# Site Characterisation and Liquefaction Assessment of the Reclamations at CentrePort

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## BACKGROUND AND OBJECTIVES

The $M_w$7.8 Kaikoura Earthquake caused significant liquefaction at the port of Wellington (CentrePort) and temporarily closed operations. The reclamations consist of soils primarily composed of end-dumped gravelly fills sourced from quarries and hydraulically placed sands. The reclamation was completed in various stages and contain a complex soil mixture. Furthermore, gravels have been commonly assumed to have higher liquefaction resistance than sand, so stronger earthquake loads are required to liquefy gravels (and deform less when liquefied). However, large liquefaction-induced lateral movements and major damage to wharves suggested the complex soils need to be properly characterised and liquefaction assessment methods revaluated to better understand reclaimed soils and their performance under seismic demands. This study aims to characterise the reclaimed soils and present initial findings from state-of-the-art simplified liquefaction evaluation procedures using subsurface geotechnical data.

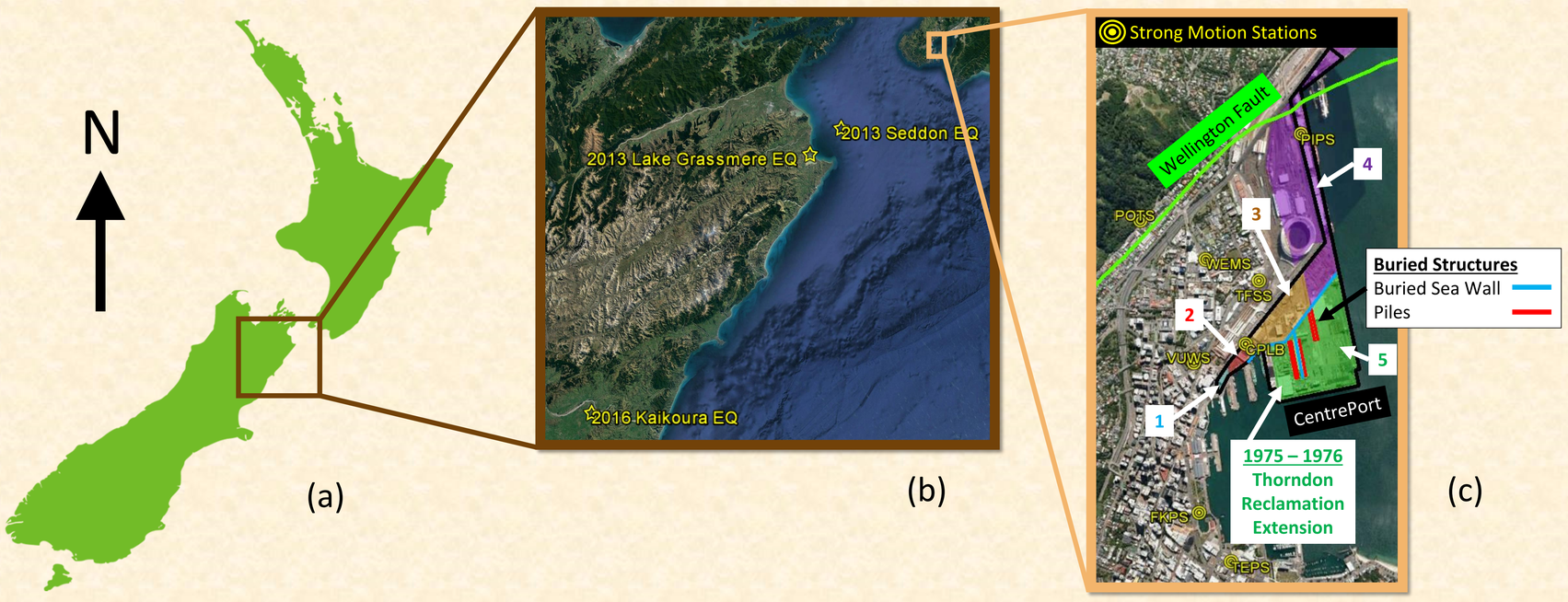


Figure 1. (a) Outline of New Zealand; (b) Aerial view of recent earthquakes which caused liquefaction at CentrePort; and (c) Aerial view of CentrePort showing the Wellington Fault, nearby strong motion stations, reclamation periods and buried structures relevant for this study (base images from Google Earth™).

CentrePort is located in the central part of Wellington and presents a key operational area for international freight. Figure 1 illustrates its historical development. The soils are composed of gravels, sands and silts from various difference sources and reclamation periods.

