

LANDSLIDES AND LIQUEFACTION GENERATED BY THE COOK STRAIT AND LAKE GRASSMERE EARTHQUAKES: A RECONNAISSANCE REPORT

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SUMMARY

Following both the Cook Strait earthquake (M_w 6.6; 21 July, 2013) and the Lake Grassmere earthquake (M_w 6.6; 16 August, 2013) reconnaissance visits were made of the epicentral regions to document the general distribution and extent of landslides, liquefaction, and other ground damage effects generated by these earthquakes. The extent of landsliding generated in central New Zealand by these two earthquakes was at the lower end of the expected range for shallow earthquakes of these magnitudes. Liquefaction effects generated by the Cook Strait and Lake Grassmere earthquakes in central New Zealand were substantially less than those generated by the 2010-2011 Canterbury earthquakes in the Christchurch area, despite the fact that the Cook Strait and Lake Grassmere earthquakes were of comparable size and proximity, and impacted grossly similar geological settings. There is no evidence of primary ground-surface fault rupture during the Lake Grassmere earthquake.

INTRODUCTION

Following both the Cook Strait earthquake (M_w 6.6; 21 July, 2013) and the Lake Grassmere earthquake (M_w 6.6; 16 August, 2013) helicopter reconnaissance flights were made of the epicentral regions to document the general distribution and extent of landslides and liquefaction generated by these earthquakes. To further verify these effects, and in the case of the Lake Grassmere earthquake to also look for evidence of primary surface fault rupture, on-ground field visits were conducted around the Wellington Harbour area (both earthquakes) and eastern Marlborough (Lake Grassmere earthquake only). Initial findings from these excursions are presented below.

LANDSLIDES

Figures 1 & 2 show the overall distribution of landslides and other ground damage effects such as liquefaction (minor), generated by the Cook Strait and Lake Grassmere earthquakes. Steep cliffs cut in Neogene sedimentary rocks, especially on the coastal bluff near Cape Campbell (Rattenbury *et al.* 2006), were the sites of many landslides during both the Cook Strait and Lake Grassmere earthquakes. A peak horizontal ground acceleration (PGA) of 0.21g was recorded within 10 km of the coast during the Cook Strait event (Holden *et al.* 2013). The same station recorded a PGA of 0.75g during the closer Lake Grassmere event. Landslides up to an estimated 100,000 m³ were triggered on the highest of the coastal mudstone cliffs (Fig. 3). The inland Needles Creek area, 4 km WNW of Ward, was particularly hard hit in the Lake Grassmere earthquake.

Many landslides were triggered from terrace edges cut into fluvial valley fill (Fig. 4a). Most were extensive shallow debris slides and falls which stripped a thin cover of stony regolith, commonly failing along stock tracks that followed the terrace edge (Fig. 4b). In addition to the high density of landslides in the Needles Creek area, there were many displaced boulders on terrace surfaces that also attest to high levels of ground shaking in this area (e.g. Van Dissen & Berryman 1994, Khajavi *et al.* 2012).

As well as landslides that failed completely, or underwent metre-scale displacements, there was incipient landslide cracking, and cracking along ridge crests throughout the epicentral region of the Lake Grassmere earthquake.

Landslides and other ground damage effects, such as settlement of embankment fills, resulting from the Lake Grassmere earthquake forced the temporary closure of State Highway 1 and the Main North Railway between Blenheim and Ward. Nevertheless, despite torrential rains the night of the earthquake (16 August) and the following day, landslides were cleared and other repairs made to the extent that the highway was reopened to general traffic by mid-day 17 August, albeit at reduced speeds. It took a couple more days for the railway to reopen.

In southern North Island PGAs reached 0.1–0.2g in both events and the only landslides seen there were some small debris falls in wave-cut deposits of unconsolidated fill at Kaiwharawhara Point in Wellington Harbour, and a small rock fall off an old quarry face at Arthurs Nose on the west side of Lyall Bay (Hancox *et al.* 2013).

