
When Simplified Methods Fall Short: What Advanced Analyses Reveal About Liquefaction

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ABSTRACT

Liquefaction assessment is a key aspect of earthquake geotechnical design in New Zealand particularly in high seismic areas such as Wellington. Simplified methods, such as Idriss & Boulanger (2014), are widely used for their efficiency and strong empirical foundation. However, these approaches assess soil layers independently based on peak ground acceleration (demand) and relative density (resistance), without accounting for interactions within the full soil profile. Dynamic effective stress analyses (ESA) overcome these limitations by simulating earthquake time histories, pore pressure generation and dissipation, and the coupled soil response throughout the deposit.

This paper compares simplified methods with dynamic effective stress analyses (ESA) for three alluvial profiles across Wellington, where liquefaction strongly influences foundation and structural design. The following challenges are investigated: (1) do thin weak layers embedded in dense soils liquefy? (2) do dense layers within weaker strata liquefy? The possible implications for foundation design are discussed.

Applying ESA alongside simplified methods improves understanding of liquefaction risks, particularly in layered alluvial deposits where simplified methods may predict isolated “pockets” of liquefaction or overlook mechanisms that can affect strength loss. This approach can result in a more targeted and cost-effective risk mitigation and foundation design by distinguishing conditions where liquefaction effects are either more severe or less critical than simplified assessments suggest.

1 INTRODUCTION

Liquefaction is a key consideration for geotechnical design in New Zealand. It occurs in loose, saturated soils when cyclic loading generates excess pore pressure, reducing effective stress and causing a sudden loss of shear strength. Liquefaction is commonly defined when the excess pore-pressure ratio reaches unity ($r_u = \Delta u / \sigma'_{vo} = 1.0$).

Simplified methods such as Idriss & Boulanger (2014) are widely used due to their speed, simplicity, and strong empirical basis. They estimate whether each soil layer will liquefy by comparing cyclic stress ratio

(CSR), typically derived from PGA, with cyclic resistance ratio (CRR) inferred from CPT qc or SPT N. Although suitable for most routine applications, simplified approaches have several limitations:

- they assess each layer independently,
- they do not simulate pore-pressure generation with time,
- they cannot model stress redistribution, drainage, or complex layering effects,
- they may over- or under-predict liquefaction severity,
- method not empirically calibrated for high PGAs (say >0.45g).

Consequences can include unnecessary costly mitigation where liquefaction is over-predicted, or poor structural performance where it is under-predicted.

In more complex cases, dynamic effective stress analyses (ESA) are appropriate. The ESA procedure is an adapted version to that presented in Ntritsos, N., & Cubrinovski, M. (2020). NZGS Module 3 recommends ESA for sites with complex stratigraphy, deformation-sensitive projects, and structures of high importance. ESA uses numerical modelling (e.g., OpenSees, PLAXIS, FLAC) to simulate:

- time-dependent pore-pressure generation and dissipation,
- stress–strain behaviour throughout the deposit,
- loss and recovery of strength (cyclic mobility) and liquefaction.

This paper compares simplified and ESA results for 3 examples where pockets of liquefaction are identified in simplified methods, and the mechanisms involved which explain the different results. It also discusses the implications of the findings for foundation design, and common pitfalls designers should be aware of when carrying out advanced analyses.

2 ARE “POCKETS” OF LIQUEFACTION REAL?

In NZ, it is common for foundations to be founded in variable Alluvial soils e.g. Wellington CBD; Nelson CBD. A typical CPT profile through Alluvial soils can indicate a variable nature and it is common to find thin “pockets/lenses/beds” of weaker deposits amongst a thick dense deposit. This prompts designers to question if the liquefaction of these thin weaker deposits predicted using the simplified method are real. Conversely, the opposite can also occur, i.e. stronger thin “pockets/lenses/beds” surrounded by weaker deposits, prompting designers to wonder if liquefaction could be more severe than expected. Accordingly, the results from three examples calculated using simplified and ESA methods are compared and discussed below to provide some insight.

