SOME ENGINEERING PROPERTIES OF A VOLCANIC SAND

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SUMMARY

Pumice sand is widespread over the central part of the North Island due to frequent past volcanic activity. The pumice has distinct properties different from that of quartz sands. The index and engineering properties are reviewed. The most significant difference from typical quartizitic sands is the grain softness of pumice. The particles are easily crushed by a finger nail. The other major difference is the void ratio, which is about twice that of typical quartz sands. This two factors are suggested as being substantailly responsible for its different behaviour, as found in a series of consolidated drained triaxial tests on specimens with free end platens.

INTRODUCTION

Extensive deposits of volcanic sand are found in the central part of the North Island. Problems have been encountered when this sand has been involved in some geotechnical projects in the recent years. The very high erodibility of the pumice sand in a hydro development has led to a catastrophic failure in the region of canals and intake structure. These occurences highlighted the unique behaviour and properties of this pumice sand, and stimulated an interest to study to the basic engineering properties and behaviour.

The distinctive property of pumice sand is the softness of the grains, which are easily crushable under only modest finger nails pressure on a glass plate. This is in contrast with quartz sand which has very high level of crushing pressure; perhaps reached at the base of large earth dams (in the order of several MPa). This difference is expected to lead to index and engineering properties of pumice sand that are different from those of quartzitic sand. As many empirical formula are derived from sand of quartzitic origin, it may be misleading to apply them to interpret test results on pumice sand.

In situ cone penetrometre tests have been been widely used to obtain data for sand deposits. Various methods for interpreting cone test result are summarised by Lunne and Christoffersen [6] and Robertson and Campanella [8]. Considering the very high pressures developed around the advancing cone the possibility of grain crushing in volcanic sands is very high.

Some testing has been done to obtain the index properties, strength properties, and the stress-strain-volume change behaviour. With the newly developed K_0 testing apparatus, the constrained modulus D, the coefficient of lateral stress at rest, K_0, and the slope of the normally consolidation line have also been obtained. The first two parameters will be useful to develop a mathematical model of expansion of a cavity in an infinite granular medium. Using this mathematical model, one can predict the difference of the cone penetration resistance between pumice sand and quartz sand, so that the commonly available formula to interpret cone test results for quartz sand may be calibrated to be used for pumice sand. The third parameter could be used to compare with the slope of the critical state line e-log p.

BASIC PROPERTIES

Grain Size Distribution

The volcanic sand used in these tests comes from the Puni river, hence it has become known as Puni sand. It containes a small amount of impurities. Mercer No 1 sand a quarzitic material, was also tested as a direct comparison. Mercer No 1 has a very small content of pumice. They have a similar range of particle sizes in the grading curve, although the distributions are not the same. A new composition of particle sizes for test specimens (of both sands) was made by excluding particle sizes bigger than 1.18 mm and smaller than 300 μm. The proportion of the particle sizes between 1.18 mm and 300 μm was based on the natural proportion of pumice sand in this range. The ratio of diameter of specimens (70 mm) to the maximum particle size was considered to be of a reasonable order. Figure 1 shows the grading curves for natural composition of both sands and that for the test specimens.

Grain Features

The main feature of the pumice grain is the softness. A small amount of very fine particles was collected at the end of each of the traixial tests. Figure 2 shows the change in the grading curve from the inital specimen grading for tests under 150 to 500 kPa cell pressures. Increase in cell pressure results in more particle crushing and further shift in the grading curve.

Scanning electron microscope photographs were taken of both a pumice grain from Puni sand, and a quartz grain from Mercer No. 1 sand. Figure 3a below shows the vesicular nature of the pumice grain. This is typical for all range of sizes. The vesicles are formed in glassy igneous rocks by the expansion of a bubble of gas or steam during the solidification of the material. It is also apparent that there are internal voids trapped within each grain. The flaky grains have subangular to angular shapes. Some have a fin-like structure on the surface. All these features make it susceptible to grain breakage and crushing. Figure 3b shows the very different nature of a quartz sand grain, which is solid, subrounded shape, and hard.

