Engineering Properties of a Pumice Sand

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Summary Extensive deposits of pumice sand are found in various parts of the North Island of New Zealand, and their soft grained nature raises questions about their engineering properties. This paper describes an investigation of the basic properties of such a sand. The first part of the investigation involves laboratory measurements of compressibility and strength, and the second part looks at penetrometer resistance using a calibration chamber. Parallel tests on the pumice sand and a quartz sand are conducted in each case. The results are surprising. The ϕ' values of the two sands are almost identical, although the pumice sand has higher compressibility. The penetrometer resistance of the pumice sand is almost independent of relative density, and only moderately influenced by confining stress. Conventional correlations between cone resistance and relative density are clearly not applicable to the pumice sand.

1. INTRODUCTION

Pumice sands are found in various parts of the North Island of New Zealand, especially along the lower Waikato River valley and in parts of the Bay of Plenty. Although they do not cover wide areas, their places of concentration in river valleys and flood plains coincide with areas of considerable human activity and development. Consequently they are not infrequently encountered in engineering projects and their evaluation is a matter of considerable interest to geotechnical engineers.

The sand is characterised by the vesicular nature of its particles; each particle contains a dense network of fine holes, some of which are inter-connected and open to the surface, while others appear to be entirely isolated inside the particles. This results in particles which are light-weight, have very rough surfaces, and are easily crushed, especially when compared to more "normal" hard grained sands such as quartz sand. This paper describes an investigation of the properties of a particular pumice sand, firstly by conducting laboratory tests and secondly by investigation of cone resistance using a calibration chamber. Identical tests on a quartz sand of similar particle size are carried out so that comparisons of behaviour can be made.

2. THE SANDS TESTED

The two sands were obtained from sand processing plants that dredge sand from the Waikato River. Although they are natural sands in the sense that they occur naturally in the river, they are both processed materials, the pumice sand having been separated out from the quartz sand dredged with it, and the quartz sand processed to remove any soft grains. The sands were selected to have particle size distributions as similar as possible; these are shown in Figure 1. Standard tests on both sands gave maximum and minimum density values and void ratios as shown in Table 1.

Table 1. Properties of the two sands.

		Pumice	Quartz
Dry Density kg/m^3	Max	730	1520
	Min	620	1320
Void Ratio	Min	1.42	0.71
	Max	1.85	0.97

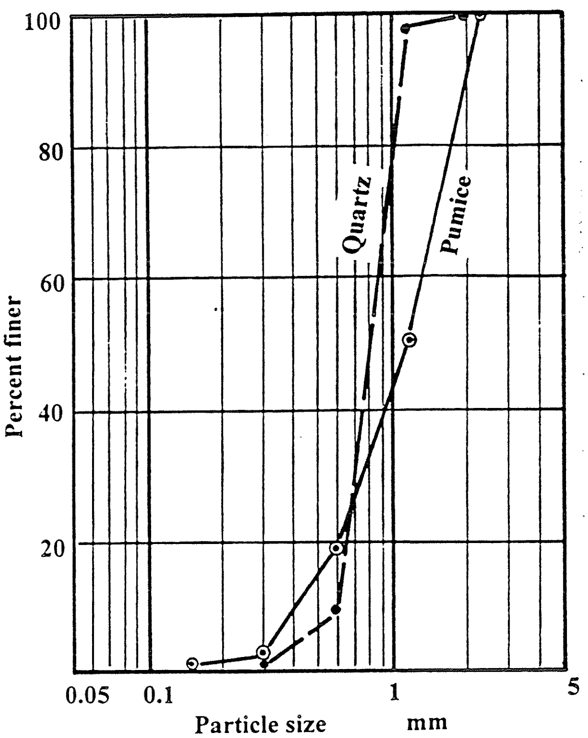

Figure 1. Particle size curves of the two sands.

3. LABORATORY TESTING

3.1 General

All laboratory measurements have been carried out on dry samples. It is not practical to carry out large chamber tests in any other way, and for uniformity the same procedure has been adopted for the laboratory tests. An indication of the strength of the pumice grains has been obtained by carrying out unconfined compression tests on several cubical samples trimmed from relatively large particles of pumice believed to be of similar composition to the grains of which the sand was composed. These samples averaged about 50mm in length and about 20mm in width. The average value of unconfined compressive strength was 2.7 MPa. This is very low compared with the values expected from hard materials such as quartz, which would be in the order of 50 to 100 MPa.