Case 1: Weak layer within dense soil

Figure 1 compares simplified (with thin layer corrections applied) and ESA outcomes for a single loose lens within dense material. Simplified methods predict liquefaction of the lens (indicated by red in the trigger bar on the right); ESA does not, indicated by $r_{u,max} < 100\%$ in figure ($r_{u,max}$ is the maximum r_u generated in the entire earthquake). In fact, the ESA did not even predict a rise in excess porewater pressure. Review of ESA results show that this layer does not liquefy because pore pressures from this lens dissipate into the surrounding dense or non-liquefiable material, preventing triggering.

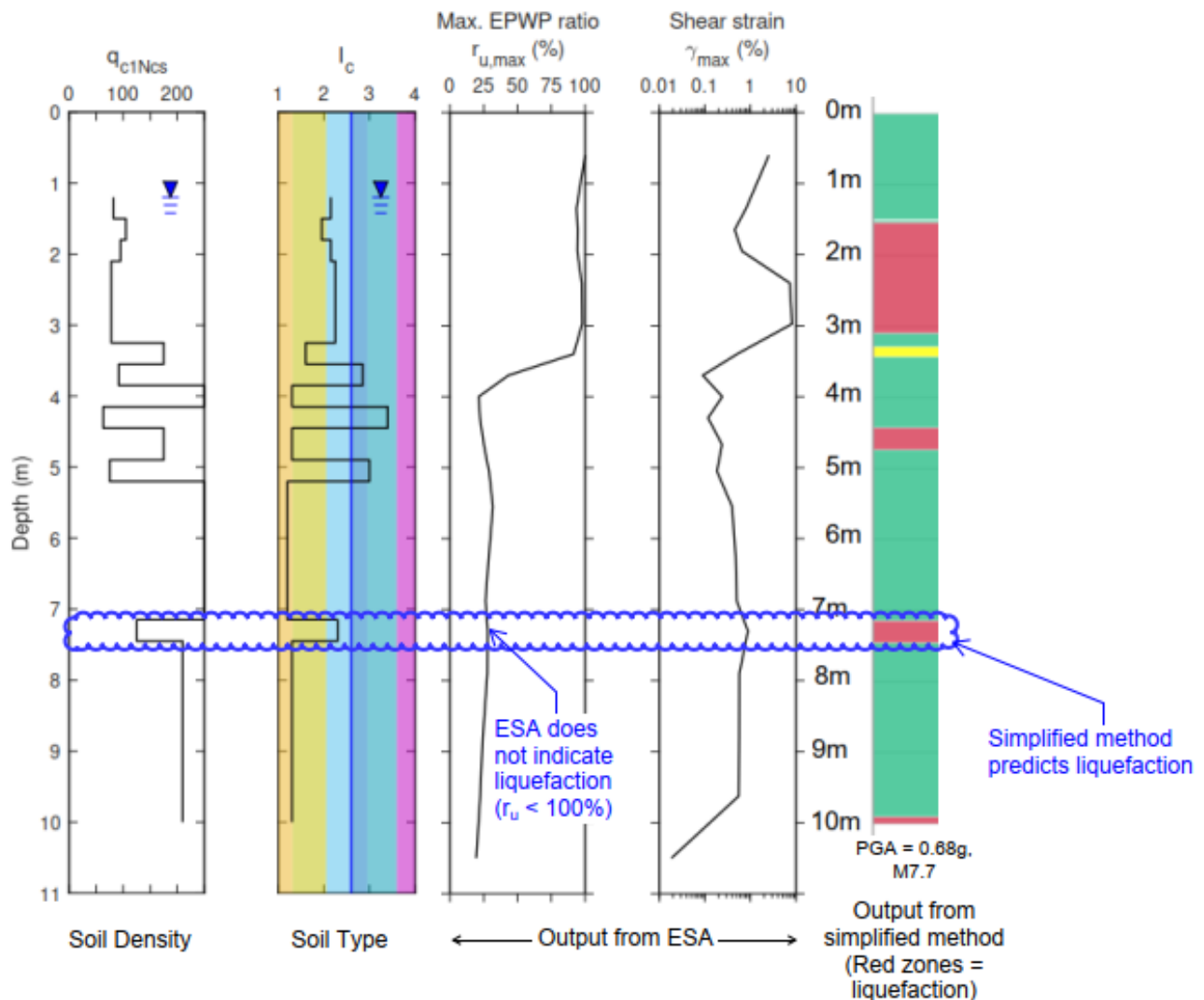


Figure 1: Case 1 - Comparison of ESA and simplified method output – Simple case with weak sub layer embedded in dense soil

Design implications:

Alluvial deposits can be highly variable and interbedded. Simplified methods typically predict isolated thin pockets of liquefaction within a dense deposit. Such engineering interpretations can lead to costly design responses such as:

- extending piles to avoid these pockets,
- designing piles as friction-only where end-bearing is deemed unreliable,
- undertaking ground improvement.

In this Case 1 example, ESA, possibly with some sensitivity analysis and selection of foundation type, could be used to justify that these design mitigation measures are not required resulting in a more cost-effective foundation.

Case 2: Dense layer within loose soil

Figure 2 shows dense layers embedded within loose material (approx. 3m, and 8m to 10m depth). The simplified method predicts no liquefaction. However, ESA identifies seepage-induced liquefaction: excess pore pressure migrates from surrounding liquefied soil, causing liquefaction of the thin dense layer. This is the opposite behaviour compared to Case 1 example.