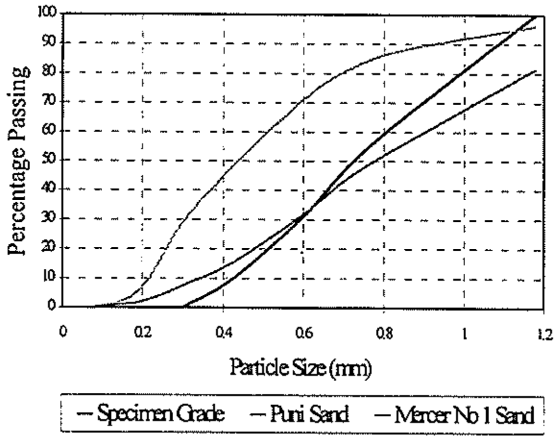

Figure 1 The natural and specimen grading curves

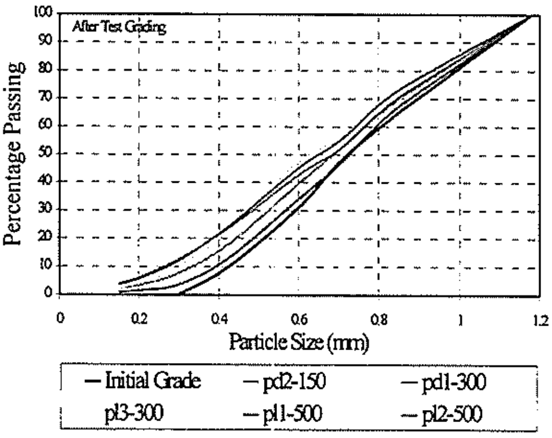

Figure 2 Grading curves initial and after test

Figure 3a Pumice grain on 710 μm sieve

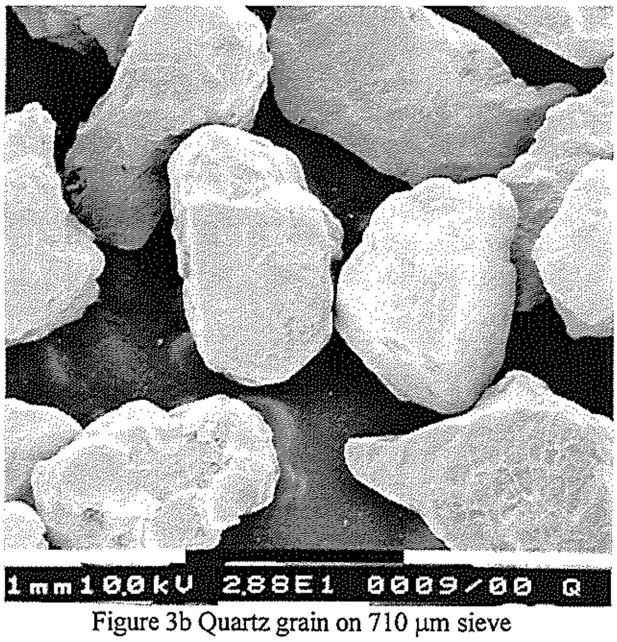

Figure 3b Quartz grain on 710 μm sieve

Specific Gravity Tests

Three series of specific gravity tests have been done on the Puni sand for each particle size range retained on the series of sieves used in determining the grading curves. The first series, which contains a small percentage of non pumiceous material, shows a clear tendency of increasing solid density with decreasing particle size, from 2.18 t/m^3 for grains on 1.18 mm sieve to 2.76 t/m^3 for grains on 75 μm sieve. As pumice is basically silica, it was expected to have an upper bound of solid density of 2.7 t/m3. However, for the fine particles of 75 to 150 μm size, which is beyond the range of sizes used in the specimen, Gs is found to be 2.76 t/m^3, greater than the supposed the upper bound. This is due to the non pumice content which has solid density greater than 2.7 t/m^3.

In the second series the impurities content was removed by a simple centrifugal technique for grain size from 300 μm up to 2.36 mm. This technique was developed as it was observed that pumice grains were light in water compared with the non pumice, some pumice even floated on the water surface. The results confirmed that larger pumice particles have a lower solid density, which implies more air trapped inside the solid. As it is very difficult to obtain pure pumice grains smaller than 300 μm, the pumice grain of 1.18 - 2.36 mm size were ground to break them into smaller particles. The very fine grains smalller than 150 μm were then collected and tested. The third test series of ground pumice shows a solid density of 2.48 t/m^3 for particles smaller than 63 μm, which is still below the solid density of silica. Figure 4 shows the consistent pattern of the solid density vs particle size.