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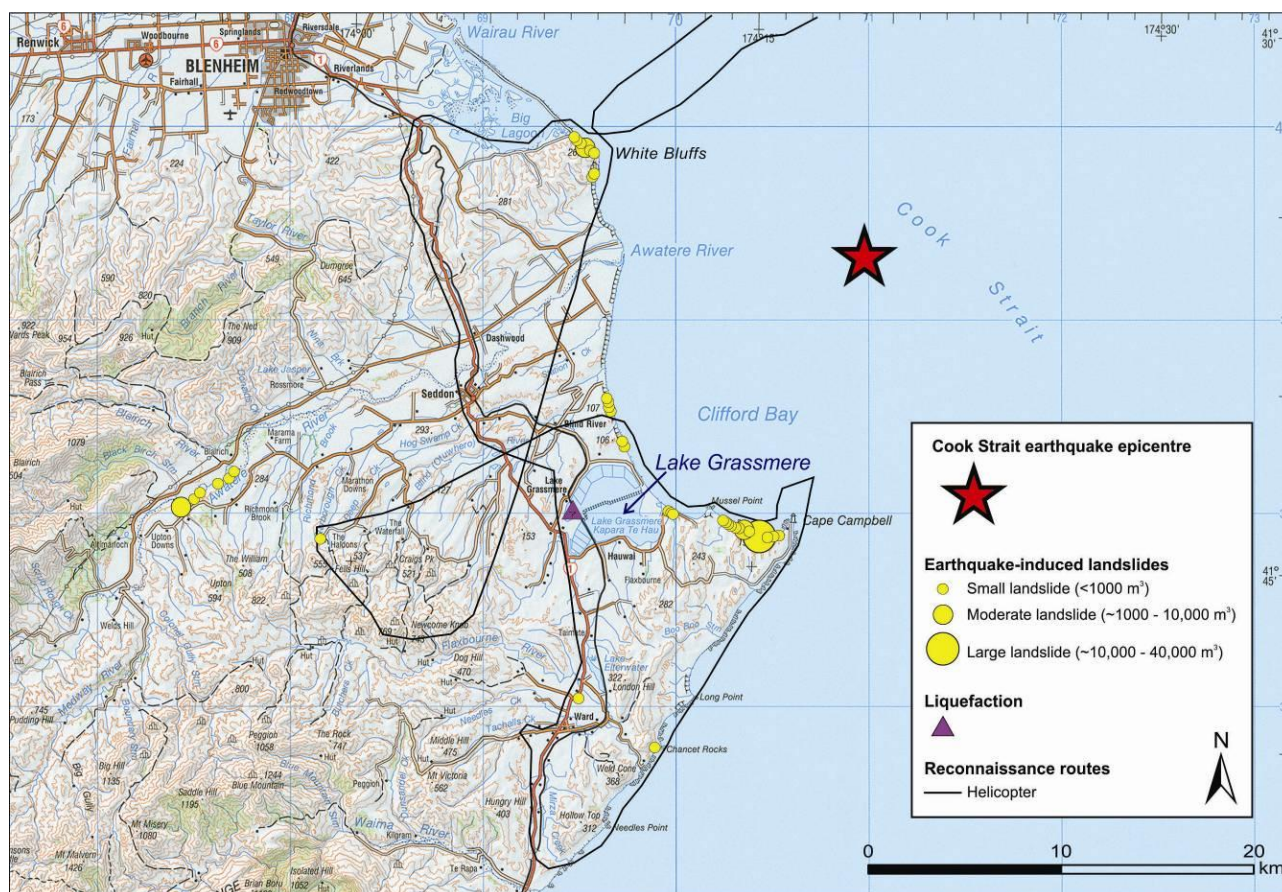


Figure 1: Map showing landslides and other ground damage in eastern Marlborough attributed to the M_w 6.6 Cook Strait earthquake of 21 July, 2013. Also shown is route of helicopter reconnaissance flight of 25 July, 2013, and epicentre of Cook Strait earthquake. (after Figure 15 of Hancox *et al.* 2013).

The extent of landsliding generated in central New Zealand in these earthquakes is at the lower end of the expected range (in terms of the numbers and size of landslides) for shallow earthquakes of these magnitudes (Hancox *et al.* 1997, 2002).