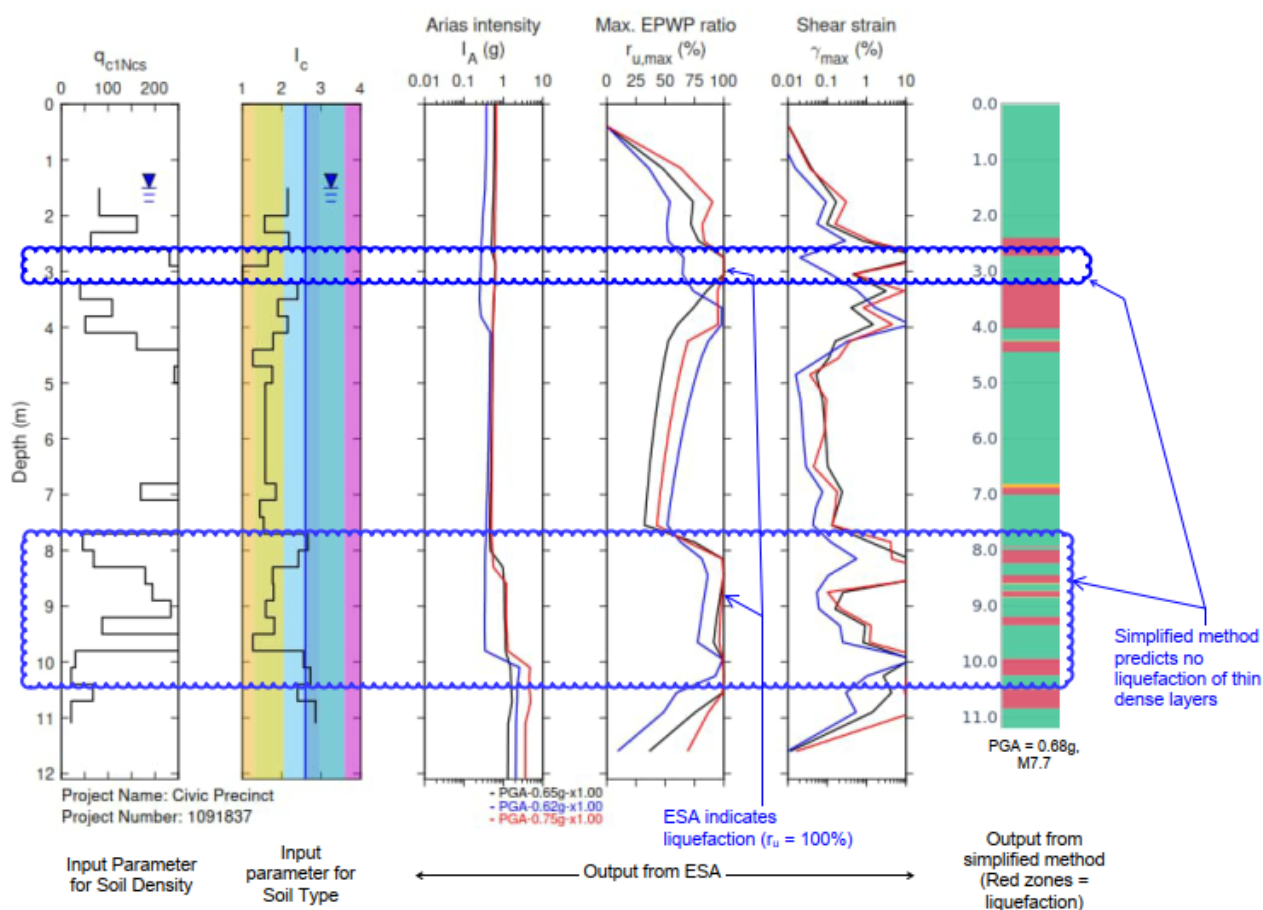


Figure 2: Case 2 - Comparison of ESA and simplified method output – Simple case with dense sub layer embedded in loose soil

Design implications:

Considering only simplified method results may result in:

- underestimating liquefaction consequences such as the magnitude of cyclic displacement and lateral spreading and therefore kinematic loading on pile foundations extending through this layer; or
- for shallow foundations founding above this layer, the bearing capacity could be overestimated as this phenomenon could reduce the thickness of the founding crust.

