# Liquefaction Evaluation in Stratified Soils

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## Background

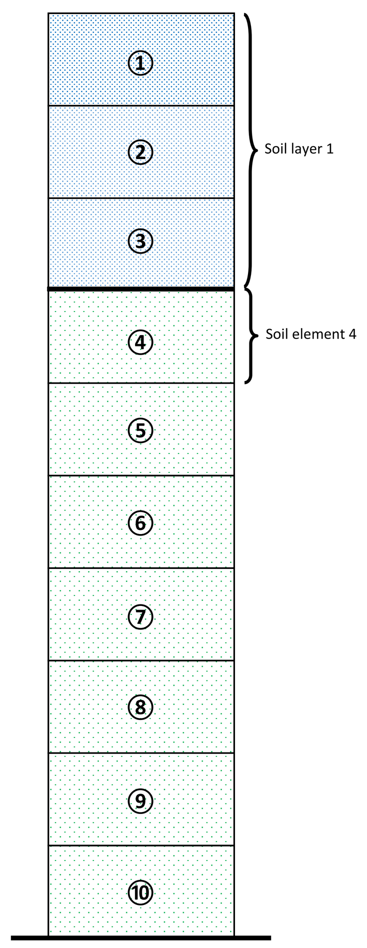
The Canterbury Earthquake Sequence 2010-2011 (CES) induced widespread liquefaction in many parts of Christchurch city. Liquefaction was more commonly observed in the eastern suburbs and along the Avon River where the soils were characterised by thick sandy deposits with a shallow water table. On the other hand, suburbs to the north, west and south of the CBD (e.g. Riccarton, Papanui) exhibited less severe to no liquefaction. These soils were more commonly characterised by inter-layered liquefiable and non-liquefiable deposits.

As part of a related large-scale study of the performance of Christchurch soils during the CES, detailed borehole data including CPT, $V_s$ and $V_p$ have been collected for 55 sites in Christchurch. For this subset of Christchurch sites, predictions of liquefaction triggering using the simplified method (Boulanger & Idriss, 2014) indicated that liquefaction was over-predicted for 94% of sites that did not manifest liquefaction during the CES, and under-predicted for 50% of sites that did manifest liquefaction.

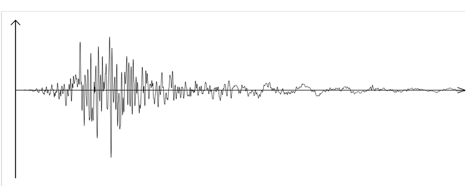
The focus of this study was to investigate these discrepancies between prediction and observation. To assess if these discrepancies were due to soil-layer interaction and to determine the effect that soil stratification has on the development of liquefaction and the system response of soil deposits.

