Technical Note 04 – The Liquefaction Phenomenon

Introduction

Earthquakes pose hazards to the built environment through five main types of processes. These include strong ground shaking (the most pervasive hazard), primary breakage of the ground surface (fault rupture), deformation of the ground surface due to fault rupture (tectonic tilting, differential uplift and subsidence), seismically-induced gravitational slope movements (slope failures), and ground deformation resulting from soil liquefaction. This technical note focuses on documenting the nature and distribution of soils that are susceptible to soil liquefaction.

This document has mostly been adapted from the Institution of Professional Engineers of New Zealand (IPENZ) liquefaction fact sheet and the relevant GNS Science publications by Saunders and Berryman (2012) titled: "Just add water: when should liquefaction be considered in land use planning?" and Rosser and Dellow (2015) titled: "Assessment of liquefaction risk in the Hawke's Bay".

In New Zealand, the most widespread observations of liquefaction since European settlement were in the 2010–2011 sequence of Canterbury earthquakes (Cubrinovski et al., 2011b, Cubrinovski et al., 2012). However, earlier instances of significant liquefaction were documented after the earthquakes in Marlborough 1848, Wairarapa 1855, Cheviot 1901 (liquefaction observed in Kaiapoi), Murchison 1929, Napier 1931, Inangahua 1968, and Edgecumbe 1987. Most of these events generated strong shaking in coastal regions with extensive deposits of recent, cohesionless, fine-grained, sedimentary deposits (Fairless & Berrill, 1984; Hancox et al., 1997). The effects of soil liquefaction during these earthquakes were the ejection of water and sand (sand boils or earthquake fountains) and lateral spreading. These phenomena resulted in vertical and horizontal displacement of the ground surface which caused extensive damage to buildings, wharves, roads and bridges, embankments, and buried services (e.g., Hancox et al., 1997).

The Modified Mercalli (MM) intensity (Dowrick, 1996; Hancox et al., 2002, Dowrick et al, 2008) threshold for liquefaction in New Zealand is generally MM7 for sand boils, and MM8 for lateral spreading, but both may occur at one intensity level lower in highly susceptible materials (Hancox et al., 1997, Dowrick et al, 2008). Liquefaction-induced ground damage is most common at MM8–10 (Hancox et al., 1997, Dowrick et al, 2008). The minimum earthquake magnitude for liquefaction is magnitude 5 based on recent experience in Christchurch, but liquefaction is more common at magnitudes of 6 and greater (Quigley et al., 2013). In terms of peak ground acceleration (PGA), a common instrumental measure of the strength of earthquake shaking at a site, the threshold for liquefaction in highly susceptible sediments is between 0.057g (Quigley et al., 2013) and 0.09 g (de Magistris et al., 2013) (where 1 g is the acceleration due to the force of gravity at the Earth's surface).

What is Liquefaction?

Liquefaction is the phenomenon where a soil suddenly decreases in strength, most commonly as a result of strong ground shaking during an earthquake. Not all soils, however, can liquefy in an earthquake. The following are particular features of soils that can liquefy:

- The soils need to be composed of loose sands and silts. Such soils do not stick together the way clay soils do (i.e., they lack cohesion);
- The soils need to be saturated (i.e., located below the water table) so all the space between the grains of sand and silt is filled with water. Dry soils above the water table will not liquefy.

When an earthquake occurs, strong shaking may cause the sand and silt grains to compress the spaces filled with water, but the water pressure builds up until the grains 'float' in the water. When this happens the soil loses strength and it has liquefied. Soil that was once rigid now flows like a fluid.

Soils that cannot liquefy may be unsaturated, or cohesive (clay is present and binds the soil together) or dense (for example, gravels deposited in a high-energy environment). If any of these features are present in a soil it will not liquefy.

Which Soils are Susceptible to Liquefaction?

Not all soils are susceptible to liquefaction. Generally, for liquefaction to occur there needs to be three soil preconditions (Tinsley et al., 1985; Youd et al., 1975; Ziony, 1985):

- Geologically young (less than ~10,000 years old), loose sediments, that are
- Fine-grained and non-cohesive (coarse silts and fine sands), and
- Saturated (below the water table).

When all three of these preconditions are met, an assessment of the liquefaction hazard is required if there is concern about the consequences of such liquefaction. Assessment of liquefaction hazard can be on a regional or district scale, or it can be site specific using, for example, cone-penetration tests. Note that the 'saturated' condition may apply seasonally or only part of the time i.e., the potential for saturation must be assessed.

