Comparison of the geotechnical properties of pumice sand from Japan and New Zealand

Comparaison des propriétés géotechniques de sables de pierre ponce du Japon et de Nouvelle-Zélande

Kikkawa N.
National Institute of Occupational Safety and Health, Japan
Pender M.J., Orense R.P.
University of Auckland, New Zealand

ABSTRACT: The geotechnical properties of pumice sands from Japan and New Zealand are compared. Both of these materials are characterised by the presence of particles that are easily crushed against a hard surface under fingernail pressure. The paper gives data on the changes in particle size distribution before and after hydrostatic compression and drained triaxial shear. It is apparent from the results of drained triaxial compression tests that the shear stress continues to climb with increasing shear strain, so that there is not a well-defined friction angle. However, the mobilised friction angle reaches quite large values when the mean principal effective stress is in the range of a few hundred kPa, but decreases as the mean principal effective stress increases further. A particularly interesting feature of the drained shear behaviour of the materials is that with a sufficiently large confining pressure they tend to deform in one-dimensional compression. In general terms, the properties of these two materials of different origin are quite similar.

RESUME: On compare les propriétés géotechniques de sables de pierre ponce provenant du Japon et de Nouvelle-Zélande. Ces deux types de matériaux sont caractérisés par la présence de particules qui sont facilement écrasées contre une surface dure sous la pression de l'ongle. Des données sont fournies sur les modifications de distribution granulométrique des particules avant et après compression hydrostatique et cisaillement triaxial drainé. Il ressort des résultats d'essais de compression triaxiale drainée que la contrainte de cisaillement continue d'augmenter avec l'augmentation de la déformation de cisaillement, de telle sorte qu'il n'y a pas d'angle de frottement bien défini. Toutefois, l'angle de frottement mobilisé atteint des valeurs très élevées lorsque la contrainte effective principale moyenne est de l'ordre de quelques centaines de kPa, mais diminue à mesure que la contrainte effective principale moyenne continue de croître. Une caractéristique particulièrement intéressante du comportement en cisaillement drainé de ces matériaux est qu'avec une pression de confinement suffisamment élevée, ils ont tendance à se déformer en compression unidimensionnelle. De manière générale, les propriétés de ces deux matériaux d'origines différentes sont tout à fait similaires.

KEYWORDS: pumice, particle crushing, shear strength mobilisation, lateral strain during drained shear

MOTS CLES : pierre ponce, écrasement de particules, mobilisation du cisaillement, déformation latérale en cisaillement drainé

1 INTRODUCTION

Pumice sands derived from volcanic activity are found in Japan and New Zealand. Both of these materials are characterised by the presence of particles that are easily crushed against a hard surface under fingernail pressure. In this paper we compare the geotechnical properties of these materials. The composition of both pumice sands is dominated by silica and aluminium oxide.

Pumice deposits are found in several areas in New Zealand. They originated from a series of volcanic eruptions centred in the Taupo and Rotorua regions of the central North Island. Although they do not cover wide areas, their concentration in river valleys and flood plains means they tend to coincide with areas of considerable human activity and development. Thus, they are frequently encountered in engineering projects and their evaluation is a matter of considerable geotechnical interest. Further information about the properties of New Zealand pumice sand are given by Wesley et al (1999), Pender et al (2006) and Naotaka et al (2011).

The Japanese pumice used in this study was sampled from the Kanoya-city located on the Osumi-peninsula in the Southern Kyushu.

Individual particles are not solid but have internal voids. This is the reason for the low unit weights presented in Table 1. The particle density is not well-defined because of the internal voids, hence only typical values are given in Table 1.

2 STRESS-STRAIN-STRENGTH BEHAVIOUR

The first comparison is given in Figure 1 where the change in volume of dry pumice sand specimens under hydrostatic compression is plotted. It is apparent that the Japanese pumice undergoes considerably more volume change than the NZ material; this may be a consequence of the different particle size range of the two samples, as shown in Figure 5, and the well-sorted size distribution of the Japanese pumice.

Figure 2 presents the deviator stress – axial strain plots for conventional drained triaxial tests on specimens of the sand after consolidation under hydrostatic pressure. Figure 3 has the volume change behaviour of these specimens; note that the de-

Table 1. Physical properties of the pumice sands used in this study.