The reported solid density of each particle size is actually an average of the results of 3 tests done simultaneously under the same conditions. It is worth noting that the variations in results were up to 0.04 t/m3, which is considerably more than that of quartz based sand. This variation was also found by Galloway [3]. The nominal solid density of the samples was calculated based on the proportion and solid density of each size range in the specimen material. For the Puni sand specimen, these procedures yields a value of 2.27 t/m3, while for Mercer No 1 sand a G_S value of 2.58 t/m3 was found.

Bulk Density and Void Ratio

Maximum and minimum densities of the specimens were obtained in accordance with NZS 4402, 1986 [12] and the corresponding minimum and maximum void ratio accordingly. The basic properties of both sands are summarised in Table 1. The void ratios for Puni sand are distinctly different, being about twice that of a typical quartz sand.

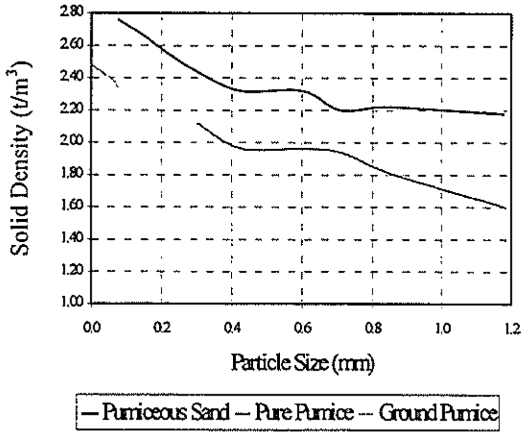

Figure 4 Solid density vs particle size

Table 1 The basic properties of the specimens

	Puni Sand	Mercer No 1 Sand
γ_{max} (t/m^3)	0.926	1.471
γ_{min} (t/m^3)	0.782	1.266
e_{min}	1.452	0.754
e_{max}	1.906	1.039
G_S (t/m^3)	2.27	2.58
d_{50} (mm)	0.73	0.73
C_U	0.741	0.741
Grain shape	flaky subangular to angular	solid subrounded

TRIAXIAL TESTING

A series of isotropically consolidated, dry, drained triaxial testing with free end platens has been carried out on both Puni and Mercer no 1 sands with 25 - 500 kPa cell pressures. These tests were done on dense and loose specimens, which were made up at the maximum and minimum void ratios. The test programme was designed to approach the critical state line both from above and below, i.e. prior to shearing some samples have void ratios larger than those at the critical state, and some others have lower void ratios.

Critical State Line

The aim of compression testing with free ends was to achieve a deformed sample in a condition known as the critical state. In this state the original structure of particles have been completely altered (Ishihara [4]), and it is achieved when the whole sample deforms homogeneously with zero volume change, zero deviatoric stress change under a constant strain rate of loading (Chu and Lo [1] ; Schofield and Wroth [11]). Developed from the idea of yield surfaces and critical voids ratio line (Roscoe, Schofield, Wroth [9]), the concept of critical state was proposed by Schofield and Wroth in 1968 [11]. This state can be achieved from any original structure and density and needs mobilisation of large strains. The critical state concept presents a unified explanation of stress-strain-volume change behaviour, although experimentally it is not easy to achieve. Hence, much discussion has occurred concerning the existence for such a state for any soil (Konrad[5],Parry [7]).

The Free Ends

Free ends were used to provide almost friction free radial expansion on the boundary of the sample. The free end was made up of an enlarged polished platten, and two layers of a rubber membrane with High Vacuum Silicon grease smeared between the membranes, and between the platen and the first membrane (Rowe, [10]; Chu and Lo [1]). The membrane was cut in a radial and circumferential fashion to lessen the constraint when it expands radially. The enlarged platen is 20 % larger than the initial sample diameter to accomodate the expanding diameter of sample as the test proceeds.

Sample Preparation

Techniques to make loose and dense specimens have been developed with reliable consistency. A dry deposition method was applied by using a small opening glass funnel to place carefully and slowly the sand at the centre of a 3 way split mould. As the funnel is raised slowly the sand will pour from the centre downward radially toward the mould at the angle of repose, and build a sand cone with the top at the tip of the funnel. When the elevation of sand in the mould has reached the required height, the surface is levelled off by a vacuum process to remove the excessive sand. The same technique is applied for a dense specimen, except that the sample is placed on a vibrating table prior to removal of the excess sand to achieve the minimum volume.