If one of these preconditions is not met, then soils are not susceptible to liquefaction. If soils are not susceptible to liquefaction then liquefaction potential does not need to be assessed in an urban or rural planning context.

Liquefaction Effects

Liquefied soil, like water, has the bearing capacity of a liquid so materials denser than the liquefied soil will sink, while materials less dense will float upward. The liquefied soil is forced into any cracks and crevices, including those in the dry soil above, or the cracks between concrete slabs, and flows out onto the ground surface as sand boils and rivers of silt and water. In some cases the liquefied soil flowing up a crack erodes and widens the crack (even to a size big enough to accommodate a car). Some other consequences of the soil liquefying are:

- Differential settlement of the ground surface due to the loss of soil from underground;
- Loss of support to building foundations;
- Floating of manholes, buried tanks and pipes in the liquefied soil – but only if the tanks and pipes are mostly empty or filled with low specific gravity fluid; and
- Near streams and rivers, the unsaturated surface soil layers can slide sideways on the liquefied soil towards the streams. This is called lateral spreading and can severely damage buildings and buried infrastructure such as buried water and wastewater pipes. It typically results in long tears and fissures in the ground surface.

Not all of a building's foundations, buried pipe networks, road networks or flood protection stop-banks need to be affected by liquefaction for damage to occur. An affected part may subside (settle) or be pulled sideways by lateral spreading, to severely damage the building. Buried services such as sewer pipes can be damaged when they are warped by lateral spreading, ground settlement or floatation. Some of these effects are illustrate in Figure 1.

Are the Consequences Significant?

Once it has been ascertained that soils are susceptible to liquefaction, it needs to be determined if the seismic hazard is sufficient to warrant consideration of liquefaction as a hazard. This is done by considering the likelihood of earthquakes strong enough, and frequent enough, to warrant concern. Whether earthquake shaking is strong enough or frequent enough will in part depend on the type of facility or infrastructure being considered (e.g., for domestic dwellings the seismic hazard that can be expected to occur more frequently than once every 500 years should be considered, but for a critical facility, liquefaction should not impact on continued functionality of the facility in a 1 in 2500 year event).

If the seismic hazard is sufficient to warrant attention for the infrastructure or facility under consideration then an assessment of the consequences of liquefaction on that land use needs be undertaken. The primary impacts of liquefaction are to the built environment (e.g., buildings); infrastructure (i.e., underground pipes and services, roads); and to the socio-economic resilience if people are not able to live in their homes and/or attend places of education and employment. Figures 2 to 8 show examples of liquefaction damage to a range of assets and infrastructure.

If the impacts of liquefaction are insignificant, then it may be appropriate that no planning actions are required. If, however, the potential consequences are more than insignificant, and a cost-benefit assessment indicates possible future losses can be mitigated, either by avoidance or by engineering solutions; then liquefaction should be a criterion assessed during planning.