Key areas of reclaimed soils in Figure 1 includes (in chronological order):

1. 1882 reclamation with sands and gravels.
2. 1893 – 1901 reclamation consisting of sands and gravels.
3. 1904 – 1916 reclamation consisting primarily of gravels and sands with traces of silts.
4. 1924 – 1932 reclamation along Aotea Quay where sands and silts were hydraulically dredged from the seabed.
5. 1965 – 1972 reclamation south of the old buried sea wall, consisting of gravel/sand/silt mixtures.

The reclaimed land south of the sea wall was further extended in 1975 – 1976 to the current coastline. Significant liquefaction-induced damage was observed in this Thorndon Reclamation Extension.

## SITE CHARACTERISATION


Figure 2. CPT locations and cross section lines (base image from Google Earth™).

Since the 2016 Kaikoura Earthquake, a comprehensive subsurface database was collected, which includes shear wave velocity profiles and 102 cone penetration tests (CPTs). The sites of the CPTs are indicated in Figure 2. Supplemented with other historical CPTs and borehole data, representative soil profiles were developed to indicate thickness of key soil layers. Cross sections of key reclamation areas shown on Figure 3 summarise important features of reclamation units and indicate ranges of typical $q_c$ and $I_c$ values derived from the CPTs. It is important to note that the vertical scale in Figure 3 has been exaggerated to better illustrate the details.

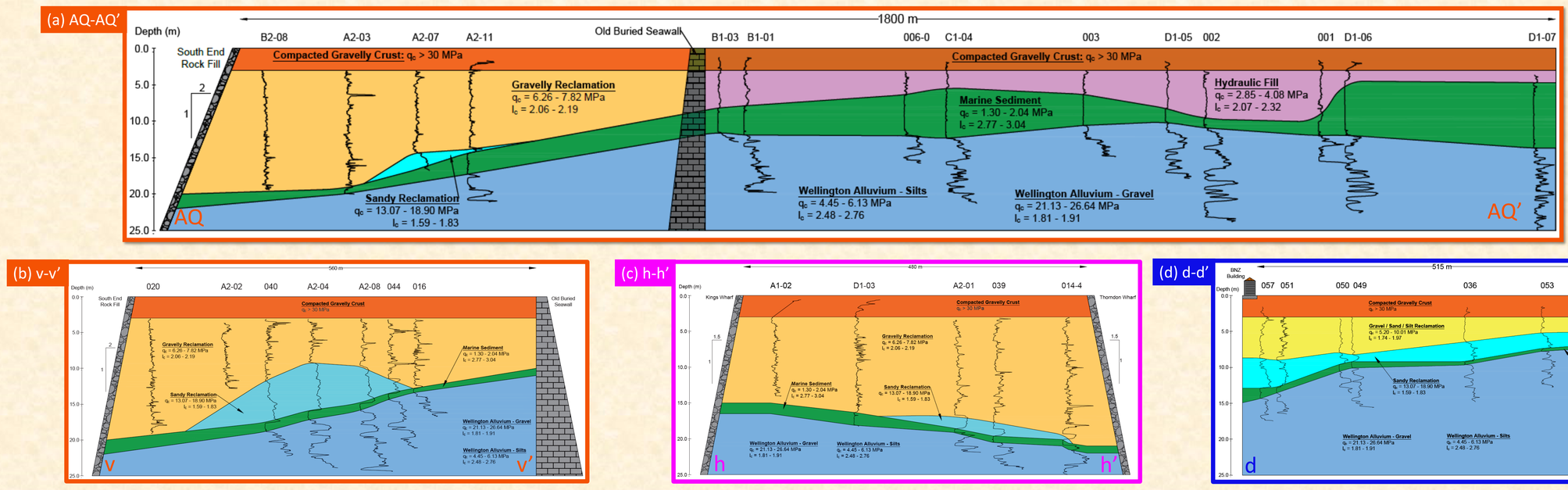


Figure 3. Cross sections depicting key soil units at CentrePort (vertical scale exaggeration 10x). Two north-south cross sections facing westwards are shown: (a) AQ-AQ'; and (b) v-v'. One east-west cross section facing north is shown: (c) h-h'. One southwest-northeast cross section facing northwest is shown: (d) d-d'. See Figure 2 for cross section and CPT locations. The $q_c$ and $I_c$ ranges are based on 25th to 75th percentile values for each soil unit across all representative CPTs. Slope geometry and interpolation of unit thicknesses and depths between CPT and Borehole sites are based on various past Tonkin + Taylor reports and the observed trends.

