>
<td></td>
</tr>
<tr>
<td>1.53–1.73</td>
<td>Dark olive grey to brownish grey silty clay, slightly mottled, moist, trench collapsing below 1.73m.</td>
<td></td>
</tr>
<tr>
<td>1.73–1.9</td>
<td>Light to medium grey silt and clay, laminated, moist, weak</td>
<td>IRBA #4</td>
</tr>
<tr>
<td>1.9–3.4</td>
<td>Medium blue-grey fine sand, well sorted, wet.</td>
<td></td>
</tr>
<tr>
<td>3.4–3.7</td>
<td>Water table estimated at 3.4m.</td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Trench log, IRBA-2

<table>
<thead>
<tr>
<th>Depth (m)</th>
<th>Description</th>
<th>PSA Sample</th>
</tr>
</thead>
<tbody>
<tr>
<td>-0.1–0</td>
<td>Liquefaction ejecta – silty fine sand</td>
<td>IRBA #1</td>
</tr>
<tr>
<td>0–0.25</td>
<td>Silty topsoil.</td>
<td></td>
</tr>
<tr>
<td>0.25–1.3</td>
<td>Medium brownish grey fine sand, well sorted, friable to slightly firm, slightly silty, slight iron staining.</td>
<td>IRBA #2</td>
</tr>
<tr>
<td>1.3–2.7</td>
<td>Light to medium yellow to brownish grey clay, slightly silty, mottled, faintly laminated, soft to firm, slightly plastic, moist, collapsing.</td>
<td>IRBA #3</td>
</tr>
<tr>
<td>2.7–3.3</td>
<td>Blue grey clay with silt interbeds, wet, soft, plastic. Minor fine sand. Water table estimated at 3.2m.</td>
<td></td>
</tr>
</tbody>
</table>

The sequence in both trenches is similar, dominated by fine sand, silt and clay, though Trench 2 is notably finer overall than Trench 1. The ground at Trench 1 was also softer and more susceptible to shaking by passing traffic. Sediments were weak, with both trenches collapsing during excavation. Below the water table, sediments were very soft, wet and plastic and appeared to be liquefied. Liquefaction features observed in Trench 2 are shown in Figure 3. Surface ejecta (Figure 3A) comprise a 1.5x0.8m patch of light grey very fine silty sand. Beneath is a thin (3–5mm) dyke of light grey fine sand with sharp margins extending down through the surficial sandy sediments (Figure 3B,
C). In places the dyke infill is pale grey to white soft wet clay (Figure 3D), and in places, a very thin layer of clay appears to form the margins of the dyke (Figure 3D, E). At 0.8m depth, the dyke was observed to bifurcate, with a minor branch extending to the base of the topsoil but not penetrating through it (Figure 3E, F). No similar features were observed in Trench 1, despite the apparently liquefied nature of the sand below the water table.

Figure 3. Photographs of IRBA Trench 2 through sand boil, corner of Halswell Junction Road and Wigram Road. (A) surface expression of liquefaction ejecta (B) irregular thin dyke of grey silty fine sand passing through brown fine sand (C) vertical sand dyke passing through soil horizon (D) thin dyke with clay infilling (pale grey) (E) bifurcating sand dyke (F) sand dyke extending from right hand branch of dyke shown in photo (E) which fails to break through soil horizon.

Particle size analysis (Figure 4) indicates that the liquefaction ejecta (sample IRBA #1) has a similar
particle size distribution to ejected sediments seen elsewhere in Christchurch. However, the apparent
source lithology in Trench 2 (Sample IRBA #3) has a greater fines content than the ejecta. Sample
IRBA #2 indicates that the liquefaction ejecta is finer grained than the sand it passes through, though
the fines content is similar between Samples #1 and #2. Sample IRBA #4 from the base of Trench 1 is
a well sorted sand which is very similar to beach sand.

Figure 4. Laser particle size analysis results, IRBA trenches. Data acquired by University of Auckland.
Comparative data (solid lines) from Orense (2010).

3 SUBSURFACE GEOLOGICAL MODEL

In order to evaluate liquefaction potential across the study area, subsurface data were compiled from
existing sources and IRBA observations (Figure 5). Geological data for the study area were generally
qualitative, with few dynamic cone penetrometer data or SPT measurements, and no CPT data.
Limited SPT measurements (Opus 2009) indicate typical N values of 1-9 for fine sands and silts at
shallow depths, with sandy gravel being N=20-30 and gravels N=26-50.