3.2 Specific Gravity

Some explanation is necessary with respect to the void ratio values given in Table 1. To calculate void ratio it is necessary to know the specific gravity of a material and this is rather problematical in the case of the pumice sand. If the specific gravity is measured in the standard way using vacuum extraction to remove air, it will almost certainly mean that air is removed from the holes inside the particles as well as the void space between the particles, and the calculated specific gravity will apply to the material of which the particles are composed rather than to the particles as a whole. The void ratio calculated on this basis would then be likely to represent the total void volume, made up of both the free voids between the particles and the voids trapped within the particles themselves.

To investigate this issue and to try to arrive at an appropriate value of specific gravity for use in void ratio calculations a series of specific gravity tests was carried out on a range of pumice samples consisting of fractions of different sizes. The material was crushed and sieved to obtain these fractions. The tests were done in two ways. Firstly, a simple displacement technique was used without air extraction, and secondly the standard procedure was used. The belief was that the first tests would minimise penetration of water into the internal voids and would thus give the particle specific gravity, while the second tests would maximise penetration into the internal voids and would give specific gravity values approaching that of the material of which the pumice was composed, assumed to be quartz. The results are shown in Fig 2.

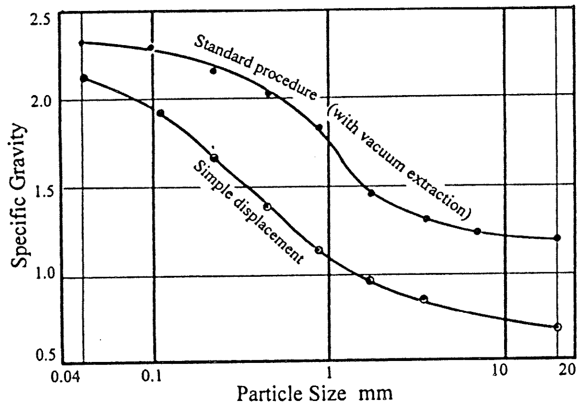

Figure 2. Specific gravity measurements on pumice sand.

It is seen that there is a substantial difference between the two values for all particle sizes, as would be expected, and that both values steadily increase as the particle size decreases. It appears that as the particle size is reduced the proportion of the internal voids into which water penetrates during the tests increases and the measured specific gravity increases. It seems surprising that even with the very fine fraction the specific gravity value does not approach that of quartz, so that even the very fine particles contain internal voids into which water cannot penetrate. The tests confirm that the internal voids in the particles are not all interconnected.

The tests throw some light on the nature of the material but they do not entirely resolve the question of the appropriate specific gravity value to use in calculating the void ratio. The changing specific gravity value with particle size suggests that even when using a simple displacement procedure and no vacuum extraction of air, some water penetrates the internal voids, and that the proportion increases as the particle size decreases, as already noted. Using the specific gravity from the simple displacement technique appears likely therefore to still lead to an overestimate of the true void ratio. The lesson from these tests is that comparisons of behaviour using void ratio as a reference parameter are subject to considerable uncertainty and likely to be misleading. The specific gravity value used for calculating the void ratios in Table 1 was 1.77, which was the value obtained with the simple displacement procedure.

3.3 Compressibility

The comparative compressibility of the sands in their loose and dense states has been measured by means of conventional oedometer tests. The results are given Figure 3 and clearly show the pumice sand to be much more compressible than the quartz sand. It appears to be about four times as compressible in both the loose and dense states.

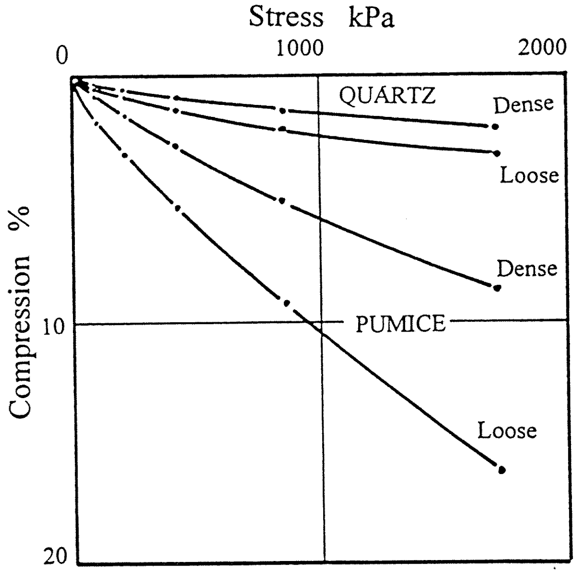

Figure 3. Compressibility measured in standard oedometer tests.