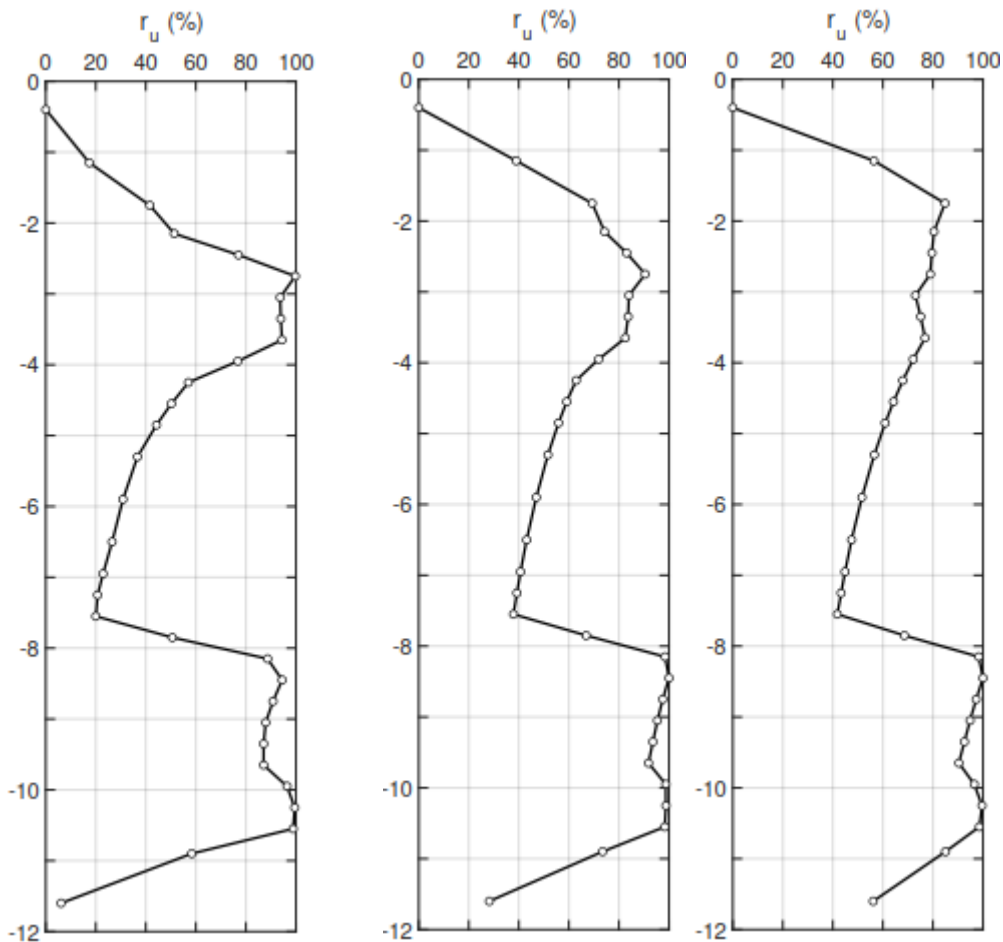


Figure 3: Excess pore pressures at 5 seconds, 15 seconds and 30 seconds

Another benefit of ESA is the ability to gain insight into soil behaviour throughout the duration of an earthquake. Figure 3 shows excess pore pressures in the profile for Case 2 at three time points in the earthquake (5 seconds, 15 seconds and 30 seconds). In this example, this shows that although the layer at 3m depth does initially liquefy (i.e. at 5 seconds), it is temporary, as excess pore pressures quickly dissipate into adjacent material (by 15 seconds), meaning the layer quickly regains some strength.

However, this dissipation increases pore pressures in adjacent soil, creating a thicker zone with reduced, though not fully liquefied, strength. This behaviour is specific to the soil type and density in this