LIQUEFACTION

The 2010-2011 Canterbury earthquakes generated wide-spread liquefaction in low-lying, Holocene coastal, estuarine and riverine settings (e.g. Cubrinovski *et al.* 2010, 2011, 2012, Kaiser *et al.* 2012); and heightened awareness throughout New Zealand, possibly globally, and certainly within the insurance sector, of the ruinous impacts of liquefaction. The recent Cook Strait and Lake Grassmere earthquakes also produced strong ground shaking in low-lying, Holocene coastal, estuarine and riverine settings. However, the extent of liquefaction generated in central New Zealand by these two earthquakes was substantially less than that generated in Canterbury by similarly sized, and close, earthquakes in the Canterbury sequence.

Lake Grassmere is the most proximal site to show evidence of liquefaction during the Cook Strait and Lake Grassmere earthquakes. A PGA of 0.75g was recorded within 10 km of Lake Grassmere during the Lake Grassmere event (Holden *et al.* 2013), but only a few sub-aqueous sand boils were observed near the eastern shore of the lake. Levees and service roads of the Lake Grassmere salt works were damaged by lateral spreading in the Lake Grassmere event. It was our impression that this damage was mainly the result of failure of weak embankment fill, but liquefaction may have contributed in some instances.

Along the Opawa River, near its confluence with the Wairau River, an ~600 m length of river bank along the inside of a meander bend experienced liquefaction and lateral spreading during the Lake Grassmere earthquake (Fig. 5), but not the Cook Strait event. The total amount of horizontal spreading was up to several decimetres, with most of this occurring within 10-20 m from the river bank. Liquefaction ejecta was composed predominantly of fine sand, but in some instances, medium sand dominated. Silt drapes capping sand boils were only rarely present. A PGA of 0.14g was recorded within ~9 km from the site; the same station recorded a PGA of 0.07g during the Cook Strait event. Sporadic liquefaction also occurred near the Opawa River westwards to Blenheim, and proximal to the Wairau River downstream of its confluence with the Wairau Diversion. Additional details regarding the geotechnical properties and liquefaction susceptibility of the sediments in the immediate Blenheim area can be found in Mason *et al.* (2013).

More distant from the earthquakes, reclaimed land of a port facility in Wellington Harbour experienced ground damage with evidence of liquefaction in both earthquakes (Fig. 6). The shaking in Wellington during the Cook Strait and Lake Grassmere earthquakes was relatively moderate (recorded PGAs within 1 km of the harbor site were 0.1-0.2g in both events); however, shaking during larger, closer earthquakes – such as rupture of the Wellington Fault – will be severe (e.g., Stirling *et al.* 2012). Current post-earthquake response plans for a severe Wellington event are reliant, to a significant extent, on shipping and use of the harbour for the delivery of emergency supplies into the city (e.g., MCDEM 2010). The Cook Strait and Lake Grassmere earthquakes have highlighted potential vulnerabilities of specific port facilities in