## Method

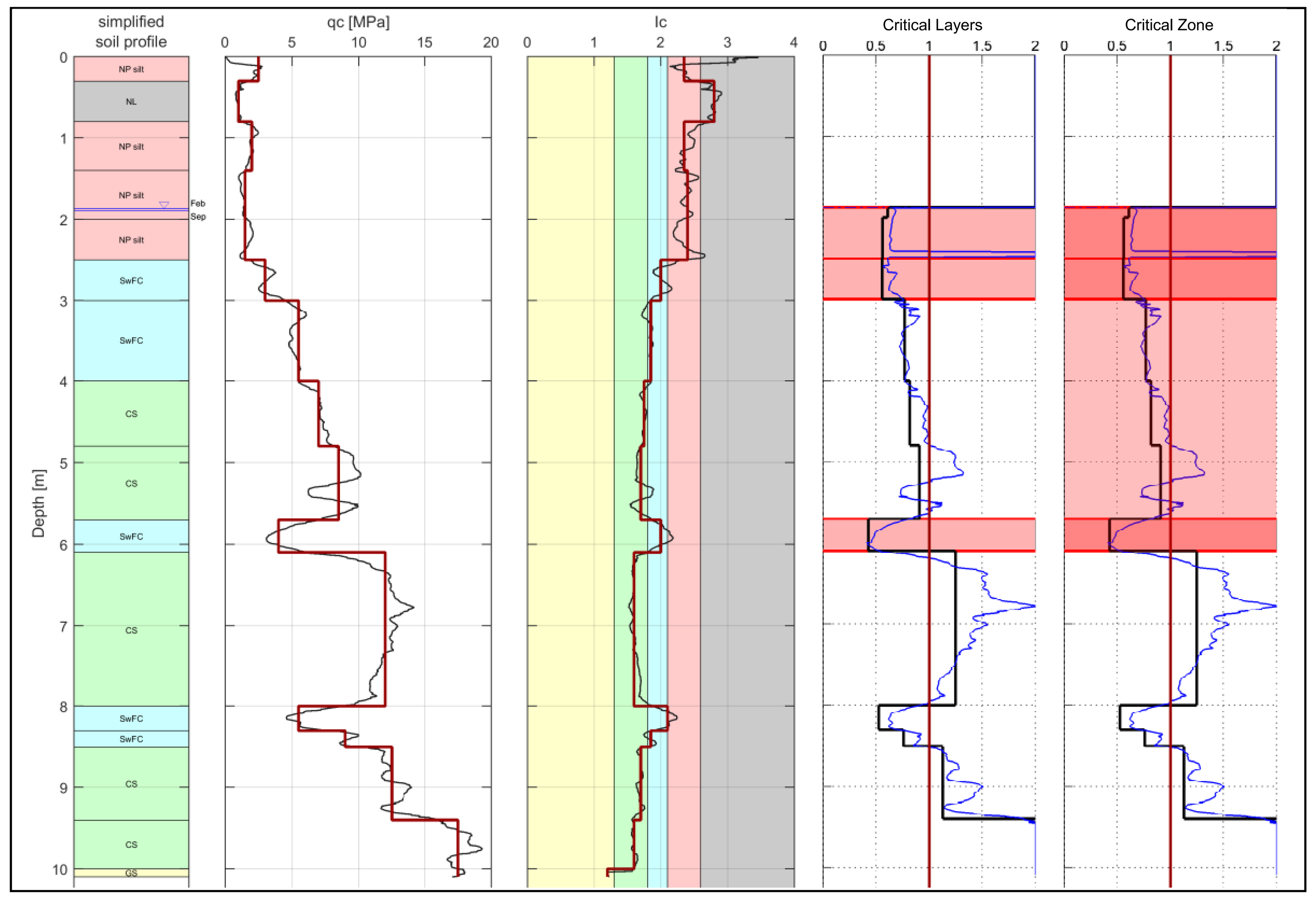
An effective stress analysis (ESA) was used with a 1D soil column model to investigate the effect of soil stratification on liquefaction development. ESA can capture key features of soil response during earthquakes including the build up of excess pore water pressure, its dissipation through water flow, and the consequent effects of ground deformation. The key input to this model was the characteristic soil profiles and soil properties.