3.4 Triaxial Tests

The triaxial tests have been performed using free end platens on samples of a nominal diameter and length of 70mm. The intention with this procedure was to induce uniform strains and to continue the tests to large strain values. The oversized "free end" platens had a diameter 15% greater than the sample diameter, and two layers of thin rubber sheeting with silicone grease between them were placed between the sample and end platens. Small porous stones were inset at the centre of the platens. All tests were "drained". The loose samples were prepared by pouring through a funnel and the dense samples prepared by vibration. Typical behaviour

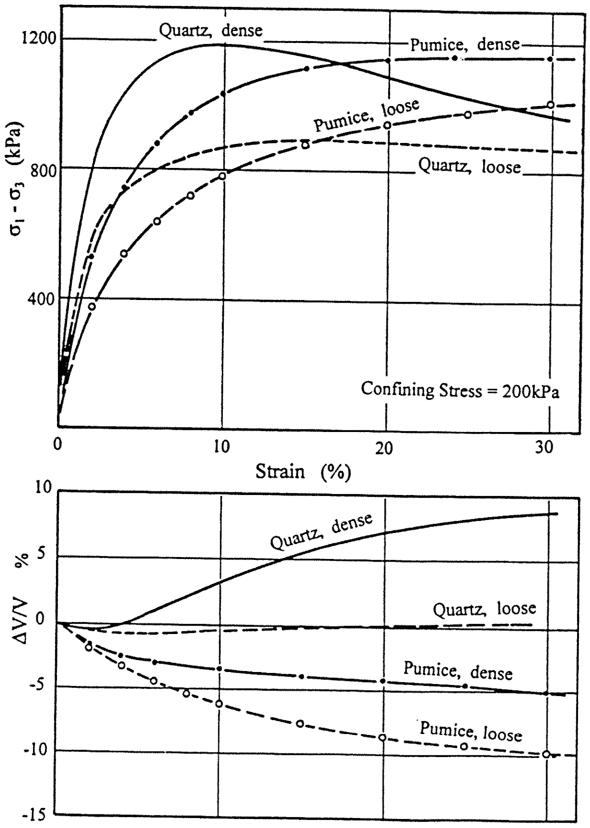

Figure 4. Typical triaxial behaviour.

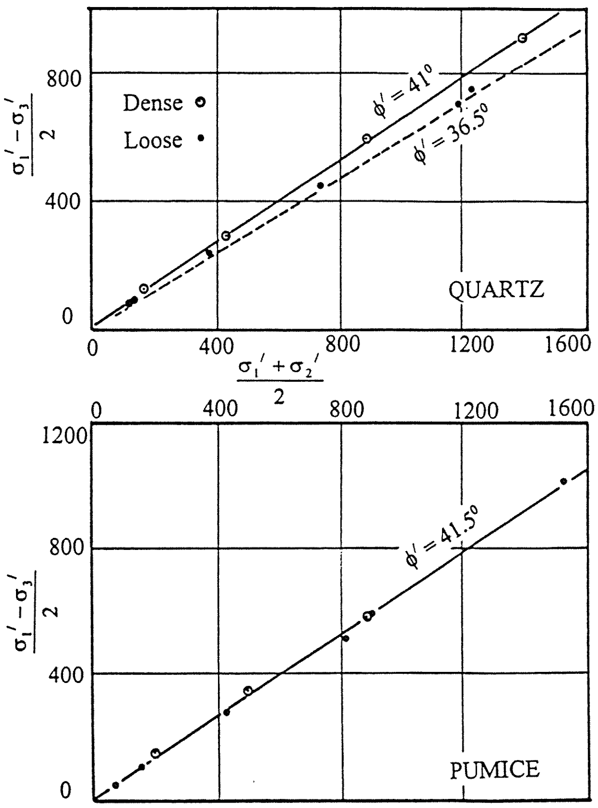

Figure 5. Failure values in triaxial tests.

during triaxial testing is illustrated in Figure 4. This shows results from loose and dense samples at a confining stress of 300kPa. It is seen that the ultimate strength of the two materials is not very different, but the strain to reach this strength is much greater with the pumice sand than the quartz sand. Also the volume change behaviour is quite different; the quartz sand shows considerable dilation in the dense state and marginal dilation in the loose state while the pumice sand shows considerable contraction (volume decrease) in both states.