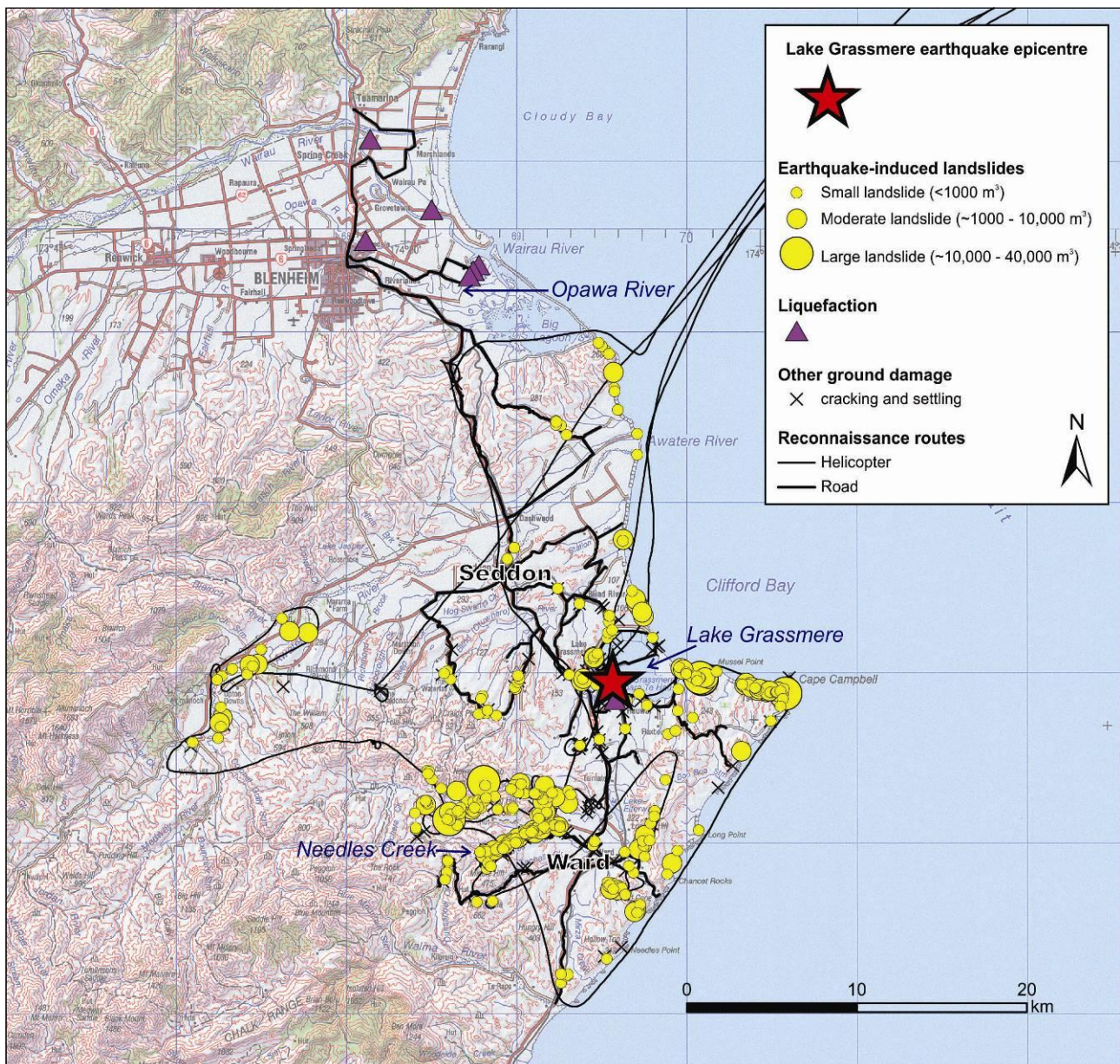


Figure 2: Map showing landslides and other ground damage attributed, in the main, to the M_w 6.6 Lake Grassmere earthquake of 16 August, 2013. Also shown are reconnaissance routes travelled (both road and helicopter), and epicentre of Lake Grassmere earthquake. Note, due to the reconnaissance nature of our investigations, it was not always possible to distinguish between those landslides triggered by the Lake Grassmere earthquake, and those triggered by the earlier Cook Strait event. In addition, immediately following the Lake Grassmere earthquake there was a day or so of very heavy rain. This rain may have triggered new landslides, enlarged landslides triggered by the Lake Grassmere earthquake, and re-activated landslides caused by the Cook Strait earthquake. Consequently, while we consider this map to be an accurate representation of the general distribution of landslides triggered by the Lake Grassmere earthquake, there is ambiguity regarding the genesis and earthquake-triggered size of specific slides.

Wellington Harbour, and the necessity to ensure – from the perspective of post-earthquake disaster response – that critical elements of Wellington’s harbour facilities have a high degree of resilience and post-earthquake functionality.

SURFACE FAULT RUPTURE

A primary objective of the on-ground field reconnaissance following the Lake Grassmere earthquake was to look for evidence, or otherwise, of primary ground-surface fault rupture. If the fault that ruptured in the Lake Grassmere earthquake extended to the ground surface, it would cut across State Highway 1 and the Main North Railway near Lake Grassmere. After detailed examination of the State Highway

and the railway, and other nearby roads, it was concluded that there was no evidence that the fault broke to the ground surface. Certainly there was cracking and slumping of the State Highway, and other roads, and damage to the railway line, but this was invariably the result of failure of unsupported embankment slopes, and differential settlement of artificial fill at bridge abutments, over culverts, and at contacts with harder bedrock.