	Grain size	Typical particle density	Minimum dry unit weight	Maximum dry unit weight	Test dry unit weight
	d mm	ρ_s kg/m^3	γ_{dmin} kN/m^3	γ_{dmax} kN/m^3	γ_d kN/m^3
NZ pumice	0.05 ~1.18	2340	5.65	6.95	5.42 ~ 5.87
Japanese pumice	0.15 ~ 0.30	2489	4.34	6.41	5.70 ~ 5.77

crease in volume means that the tests were done on loose material. Also marked on these plots is a line indicating one dimensional compression, that is the volumetric strain is equal to the axial strain, hence along this line the shearing occurs without change in diameter of the specimen.

Figure 4 plots contours of equal axial strain on a set of axes with deviator stress on the vertical axis and mean principal effective stress on the horizontal axis. (The deviator stress is: $q = \sigma'_1 - \sigma'_3$, and the mean principal stress is: $p' = (\sigma'_1 + 2\sigma'_3)/3$). The first, and most important observation from these plots, is that the mobilization of the drained shear resistance for both pumice sands continues to increase with increasing axial strain, also apparent from Figure 2. Note that this is not so for the undrained test also shown in Figure 2b. Any point on the plots in Figure 4 indicates a mobilized friction angle, as the ratio of q/p' can be used to calculate the mobilized friction angle at that point. Looking at the data in Figure 4a, one can draw a tangential envelope near the origin which defines a friction angle of about 41 degrees. Next taking the highest point on the 20% strain contour the q/p' ratio defines a friction angle of about 30 degrees. Thus although the shear resistance continues to increase with increasing axial strain the mobilized friction angle decreases. Similar comments can be made about the data for the New Zealand pumice shown in Figure 4b.

