

Title: Liquefaction characteristics of pumiceous deposits from high-quality sampling

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Project Abstract:

Pumice materials, which are problematic from engineering viewpoint because of their crushability, are widely spread in many parts of the North Island. Following the 2010-2011 Christchurch earthquakes, a clear understanding of their properties under earthquake loading has become necessary because current empirical methods, derived from hard-grained sands, appear to be not readily applicable. In previous QuakeCoRE research projects, the applicants focused on sites where liquefaction had been observed following the 1987 Edgecumbe earthquake. They attempted to confirm the occurrence of liquefaction through empirical methods based on various field testing techniques and also examined the best available sampling technique to obtain high-quality pumice samples.

Building on the results of these projects, the aim of the current proposal is to obtain additional high-quality undisturbed soil samples from various pumiceous sites in the Waikato Plain, and perform cyclic undrained triaxial tests to characterise their liquefaction performance. Field testing, such as CPT and shear-wave velocity profiling, will be conducted at the sampling sites to supplement the characterisation. The liquefaction resistance obtained from the cyclic tests will be compared with that from field-based approach and, together with the results of previous studies, the liquefaction resistance of pumiceous deposits will be investigated.

Detailed outline of project:

Research context:

The recent earthquakes in Christchurch have demonstrated the impact of soil liquefaction to the built environment (e.g., Cubrinovski and Orense, 2010; Orense et al. 2011; Cubrinovski et al. 2012; Orense et al. 2012a). With the central government, local councils and community residents in New Zealand now fully aware of the devastating effects of earthquakes in general and of soil liquefaction in particular, attention has shifted to the seismic performance of local soils, i.e., whether soils in certain localities will undergo the same degree of liquefaction as the Christchurch soils did.

Pumice deposits, which originated from a series of volcanic eruptions centred in the Taupo and Rotorua regions, are found in several areas of the North Island. They are frequently encountered in engineering projects and their evaluation is a matter of considerable geotechnical interest. Because of their lightweight, highly crushable and compressible nature, they are problematic from an engineering and construction viewpoint. Moreover, no study is available as to whether empirical correlations derived for hard-grained soils are applicable to pumice deposits because there has been very little research done on their characteristics.

The applicants have conducted basic research on the properties of pumice sands by investigating the undrained monotonic and cyclic characteristics of pumiceous soils using triaxial compression test apparatus (Pender 2006; Pender et al. 2006; Orense et al. 2012b). Most of the tests were done on commercially-available pumice sand, which is not a natural deposit but was derived by processing sand from the Waikato River, i.e. the particles were centrifugally separated from the other river sand particles so that the samples consist essentially of pumice grains almost exclusively. The test results provided very interesting observations on the role of particle crushing and its effect on the liquefaction resistance of pumice sands (Orense et al. 2012b; 2012c; 2012d). For example, compared to hard-grained

sands, relative density does not have significant effect on the liquefaction resistance of pumice. The reason for this behaviour is possibly because the stresses imposed by the penetrometer are so severe that particle breakage forms a new material and that the properties of this are nearly independent of the initial state of the sand (Wesley et al. 1999). Thus, conventional relationships between the CPT q_c value and relative density, which in turn is correlated with liquefaction resistance, cannot be used for these soils.

The results of the above-mentioned research on commercially available pumice sands are not readily transferable to the in-situ materials frequently encountered in the field, which are characterised by high fines content, various degrees of weathering, presence of aging, soil fabric and stress history, cementation between particles and other in-situ factors. Thus, it is necessary to investigate the behaviour of undisturbed specimens while maintaining their in-situ condition. Attempts made by the applicants on limited “undisturbed” soil samples using conventional push tubes showed that penetration-based approaches, such as cone penetration tests and seismic dilatometer tests, underestimated the liquefaction resistance of pumice deposits, confirming that any procedure where the liquefaction resistance is correlated with density will not work on these crushable deposits (Orense et al. 2012b; Orense and Pender 2013). The same research showed that empirical method based on shear wave velocity seemed to produce good correlation with liquefaction resistance of pumiceous soils. Admittedly, the above conclusions were obtained from limited number of test data and such conclusions have not been well-validated. With many geotechnical practitioners constantly asking for advice on how to evaluate the liquefaction susceptibility of pumice deposits, there is indeed a need to clarify and address this issue.