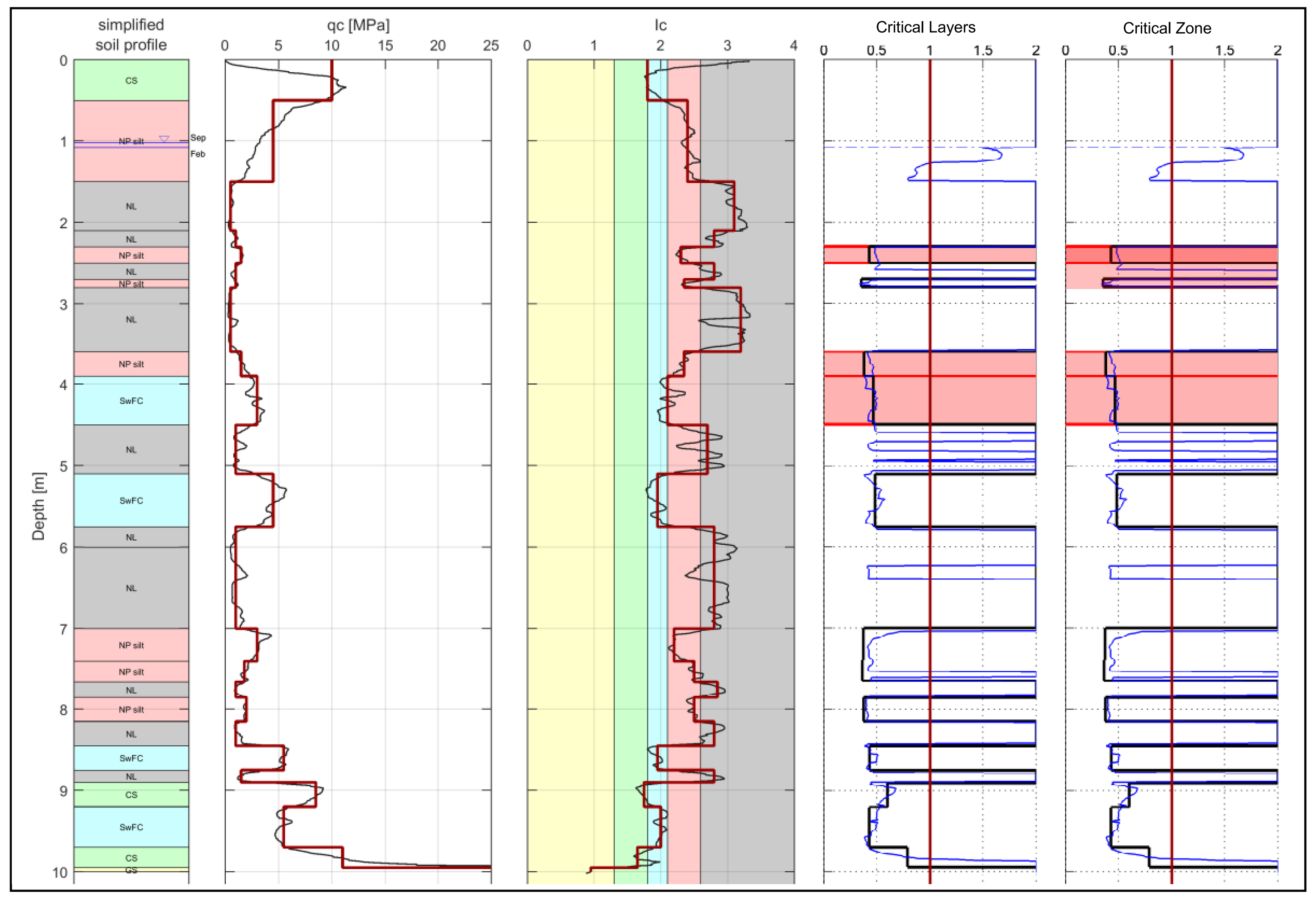



The CPT, borehole and $V_s$ data gathered for the 55 Christchurch sites was used to develop characteristic soil profiles to be used in the ESA. These were chosen to represent Christchurch soil deposits that both did (YY sites) and did not (NN sites) manifest liquefaction during the $M_w$7.1 September 2010 (SEP10) and $M_w$6.2 February 2011 (FEB11) earthquakes.



Boulanger, R. W. & Idriss, I. M. (2014). *CPT and SPT Based Liquefaction Triggering Procedures.* Centre for Geotechnical Modelling, Davis, CA
Cubrinovski, M., Rhodes, A., Ntritsos, N. (2017). *System Response of Liquefiable Deposits.* PBD III Conference Proceedings, Vancouver
Ntritsos, N. (2016). *Numerical Insights into the Engineering Evaluation of Soil Liquefaction.* PhD Research, University of Canterbury
Rhodes, A. (2017). *Liquefaction Evaluation in Stratified Soils.* ME Thesis, University of Canterbury