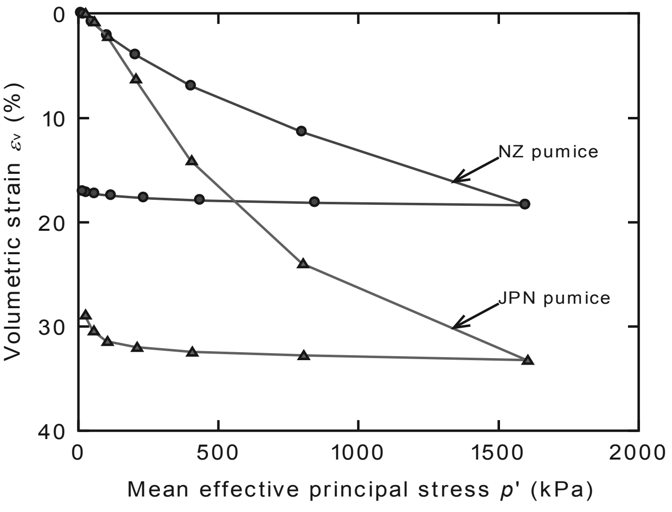
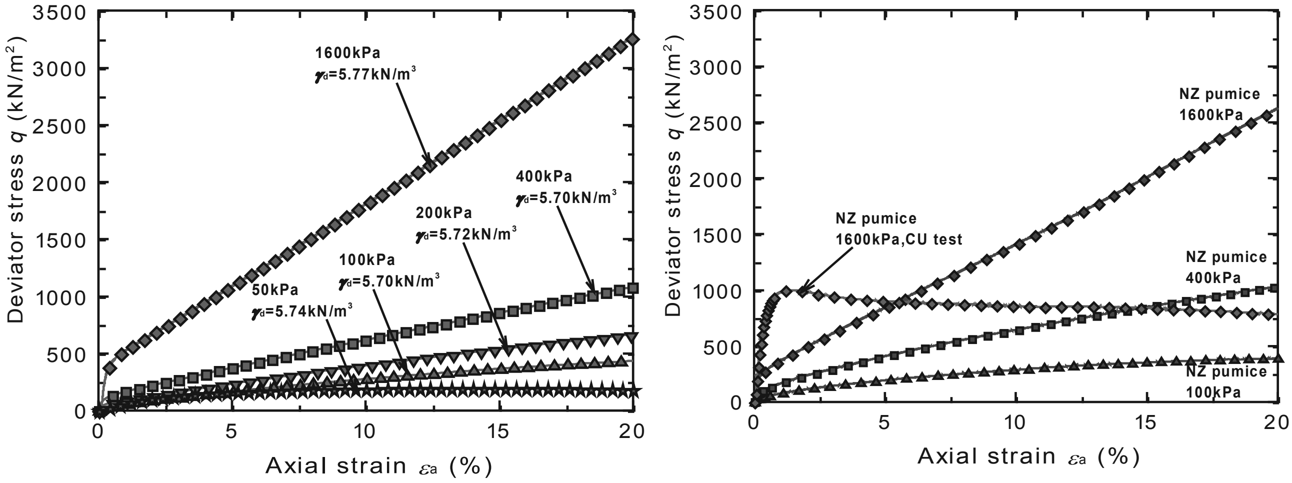
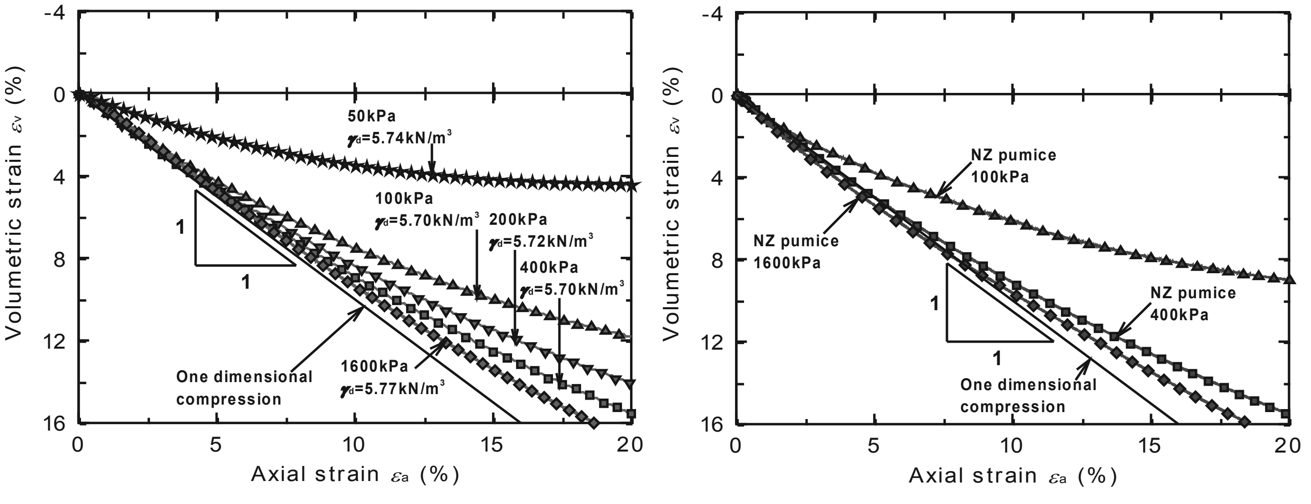


Figure 1. Volumetric strain under hydrostatic compression.