example; other soil conditions may produce different responses. Designers are therefore encouraged to carefully review results for each analysis.

Design implications:

If relying only on simplified methods, a shallow-foundation designer might consider only a weak, liquefied layer at 3 m depth and the potential for punching failure. ESA, however, shows that strength loss also occurs in the crust. A thicker zone from about 1.5 m depth experiences reduced shear strength, lowering the bearing capacity. Figure 4 illustrates these scenarios and the influence of liquefaction and excess pore pressures on bearing capacity. In this case, the reduced crust strength governs the design.

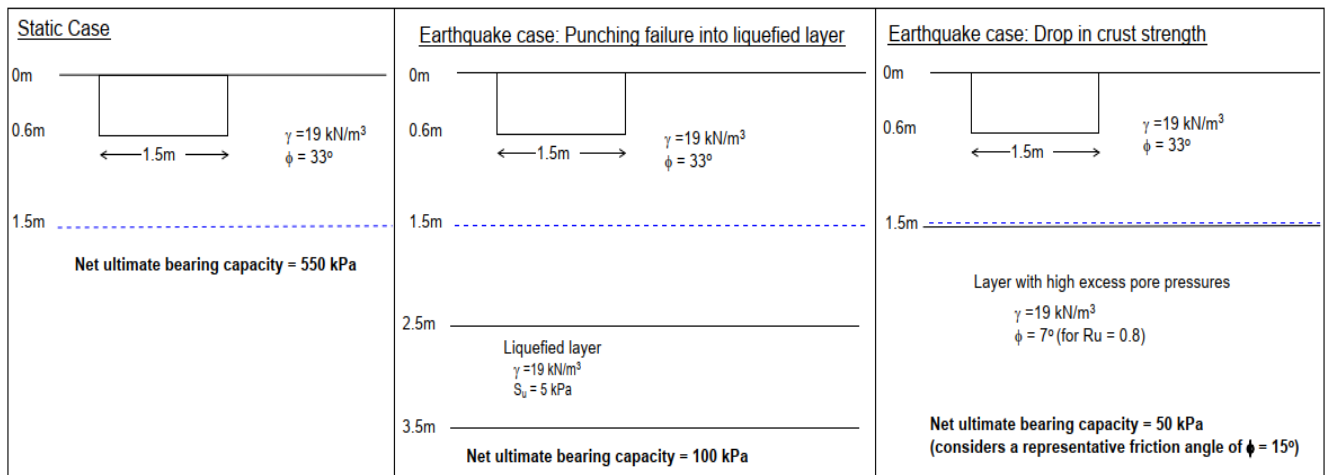


Figure 4: Design scenarios to consider for assessing bearing capacity of a shallow foundation in Case 2 ground conditions