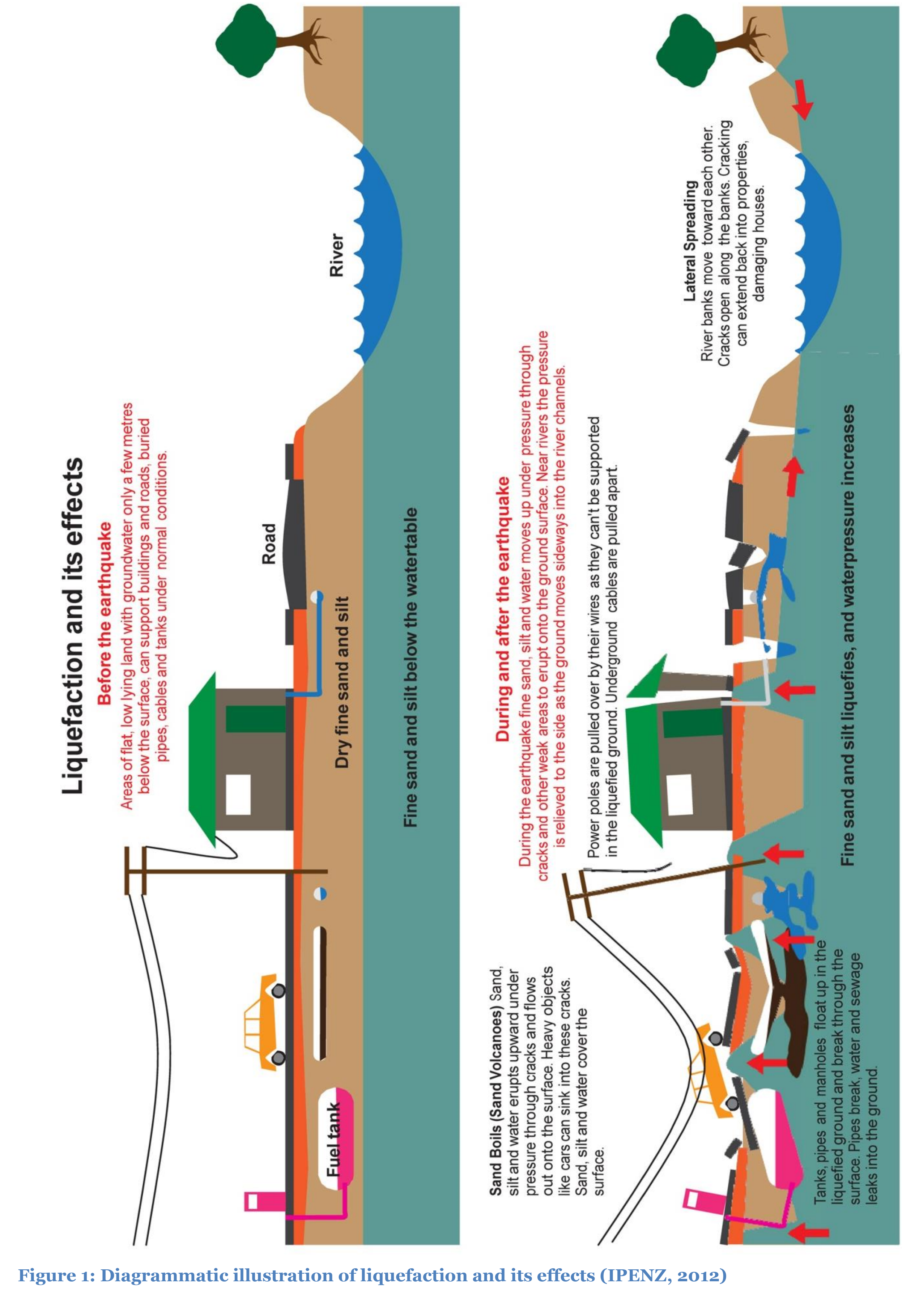

Figure 1: Diagrammatic illustration of liquefaction and its effects (IPENZ, 2012)

Figure 2: Sand boils caused by liquefaction in Kaiapoi, 45 kilometres from the epicentre of the magnitude 7.1, 4 September 2010 Darfield earthquake. (Photo: N. Litchfield, GNS Science)

Figure 3: Liquefaction ejecta in a suburban Christchurch Street in the suburb of Bexley, approx. 10 km from the epicentre after the magnitude 6.3 Christchurch earthquake of 22 February 2011. (Photo: NZ Herald)

Figure 4: Buoyancy of a pump-station floated up to 500 mm out of the ground by liquefaction adjacent the Avon River near the eastern end of Morris Street, approx. 10 km form the epicentre after the magnitude 6.3 Christchurch earthquake of 22 February 2011. (Photo: D. Beetham, GNS Science)

Figure 5: Lateral spreading fissures run parallel to the Avon River in Avonside Drive, Christchurch, approx. 10 km form the epicentre after the magnitude 6.3 Christchurch earthquake of 22 February 2011. (Photo: D. Beetham, GNS Science)

Figure 6: Compression-induced buckling of a bridge over the Avon River near Medway Street due to lateral spreading displacement of the abutments approx. 10 km form the epicentre after the magnitude 6.3 Christchurch earthquake of 22 February 2011. (Photo: D. Beetham, GNS Science)

Figure 7. Liquefaction-induced lateral spreading through the foundation of a house after the magnitude 6.3 Christchurch earthquake of 22 February 2011, location unknown.

Figure 8. Damage to underground infrastructure from liquefaction, in this case lateral spreading has pulled a pipe joint apart in Cashmere after the magnitude 7.1 Darfield earthquake of 10 September 2010.

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