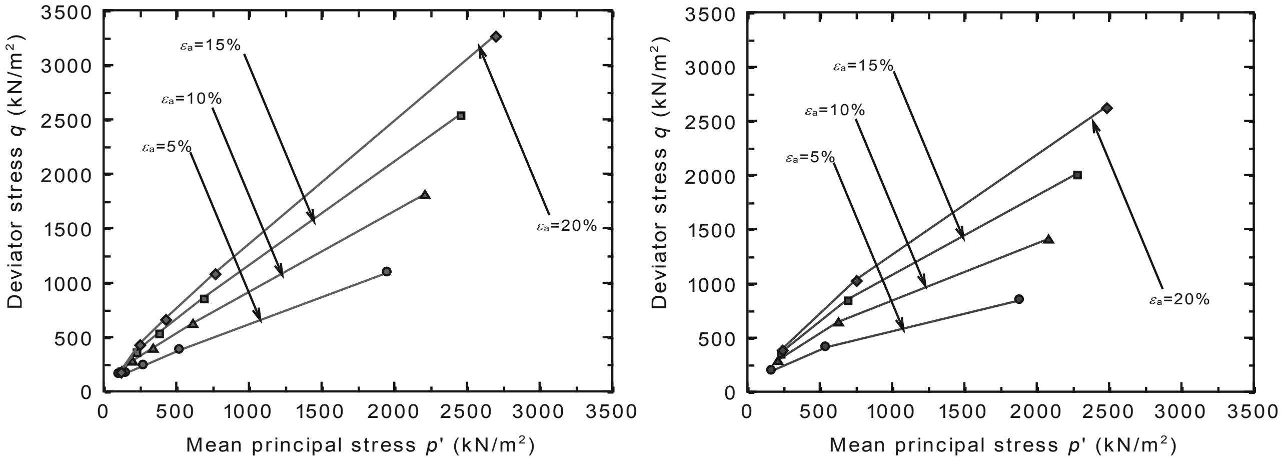
(a) JPN pumice (b) NZ pumice

Figure 2. Triaxial test deviator stress versus axial strain.



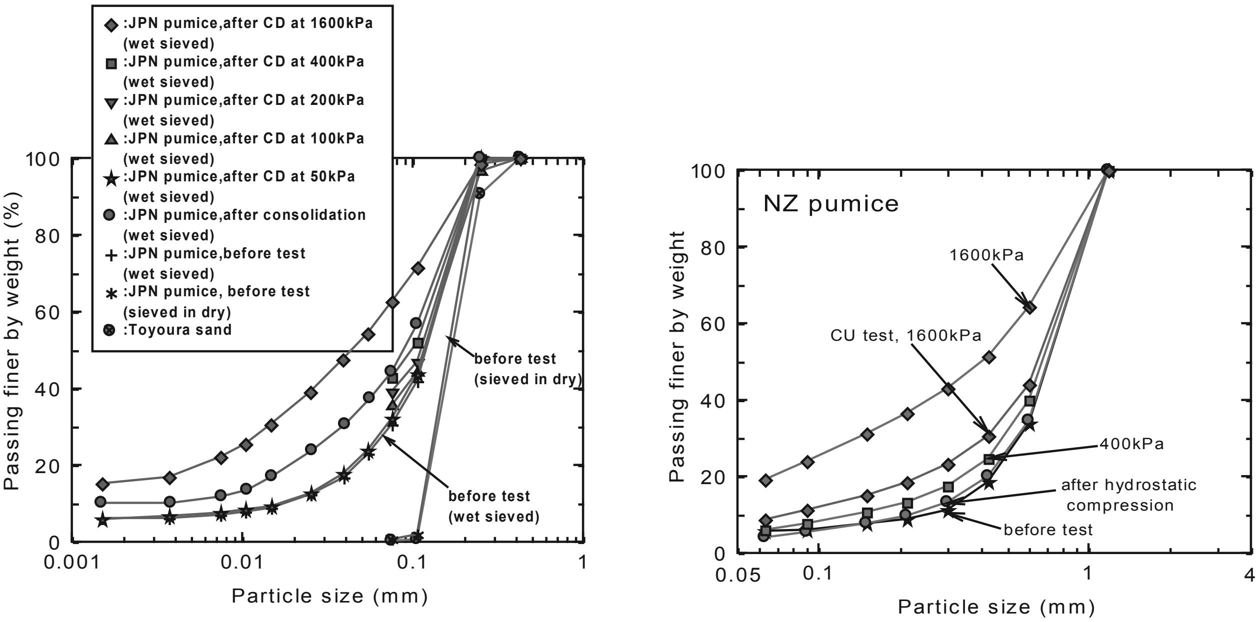
(a) JPN pumice (b) NZ pumice

Figure 3. Drained triaxial test volumetric strain versus axial strain.