Case 3: Highly interlayered profile

Figure 5 illustrates a more complex profile. The simplified method predicts multiple isolated liquefaction pockets to considerable depth. In contrast, ESA identifies no liquefaction from 6.5 m to 11 m (blue zone) due to drainage (excess pore water pressure dissipation) into dense layers.

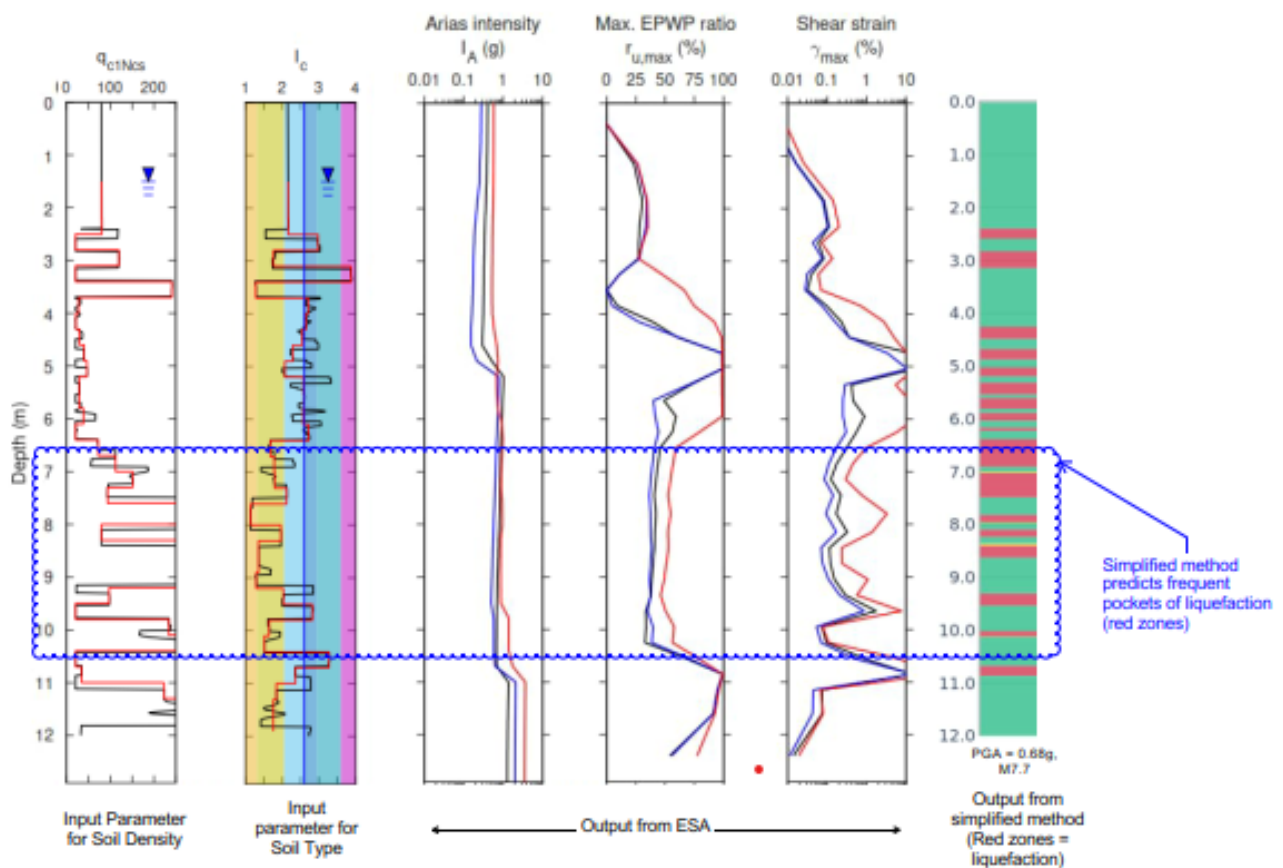


Figure 5: Case 3 - Comparison of ESA and simplified method output – Highly interlayered profile.