The failure values from all the triaxial tests are plotted in Figure 5. These show a typical difference of about 5^0 in the ϕ' values for the loose and dense states of the quartz sand, but very little difference in the case of the pumice sand. The ultimate strength of the pumice sand for both states approaches that of the quartz sand in the dense state. The fact that the ϕ' value for the pumice sand does not alter significantly between loose and dense states is perhaps not surprising in view of the fact that the deviator stress curves do not show peaks. However it does seem surprising that the ϕ' value of the pumice sand is as high as that of the quartz sand in the dense state.

As already mentioned in relation to Figure 4, the strain to failure and the accompanying volume change is much greater in the case of the pumice sand than the quartz sand. To further illustrate this difference in behaviour Figure 6 has been prepared. This summarises the data from all of the tests, and illustrates very clearly how much greater both strain to failure and volume change are in the case of the pumice sand.

With the pumice sand, the strain to failure in the tests at high stress levels is somewhat arbitrary, since the deviator stress was still tending to increase even at the very large strain values to which the tests were taken (greater than 30%).

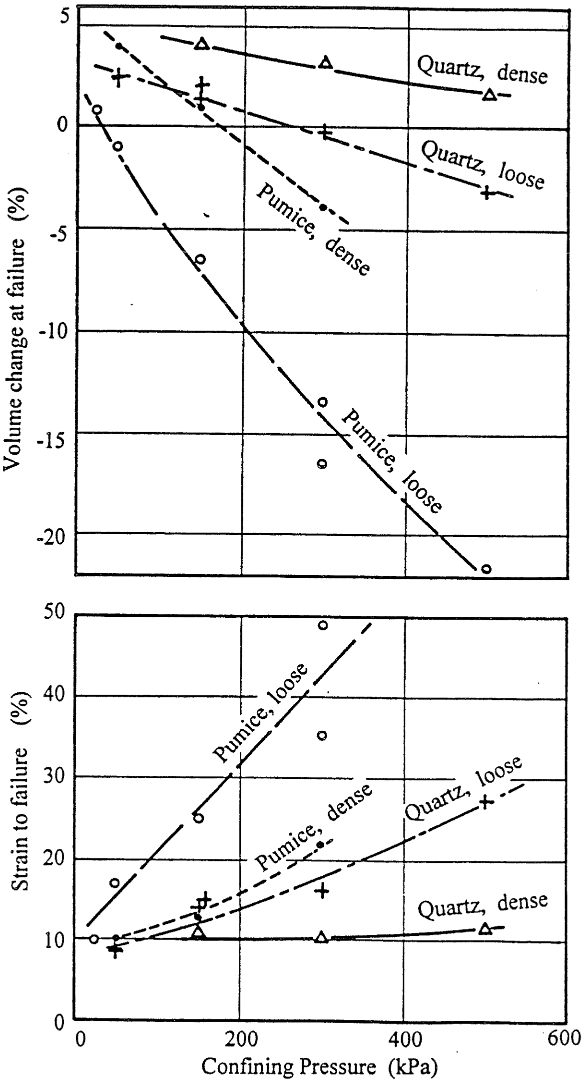

Figure 6. Volume change and strain to failure in triaxial tests.

4. PENETROMETER TESTING

4.1 The Calibration Chamber

A series of tests was carried out using a "calibration" chamber, the principal objective being to find out whether standard correlations developed from hard grained sands can be applied to soft grained materials such as pumice sand. Each test was carried out twice, firstly on the pumice sand and secondly on the quartz sand. The correlations in question are those which relate cone resistance to relative density and vertical effective stress. Such correlations have been based primarily on tests done using large containers known as calibration chambers. Various types and sizes are in use in laboratories around the world. The calibration chamber used for the current tests was one of the earliest ever made, having been developed by the Country Roads Board of Australia and Monash University in the nineteen sixties. Its loan to Auckland University was made possible by Dr Alan Parkin, senior lecturer in geotechnnical engineering at Monash University.