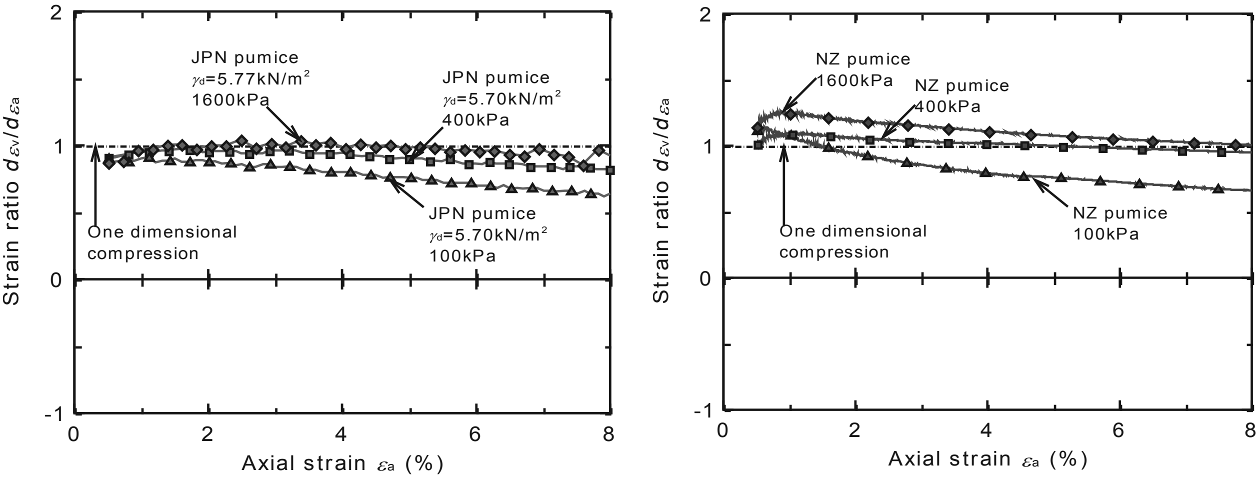
(a) JPN pumice (b) NZ pumice

Figure 4. Deviator stress against mean principal effective stress for drained triaxial tests.



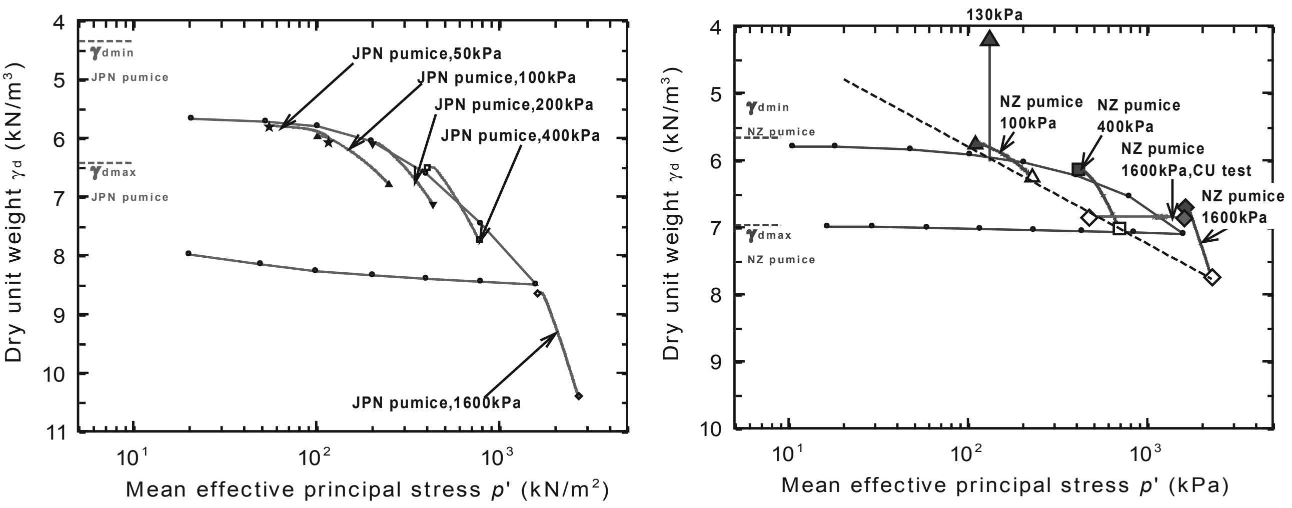
(a) JPN pumice (b) NZ pumice

Figure 5. Particle Size Distribution before and after testing.