Two previously-funded QuakeCoRE research projects of the applicants attempted to elucidate this further. The first investigated made use of field testing to characterise the liquefaction resistance of pumice deposits at sites where liquefaction have been observed following the Edgecumbe earthquake. Using field-obtained parameters (CPT, shear wave velocity), assessment of the occurrence/non-occurrence of liquefaction at these sites following the earthquake was done using available empirical chart-based approaches (Orense et al. 2016). The second evaluated the most appropriate sampling technique that can be used to obtain high-quality undisturbed pumice deposits from the same sites. Conventional push-tube sampling and more advanced sampling techniques, such as the gel-push sampler and Dames-Moore sampler, were used to obtain high-quality samples (Stringer et al. 2016). Although these projects are nearing their completion at this stage and the final outputs are not yet available, it is believed that more field tests and soil sampling, as well as laboratory testing, are required at other pumiceous sites in the North Island to supplement current findings.

Thus, as a continuation of these research projects, it is planned to perform laboratory tests on undisturbed soil samples to determine their liquefaction resistance. The laboratory-obtained strengths would then be correlated with the field-based strength obtained from the planned in-situ testing. Finally, the two results (lab-based and field-based strengths) will be integrated and a step-by-step procedure would be developed for characterisation and liquefaction assessment of pumiceous soils.

The overarching aim of the whole research is to supplement the previous work and further investigate the liquefaction characteristics of pumice deposits, especially those found in the upper and central North Island. The existing empirical correlations being preferred by the local profession, which are based on natural hard-grained sands may not work for the characterisation of pumice deposits and could mislead engineering assessment. It is believed that the final research outcome would address the serious issues facing local geotechnical engineers and practitioners on how to evaluate the liquefaction potential of these deposits. Currently, many large engineering projects are being constructed in volcanic areas (especially

in the Waikato – Bay of Plenty region) and the “normal” practice is to implement ground improvement measures every time pumiceous deposits are encountered. With the availability of better methods for characterising pumice deposits, significant costs spent in mitigating potentially non-existent liquefaction hazards would be reduced.

Key objectives:

The key objectives of this research proposal are as follows:

- [1] Characterise various pumiceous sites in the Waikato Region by performing field testing at designated sites through cone penetration tests, shear wave velocity profiling and high-quality undisturbed soil sampling.
- [2] Identify appropriate approach(es) for evaluation of liquefaction triggering in pumiceous deposits.

It is envisioned that the results of this project will aid in the development of industry guidelines for evaluating liquefaction potential of pumiceous soils.

Research methodology:

In order to address the above objectives, the following steps will be conducted:

- [1] Identify target sites in the Waikato Region where field testing and sampling will be performed.
- [2] Perform field testing at the designated sites. If possible, CPT and Vs-profiling and undisturbed sampling would be conducted as close to each other as possible (ideally 2m between investigations).
- [3] Obtain undisturbed pumiceous samples from the target sites using advanced (e.g. Gel-push and Dames & Moore samplers) sampling techniques. The choice of sampler for each interval will be guided by the results from the 2016 QuakeCORE project concerning the sampling of volcanic soils.
- [4] Conduct stress-controlled undrained cyclic triaxial tests on the undisturbed soil samples obtained (from previous project as well as this project) and determine the liquefaction resistance of the samples, as well as the development of strain and excess pore water pressure with the applied cycles.
- [5] Compare the cyclic resistance obtained in the laboratory with the field-based cyclic resistance estimated from field-based parameters. Also, attempt to perform energy-based and/or strain-based approach to best explain the liquefaction resistance of pumiceous soils.

Expected impacts:

One of the issues that have been constantly brought to attention by the engineering community is the lack of guidance for geotechnical characterisation and property evaluation of pumiceous soils. Such soils are often referred to as ‘problematic’ because their behaviour is poorly understood, and preliminary laboratory testing, not surprisingly, indicates that the behaviour of highly porous and ‘crushable’ volcanic materials is different from that of hard-grained sands. Therefore, existing empirical correlations based on sands may not work for their characterisation and could mislead engineering assessment. In this context, the profession is facing serious issues on many large engineering projects, especially in the Waikato – Bay of Plenty region, in relation to liquefaction evaluation of pumiceous soils and associated significant costs for mitigating potentially non-existent liquefaction hazards.

Thus, in the short-term, the research output will assist the local profession through guidelines on obtaining high-quality undisturbed soils for use in geotechnical investigation and appropriate field testing at pumiceous sites. Careful examination of the material behaviour under different loading conditions in the laboratory are expected to advance our

understanding of the similarities and differences in the behaviour of natural pumiceous deposits relative to purely hard grained material. In the long-term, the research outputs will be combined with previous, on-going and planned future work to develop design guidelines in evaluating liquefaction potential of pumiceous deposits. In addition, the planned journal publications and conference presentations detailing the research outputs will inform the end-users on how to deal with these soils.

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