Foundations on Deep Alluvial Soils

Technical Report Prepared for the Canterbury Earthquakes Royal Commission

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Executive Summary

The series of earthquakes that hit Christchurch in the period between 4 September 2010 and 13 June 2011 caused repeated liquefaction through its suburbs and the Central Business District (CBD). The 22 February earthquake was the most damaging. The liquefaction in the CBD adversely affected the performance of many buildings resulting in residual deformation and damage to buildings. This report presents a general review of the alluvial soils found in the CBD, and identifies the general concepts that should be followed in the design of foundations for buildings on these soils.

The Canterbury Plains are built of complex inter-layered soil formations deposited by eastward-flowing rivers from the Southern Alps towards the Pacific coast. In the top 20 m to 25 m, the CBD soils consist of recent alluvial soils including gravels, sands, silts, peat and their mixtures. The soils are highly variable within relatively short distances, both horizontally and vertically. Considering their composition (sandy soils and non-plastic silts), age (recent deposits, few hundreds to a few thousand years old) and depositional environment (river, swamp and marine sediments), these soils are generally considered susceptible to liquefaction, and in some cases (when deposited in a loose state) they exhibit very low resistance to liquefaction.

The principal zone of liquefaction (due to the 22 February earthquake) stretching west-east along the Avon River affected several high-rise buildings in different ways. Buildings on shallow foundations, supported on loose to medium-dense sands and silty sands that liquefied, suffered differential settlements, residual tilts, and bearing capacity failures (sinking of the building in the soil). Pile supported structures, particularly when the piles reached competent soils at depth, generally showed less differential and residual movements. There is evidence that hybrid building foundations (consisting of shallow and deep foundations or piles of different lengths) performed relatively poorly during the earthquakes. Multi-storey and high-rise buildings supported on shallow foundations sitting on shallow gravels showed mixed performance. The variable thickness of the gravel layer and underlying soil layers contributed to uneven settlements and residual deformations. These adverse effects were particularly pronounced in transition zones where ground conditions and behaviour change substantially over short distances, including zones of marked ground weakness and lateral spreading.

Robust shallow foundations, often accompanied by land improvement measures, and deep foundations reaching competent foundations soils at large depths are appropriate for founding buildings on deep alluvial soils. These types of foundations have shown to provide an improved and acceptable performance during strong earthquakes. Attention to details in the design and due considerations of the soil-foundation-structure system as a whole are essential for ensuring a satisfactory performance during strong earthquakes. The design process has to be supported and based upon results of appropriate field investigations, the extent and nature of which will depend on the particular features of the site and requirements of the building considered. The report identifies some general concepts that should be followed in the design of foundations for buildings on alluvial soils in relation to the observed performance during the 2010-2011 earthquakes and the current seismic design philosophy.
1 Introduction

In the period between September 2010 and June 2011, the City of Christchurch was shaken by a series of strong earthquakes including the 4 September 2010, 26 December 2010, 22 February 2011 and 13 June 2011 earthquakes. These earthquakes produced very strong ground motions throughout the suburbs of Christchurch and in its Central Business District (CBD) causing substantial damage to buildings, infrastructure and lifelines, and an enormous impact on the community as a whole. The 22 February earthquake was particularly devastating; it caused 181 fatalities, collapse or partial collapse of many unreinforced masonry structures, collapse of two multi-storey reinforced concrete buildings, and widespread liquefaction in the suburbs to the east of the CBD and within the CBD itself. Soil liquefaction in a substantial part of the CBD adversely affected the performance of many multi-story buildings resulting in total and differential settlements, lateral movement of foundations, tilt of buildings, and bearing failures. At the outset, we have to put these unfortunate outcomes in the context of the very strong ground shaking produced by the February earthquake. The ground motions generated by this earthquake in many parts of Christchurch were intense and substantially above the ground motions used to design the buildings in Christchurch.

With this background in mind, this report provides a general review of the alluvial soils found in the Christchurch Central Business District and focuses on their performance and effects to CBD building foundations during the recent strong earthquakes. Typical modes of failure for such soils are discussed, and methods of founding buildings on such soils that would avoid such failures are outlined. A comparison between the liquefaction observed in the recent earthquakes and the anticipated liquefaction during an Alpine Fault event is also presented. The report contains technical information, however, when possible the phenomena and their effects are described in non-technical language for a general audience. We hope that the readers will not be hugely inconvenienced one way or another by the adopted approach, and that the report will offer information to a wide readership, while preserving but not imposing the technical detail.