(a) JPN pumice (b) NZ pumice

Figure 6. Strain ratio against axial strain for the drained triaxial tests.



(a) JPN pumice (b) NZ pumice

Figure 7. Paths of dry unit weight against mean principal effective stress for the hydrostatic compression and drained triaxial tests.

Figure 5 shows that for both pumice sands there is considerable particle breakage during the drained shearing and that this is progressively more severe as the confining pressure increases. Note that the Japanese pumice is much finer than the New Zealand material but the general features of particle crushing are similar for both materials. One interesting observation for the NZ material is that there is much less particle crushing for the undrained test following consolidation to 1600 kPa than for the drained test from the same consolidation pressure. The reason is because of the differing stress paths. For the drained test the stress paths for drained compression, if plotted on the set of axes in Figure 4, is a line of slope +3 upwards and towards the right. On the other hand since the specimens are loose the undrained effective stress path will move to the left and so subject the sand particles to lower effective stresses.

Figure 6 presents a surprising insight into the deformation behaviour of these materials. In the drained triaxial test the axial deformation and the volume change are measured. From this it is possible, with the usual assumption that the specimen deforms as a right circular cylinder, to determine the change in diameter of the specimen. The figure shows that for higher consolidation pressures there is zero or very little change in diameter of the specimen. In fact, for the New Zealand pumice for consolidation pressures of 400 and 1600 kPa it is seen that the diameter of the specimen actually decreases, that is there is a decrease in length because of the compression and also lateral compression. In our view this is a consequence of the large amount of particle crushing at these higher consolidation pressures. This observation was first made in the paper by Pender at al (2006) on the properties of New Zealand pumice sands.

Figure 7 plots the dry unit weight of the specimens tested on the vertical axis against the logarithm of the mean principal effective stress on the horizontal axis. In the Critical State literature diagrams such as this are plotted with the void ratio on the vertical axis. However, one of the difficulties of dealing with material having voids within the particles is that the value for the “operational” solid density is unclear. So in Table 1 the values given for the solid density are reasonable indications but not exact values. One way to overcome this difficulty is to use the dry unit weight rather than the void ratio, hence the vertical axes in Figure 7. The beginning and end points of the various shear tests are shown in Figure 7 along with the hydrostatic compression curves. For the New Zealand pumice results in Figure 7b a dotted straight line is drawn through the end points. However, this cannot be regarded as a critical state line as Figures 2 and 3 show that the state of the specimens has not reached a condition with constant q and constant volume.

3 CONCLUSIONS

The main conclusions derived from this brief comparison of the properties of New Zealand and Japanese pumice sands are:

- The properties of the materials are very similar, despite their different origins and particle size distributions.
- In drained triaxial testing, neither the shear stress or the specimen volume reaches a steady value even at axial strains of 20% (Figs. 2 & 3).
- During drained shearing particle crushing is considerable (Fig. 5).
- There is no well-defined angle of shear resistance (Fig. 4).
- At high confining pressures the lateral deformation during drained shear indicates behaviour close to one-dimensional compression (Fig. 6).
- Figure 7 indicates that the materials have not reached a critical state condition.

4 ACKNOWLEDGEMENTS

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5 REFERENCES

Kikkawa, N., Orense, R.P. & Pender, M.J. (2011). ”Mechanical behaviour of loose and heavily compacted pumice sand,” *Proc., 14th Asian Regional Conference on Soil Mechanics and Geotechnical Engineering*, Hong Kong, 23-27 May 2011, Paper 214. 6pp.

Pender, M J, Wesley, L D, Larkin, T J and Pranjoto, S (2006) “Geotechnical properties of a pumice sand.” Soils and Foundations, Vol. 46, No. 1, pp. 69-81.

Wesley, L. D., Meyer, V. M., Pranjoto, S, Pender, M. J., Larkin, T. J. and Duske, G. C. (1999) “Engineering properties of pumice sand” Proc. 8th Australia-NZ Conference on Geomechanics, Hobart, Vol. 2, 901-908.