Results and Discussion

Figure 5a and 6a show that the deviator stress vs axial strain curves of Puni sand and Mercer No 1 sand have a different pattern. The peak and residual stress for Mercer sand were typically achieved at 5 - 15 % axial strain, while for Puni sand the strain was from 10 % to 50 % (even more for loose specimen under 500 kPa cell pressure, test pl6-500). A rapid and marked decrease from peak stress to residual stress is also demonstrated for Mercer sand, as opposed to a lower gradient and smaller decrease in stress for Puni sand specimens.

For the Puni specimens, some portion of the voids are actually recesses on the grain surface, while some occur between the fin-like structures on the surface. This portion is not accesible by the moving grains during the shearing process. However, it seems of no major relevance as indicated in Figure 5b and 6b that a much larger percentage of void ratio in contractive Puni sand specimens was reduced than that of Mercer No 1 sand specimens. In other word Puni sand is highly compressible, and it requires a large strain mobilisation before the peak and/or residual stress are achieved. The high compressibility is very likely facilitated by the flaky angular shaped grains, which is responsible for the high void ratio, and the softness of the grains which results in fracture during compression tests and give leads to a large reduction in the void ratio. The amount of particle crushing is not completely reflected in the shift of the grading curve as some of the fractured grains derived from angular particles will still have the same effective particle diameter.

The critical state lines are shown for both Puni and Mercer No 1 sands on the e vs log p' curves in Figure 5b and 6b. The critical state parameters for the e vs ln p' plane are derived as follows:

Puni sand: $\lambda = 0.347$, $\Gamma_1 = 4.400$

Mercer No 1 sand: $\lambda = 0.119$, $\Gamma_1 = 2.603$

where: λ = the slope of critical state line

Γ_1 = the specific volume at $p' = 1$ kPa

p' = the mean effective pressure = $(\sigma_1' + \sigma_2' + \sigma_3')/3$.

The pumiceous sand results give a clearer definition of critical state line than those of the quartzitic sand. This may be due to the difficulty in achieving stabil dilatative samples which expand uniformly along the height.

Compared with other sands' critical state lines (Collins et al [2]), the location of Puni sands is very remote from the other reported results. For example, Ottawa sand and Reid Bedford sand were reported as having $\lambda= 0.028$, $\Gamma_1= 1.754$; and $\lambda= 0.065$, $\Gamma_1= 2.014$, respectively. The slope of critical state line for Puni sand is also found to be parallel with the normally consolidated line obtained from the K_o tests ($\lambda=0.375$), an agreement which is expected within the framework of critical state theory (Figure 7).

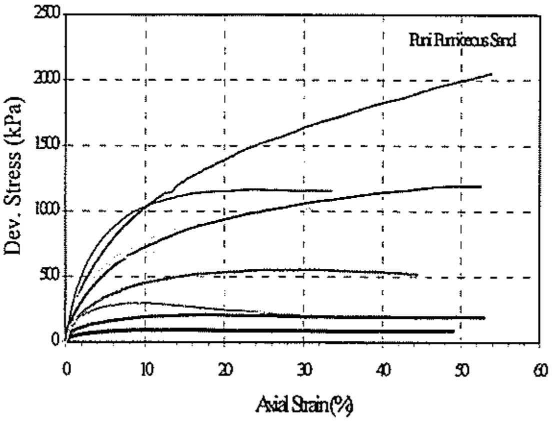

Figure 5a Deviator stess vs axial strain curves (Puni Sand Tests)

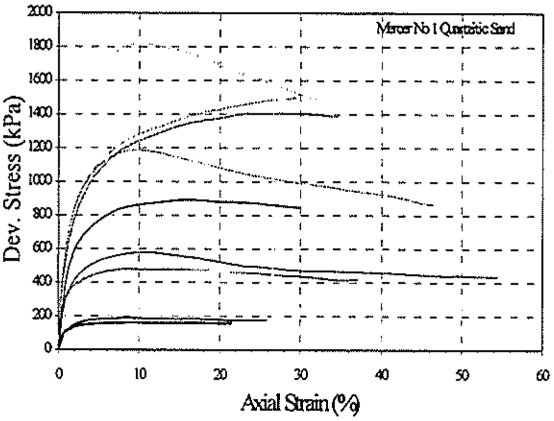

Figure 6a Deviator stress vs axial strain curves (Mercer No 1 Sand Tests)