CONCLUSIONS

- 1) There is no evidence of primary ground-surface fault rupture during the Lake Grassmere earthquake.

- 2) Liquefaction effects generated by the Cook Strait and Lake Grassmere earthquakes in central New Zealand were substantially less than those generated by the Canterbury earthquakes in the Christchurch area, despite the fact that the Cook Strait and Lake Grassmere earthquakes were of comparable size and proximity, and impacted grossly similar geological settings.
- 3) The extent of landsliding generated in central New Zealand in the Cook Strait and Lake Grassmere earthquakes was at the lower end of the expected range for shallow earthquakes of these magnitudes.

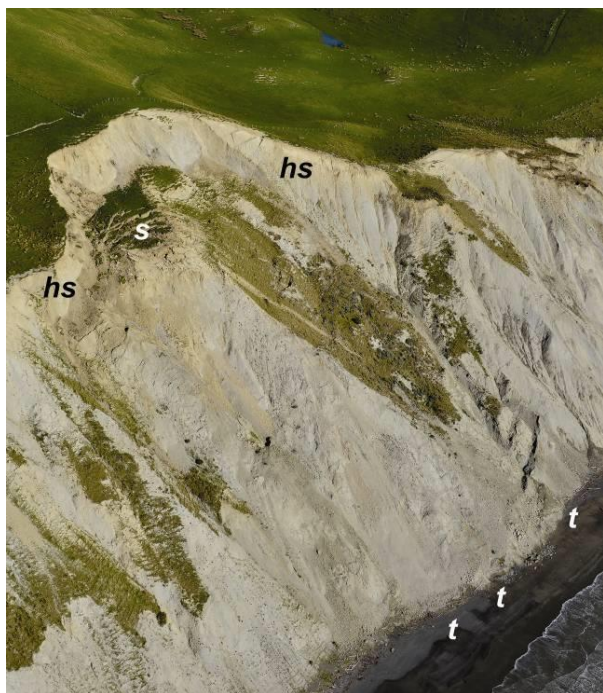


Figure 3: View of the largest landslide triggered by the Cook Strait earthquake on the coastal cliffs 1 km west of Cape Campbell. Height of cliff is ~120 m. Multiple fresh slump scarps (s) are visible below the ~20 m high head scarp (hs) at the top of this rotational landslide. Bulging at the convex toe (t) of the failure appears to have locally narrowed the beach. (photo: G. Hancox, GNS Science; taken 25 July, 2013).

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Figure 4: Landslides in the Needles Creek area triggered by the Lake Grassmere earthquake. a) Aerial view looking NNW. b) View looking ENE. (photos: D. Townsend, GNS Science; taken 2 September, 2013).



Figure 5: (above) Liquefaction and lateral spreading in the Opawa River area caused by the Lake Grassmere earthquake. (photos: D. Townsend, GNS Science; taken 3 September, 2013).

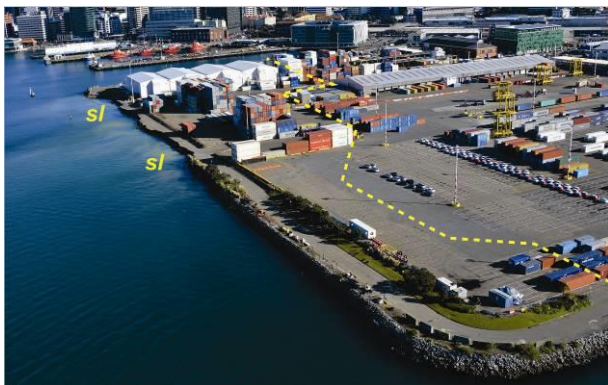


Figure 6: (left) Aerial views of the area of slumping (sl) and cracking (yellow dotted line) at the container storage area in Wellington Harbour caused by the Cook Strait earthquake. (photos: G. Hancox, GNS Science; taken 25 July, 2013).