Design implications:

Design considering simplified methods only may result in the foundation designer considering the following:

- There is no reliable capacity in the top ~11m;
- Considerable thickness of soil imposing post-earthquake negative skin friction on the piles.

However, ESA suggests that ground from 6.5m depth is unlikely to liquefy. Therefore, a foundation designer can consider allowing for some additional beneficial skin friction and reduce the magnitude of negative skin friction to allow for. This may result in a reduction in pile lengths.

3 CAN WE BELIEVE THE RESULTS OF AN ESA?

ESA is a powerful tool and with any other geotechnical software, it should be used with care. Designers should beware of the following common pitfalls:

- **Assuming ESA is automatically more accurate than simplified methods.**
ESA can produce convincing output even when input parameters/assumptions are poor. Results must be checked against simplified assessments, case histories, and engineering judgement.
- **Using unrepresentative input ground motions.**
A single or non-hazard-consistent motion may significantly over- or under-estimate demand. A suite of hazard-consistent motions is recommended which capture a range of earthquake characteristics, and their associated impact on the soil behaviour.
- **Relying on a single CPT profile.**
Use multiple investigations to understand variability; avoid selectively choosing data or making conclusions on the basis of very limited data. Holistically draw conclusions about liquefaction potential at a site.
- **Misinterpreting r_u and liquefaction triggering.**
Equating $r_u = 1.0$ directly with liquefaction or assuming that any $r_u < 1$ means “no problem”. Soils which liquefy may recover strength quickly. Similarly, soils which never reach r_u of 1 or show cyclic mobility may still experience significant strength loss, and damaging deformations. Engineers should consider time-dependent shear strain development and post-triggering behaviour, not just maxima.
- **Incorrectly applying ESA results to foundation design.**
Soil–structure interaction and structural loads may alter soil behaviour which must be considered.

4 CONCLUSION

This study demonstrates that while simplified liquefaction assessment methods are invaluable for routine design, they can misrepresent the potential true behaviour of layered alluvial deposits common in NZ. Simplified approaches may over predict isolated pockets of liquefaction or overlook mechanisms such as seepage induced triggering, potentially leading to either overly conservative or unconservative design decisions. Effective stress analyses provide critical additional insight by modelling the time dependent interaction of pore pressures, drainage, and soil stiffness across the full profile.

The comparison of ESA and simplified methods across three cases highlights that thin weak layers within dense soils may remain stable due to drainage, while dense layers within loose strata can transiently liquefy because of pore pressure migration. These behaviours cannot be captured by layer by layer empirical screening. When used appropriately with high quality input data, hazard consistent ground motions, and engineering judgement, ESA supports more robust interpretation of liquefaction hazards and enables more targeted, cost-effective foundation solutions.

5 REFERENCES

- Idriss, I.M. & Boulanger, R.W. (2014). *CPT and SPT Based Liquefaction Triggering Procedures*. Report UCD/CGM-14/01. University of California, Davis.
- New Zealand Geotechnical Society (NZGS). (2021). *Module 3: Earthquake Geotechnical Engineering Practice – Identification, Assessment and Mitigation of Liquefaction Hazards*. NZGS, Wellington, New Zealand.
- Ntritsos, N., & Cubrinovski, M. (2020). A CPT-based effective stress analysis procedure for liquefaction assessment. *Soil Dynamics and Earthquake Engineering*, 131, 106063. <https://doi.org/10.1016/j.soildyn.2020.106063>