## SIMPLIFIED LIQUEFACTION ASSESSMENT

The CPTs were used to evaluate liquefaction triggering for the 2016 Kaikoura Earthquake and its consequences using state-of-the-art simplified procedures. Figure 4 shows the result of the liquefaction assessment at CPTuA2-04. This site represents a characteristic soil profile in the Thorndon Reclamation where 9.1m of gravelly fill from the 1965-1972 reclamation period overlies sandy reclamation, which sits atop marine sediments followed by the Wellington alluvium (Figure 4).

The results indicate the factor of safety against liquefaction ($FS_{liq}$) is well below one for the induced demand caused by the 2016 Kaikoura earthquake. Hence, liquefaction is predicted to have triggered at this site. 125mm of liquefaction induced vertical settlement is predicted, which is largely consistent with observed settlements of 180mm. Similar analyses at all other sites suggest most of the reclaimed land in CentrePort was predicted to have liquefied with large deformations. This result is consistent with the observed liquefaction effects (e.g. soil ejecta, and vertical and horizontal ground movements) observed at the port after this event.

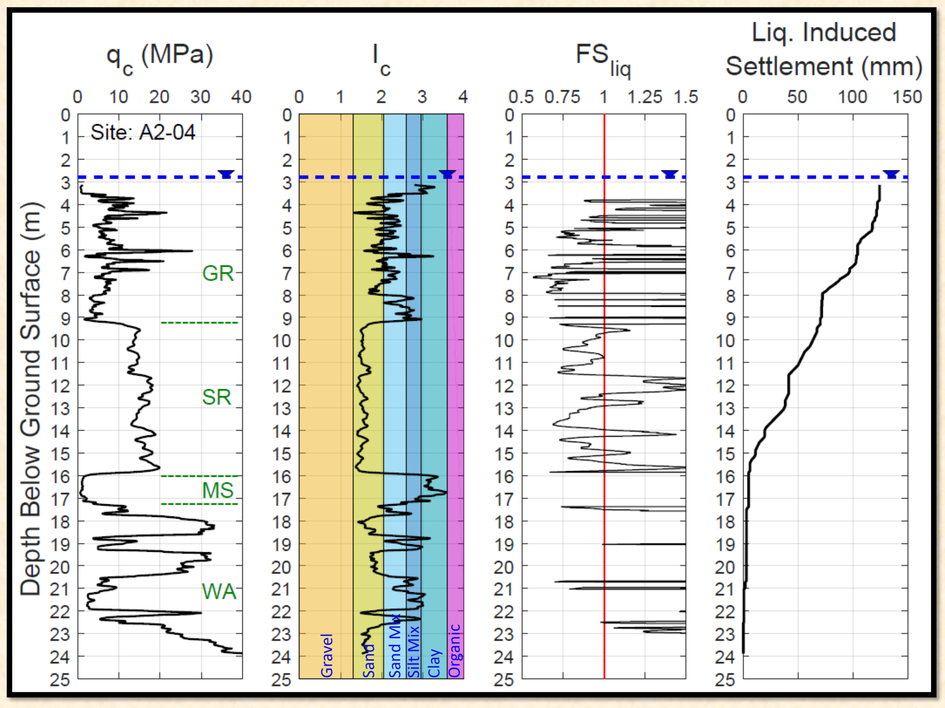


Figure 4. CPT tip resistance ($q_c$), soil behavior type index ($I_c$), factor of safety against liquefaction ($FS_{liq}$), and post-liquefaction vertical settlement profiles calculated under the shaking demand of the 2016 Kaikoura event for a representative soil profiles in site A2-04. GR denotes layers of gravelly reclamation, SR denotes sandy reclamation, MS denotes marine sediments, and WA denotes Wellington alluvium. See Figure 2 and Figure 3 for the CPT location.

## CONCLUSIONS

Site Characterisation:

- Characteristic soil properties ($q_c$, $I_c$, etc.) determined.
- Soil behaviour index ($I_c$) indicate the sands and silts control the gravel/sand/silt matrix in the reclamations.

Liquefaction analysis for the 2016 Kaikoura Earthquake:

- All sites predicted to liquefy when analysed using simplified procedures.
- Liquefaction-induced settlements consistent with observed settlements.

## FUTURE WORK

The following work has begun or is planned to begin to supplement this work:

- Further boreholes added to the site characterisation.
- Simplified analysis for other earthquake events
- Sensitivity analysis for the simplified procedure.
- Nonlinear seismic effective stress analyses calibrated to the simplified procedures.
- Laboratory testing of soil units.
- Nonlinear seismic effective stress analyses calibrated to the laboratory test results.