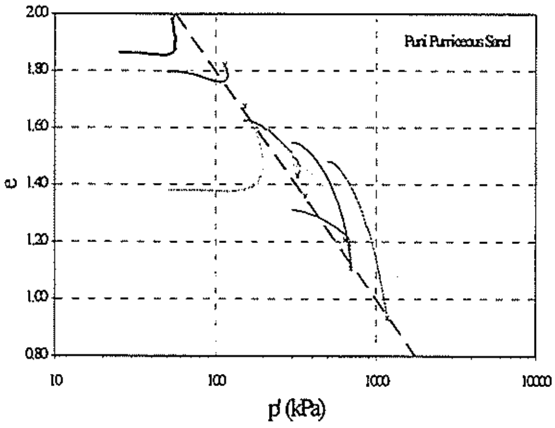

Figure 5b Void ratio e vs log p' curves (Puni Sand Tests)

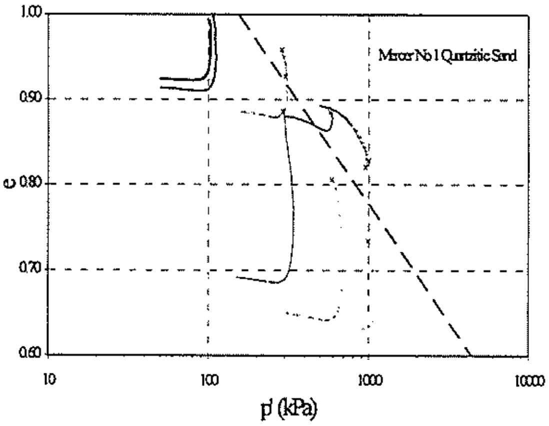

Figure 6b Void ratio e vs log p' curves (Mercer No 1 Sand Test)

Legend for Figures 5a and 5b:

— p18-25 — p15-50 — p14-150
p13-300 — p17-300 — p16-500
pd5-50 pd2-150 — pd3-300
— cs-line

Legend for Figures 6a and 6b:

— q15-50 — q17-50 — q12-150
q16-150 — q11-300 — q13-500
— q18-500 — qd3-150 qd1-300
qd2-500 — cs-line

Table 2 indicates that the internal friction angle ϕ' is not solely dependent on the hardness of the grain nor the compressibility. Nevertheless the high maximum strength of Puni sand is unlikely to be utilised since it requires mobilisation of deformation beyond the range of normal engineering practice.

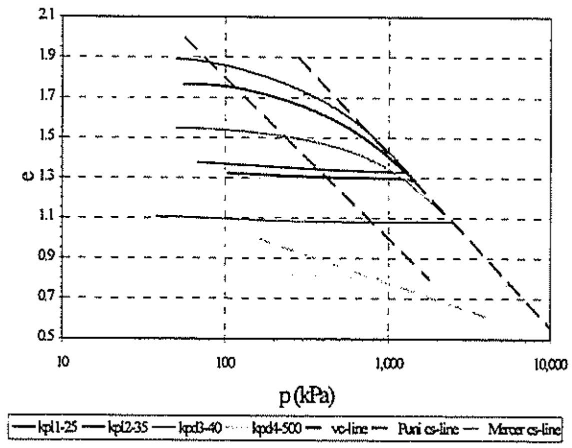

Figure 7 e vs p' from K_o test for Puni Sand

Table 2 Peak and residual internal friction angle ϕ

	Dense	Loose	Residual
Puni Sand	44	41	41
Mercer No 1 Sand	41	38	38

CONCLUSION

The basic engineering properties and behaviour of Puni sand has been identified. The trapped air in the "solid" grain of Puni sand results in a decreasing solid density with increasing particle size, and a high variation of the solid density results between the simultaneously conducted tests for a particular particle size range. The high compressibility of Puni sand specimens is responsible for the large strain mobilisation required to achieve the peak and residual stress. The softness and flaky angular shape of the grains are suggested as the key factors of the high compressibility. Although the Puni grain is easily crushed by finger, it has peak and residual internal friction angles greater than 40 degrees. The critical state line was also successfully determined for both sands. The one dimensional consolidation line, from K_o tests, was found to be parallel with the critical state line.

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