The primary subsurface data source for the study was the Environment Canterbury (ECAN) water well
database, comprising 108 wells for which lithological data were available. Wells are not necessarily in
ideal locations, and may not be deep enough to be useful. Data quality is variable, with poor recording
of lithologies and inconsistent descriptions. Data compiled for geotechnical and environmental studies
in the vicinity are generally of higher quality, however the depth of investigation is generally limited
with test pits being more common than drillholes.

Groundwater levels across the study area were obtained from published data (Pattle Delamore 2007),
who noted that seasonal variations can be in the order or 2m. Here we use the worst case scenario for
water levels, though our observations 6 weeks after the September earthquake indicate that levels in
the study area were about 2m lower than this scenario. There is a strong groundwater gradient
decreasing towards the southeast of the study area (Figure 5), reflecting the topographic gradient
evident in Figure 2.

Water well lithology data confirm the study area is underlain throughout by alluvial gravels, at depths
varying from near-surface in the northwest to 13.5m in the southeast (Figure 5). The shallow gravels
represent deposits within the Islington Channel. Overlying sediments are generally floodplain silts and
clays, as seen in the IRBA trenches. Fine sands representing minor fluvial channels are present in the
southern portion of the study area, and exposed in cut faces adjacent to Awatea Road across the north
of the area. Organic silts with woody debris are also recorded from drillholes, and were observed near
Awatea Road. These represent former vegetated floodplains.
DISCUSSION AND CONCLUSIONS

Subsurface investigation and compilation of existing geological data has enabled an assessment of liquefaction potential within the Awatea Block. The typical range of fluvial sediments, from gravel to sand to silt and clay, is present within the study area. The envelope of liquefiable sediments is bounded by the water table at the top and the upper surface of consistent gravel deposits at the base, with lateral boundaries determined by the extent of suitably liquefiable fine silty sands. Geomorphic analysis of LIDAR data indicates that point bar and low energy channel deposits lie within or adjacent to the study area, and it is likely that liquefaction experienced in the area during the September 2010 earthquake was largely controlled by the position of these drainage axes.

The liquefaction features observed in Trench 2 provide evidence about the mechanisms which allow sediment and water to be ejected from depth (in this instance >3m) and pass through capping strata with no apparent disruption. In this instance, a very narrow, irregular dyke of sand was found to be feeding the surface ejecta. Despite passing through sand with fair estimated permeability, ejecta are constrained within the dyke. The presence of clay as both an infilling and lining of the feeder dyke may explain why ejecta do not infiltrate into surrounding sediments. There may also have been insufficient time to allow for lateral infiltration.

Particle size data indicates that the ejecta at this site has a different particle size distribution from the apparent source material. This may indicate that thin sandy layers or lenses have been mobilised to the surface, leaving finer grained material in situ. Despite a liquefied appearance, the sands below the
water table in Trench 1 were not mobilised to the surface, probably because of lack of fines allowing excess pore pressures to dissipate. In both trenches, the nature and thickness of the confining strata were similar.

Liquefaction ejecta observed throughout Christchurch were consistently grey fine silty sand. The lack of brown sands indicates ejected material was sourced below the normal water table. In most instances, the source strata appear to be below 3–4m depth (Tonkin & Taylor 2010), suggesting that the regional water table was not notably elevated at the time of the earthquake. In areas with a near-surface water table such as the Avon-Heathcote estuary (Reid et al. 2010), liquefaction features included short subsurface conduits of approximately 250mm diameter extending to liquefied sand at depths of 100–300mm. These may be considered one end member of the spectrum of possibly liquefiable sites, with a very high water table, shallow source strata and wide conduits, whereas the Awatea area may be considered to represent the opposite end, with a deeper water table, deeper source strata, stronger/thicker confining strata and narrow conduits.

Qualitative analysis of largely existing data enabled identification of areas of high liquefaction potential within the Awatea Block, and elimination of those areas where liquefaction is unlikely to occur. Such a study is valuable for refining a strategy for further investigation using quantitative methods such as CPT or SPT testing, following the recommendations recently proposed by the New Zealand Geotechnical Society (2010).

The findings from this study support the conclusion that what occurred was a process made complex by the ground conditions resulting from the varied geological and hydrological phases present in the area. Knowledge of these processes is critical to understanding current ground conditions and hence the detailed liquefaction potential of possible infrastructure.

REFERENCES:


Opus International Consultants Ltd 2009. Christchurch Southern Motorway Supplementary Investigations 2009. Logs of drill holes and test pits (selected sites within area of interest only).


ACKNOWLEDGMENTS:

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