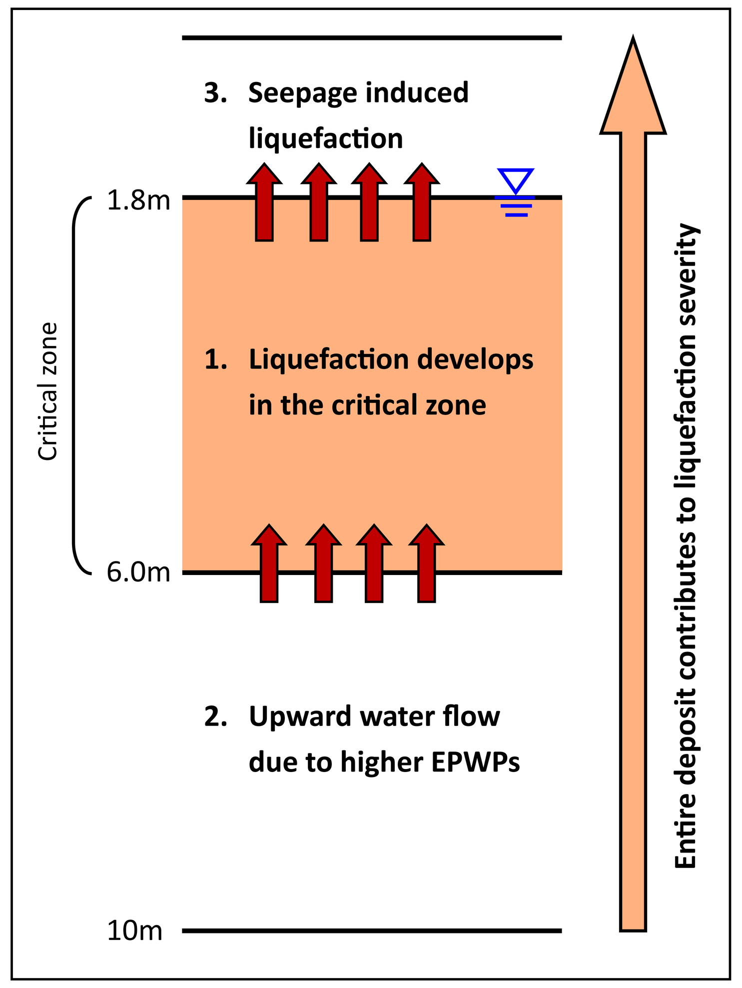




## Characteristic Profiles—YY1

- The whole soil deposit is potentially liquefiable
- The critical layer is below the ground water table and has $q_{c1Ncs}$ = 80
- The critical zone (of connected liquefiable material) is 4.2 m thick

**Results:**

- Liquefaction developed in the critical layer first
- The whole critical zone was liquefied after 10 s
- Very high excess pore water pressures developed in the layers below the critical zone (approx. 70 kPa, higher than in the critical zone even though it did not liquefy)

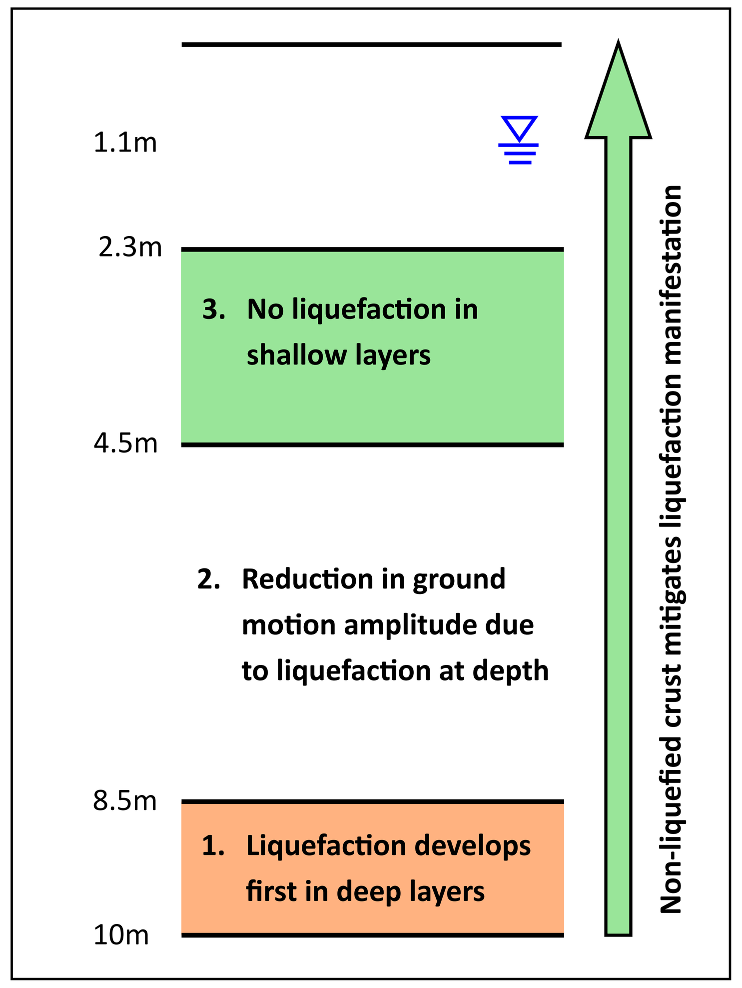



## Characteristic Profiles—NN2

- Highly interbedded profile including liquefiable and non-liquefiable layers
- Vertically disconnected critical layers
- The shallowest critical layer is below the ground water table and has $q_{c1Ncs}$ = 80
- The liquefiable layers have similar properties ($q_{c1Ncs}$) to the critical layer in the YY1 profile

**Results:**

- Liquefaction developed in the deeper critical layer first
- Liquefaction of the deeper layer caused damping of acceleration amplitudes, hence the shallower soil layers were shaken by a modified ground motion

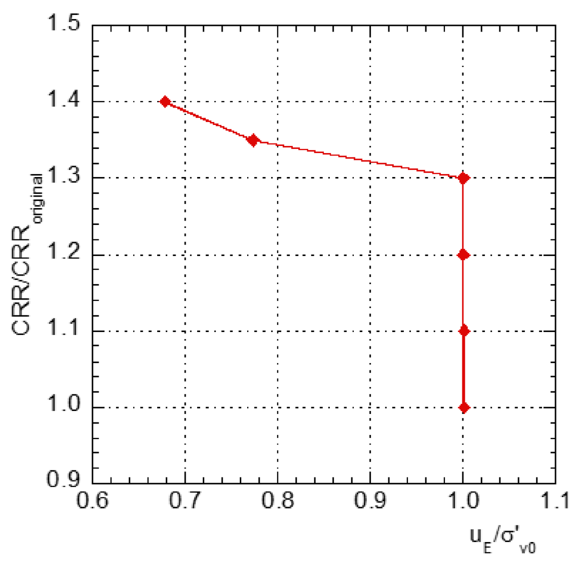



## System Response

**YY1 Profile:**

This profile is characterised by vertically continuous liquefiable layers.

1. Pore water pressure seepage from deeper layers exacerbated the liquefaction response in the critical zone
2. Pore water seepage from the critical zone into the near-surface soil layers above the water table induced seepage liquefaction of these layers.




**NN2 Profile:**

This profile is characterised by vertically discontinuous liquefiable and non-liquefiable layers

1. Liquefaction of the deeper critical layer reduced the ground motion demand (shear stresses) at the shallower layers
2. If the shallow critical layers have slightly increased liquefaction resistance (due to partial saturation), this reduction of ground motion amplitude is sufficient to prevent liquefaction near the ground surface and hence, potentially prevent liquefaction manifestation.

## Summary

The research presented herein was part of an ME thesis project (Rhodes, 2017). Mechanisms for intensification (YY sites) and mitigation (NN sites) are presented in Cubrinovski et al. (2017). The key finding of this study is that vertical communication between soil layers and the system response of liquefiable deposits is a critical factor controlling the severity of liquefaction manifestation at the ground surface.

Research is currently underway addressing additional soil profiles (NY sites that manifested liquefaction in the FEB11 but not in the SEP10 earthquakes), rigorous statistical and probabilistic analysis of the soil profiles, and rigorous modelling of the soil parameters using laboratory test results (Ntritsos, 2016).

This study focussed on one aspect of soil-layer interaction, the modification of ground motion. We recommend that further research into the effect of water flow and dissipation of pore water pressures, as well as the combination of this and ground motion modification is attempted.