The chamber is composed of a double walled barrel, a base piston and a top lid, and is shown schematically in Figure 7. It is approximately 1m tall and 0.8m in diameter. The sand specimen is enclosed at the side and base by rubber membranes, with the side membrane sealed around a platen at the top of the specimen. Vertical stress is applied to the specimen via the base piston using water under controlled pressure. Radial stress is controlled via the water-filled annular space surrounding the specimen. For the current tests K_0 conditions were maintained by preventing water entering or leaving the annular space. The penetrometer used was a standard 60^o cone with and an area of $10cm^2$ and

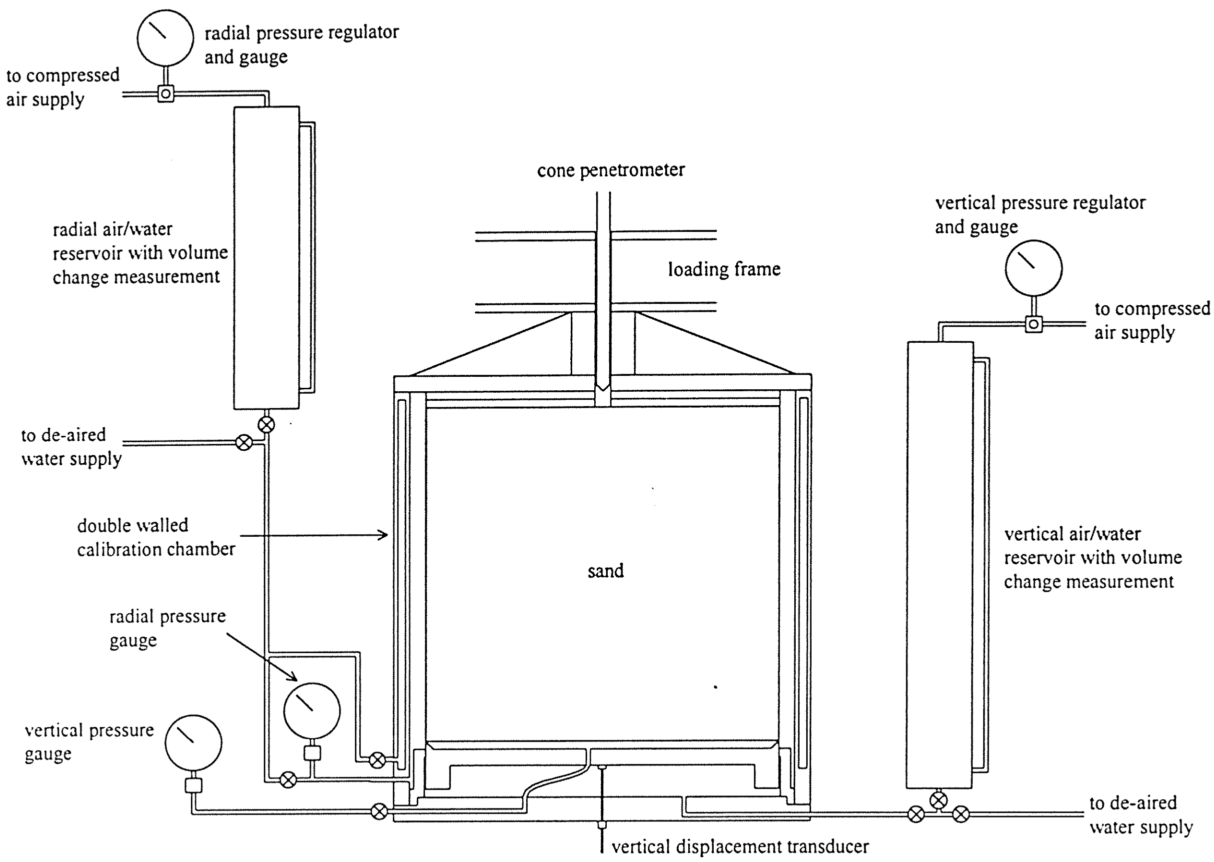

Figure 7. Schematic view of the calibration chamber.

50 kN capacity. The tests were performed using servo-controlled hydraulics and a personal computer, the latter simultaneously recording the cone output during testing.

4.2 Test Programme and Sample Preparation

The intended test programme was 6 tests on each sand, 3 at minimum and maximum density respectively, using vertical stresses of 50, 100, and 200 kPa at each density. Because of some initial difficulties in achieving maximum and minimum densities, the number of tests on the pumice sand was actually 9, with several at "unplanned" intermediate densities. The best procedures for achieving minimum and maximum density states

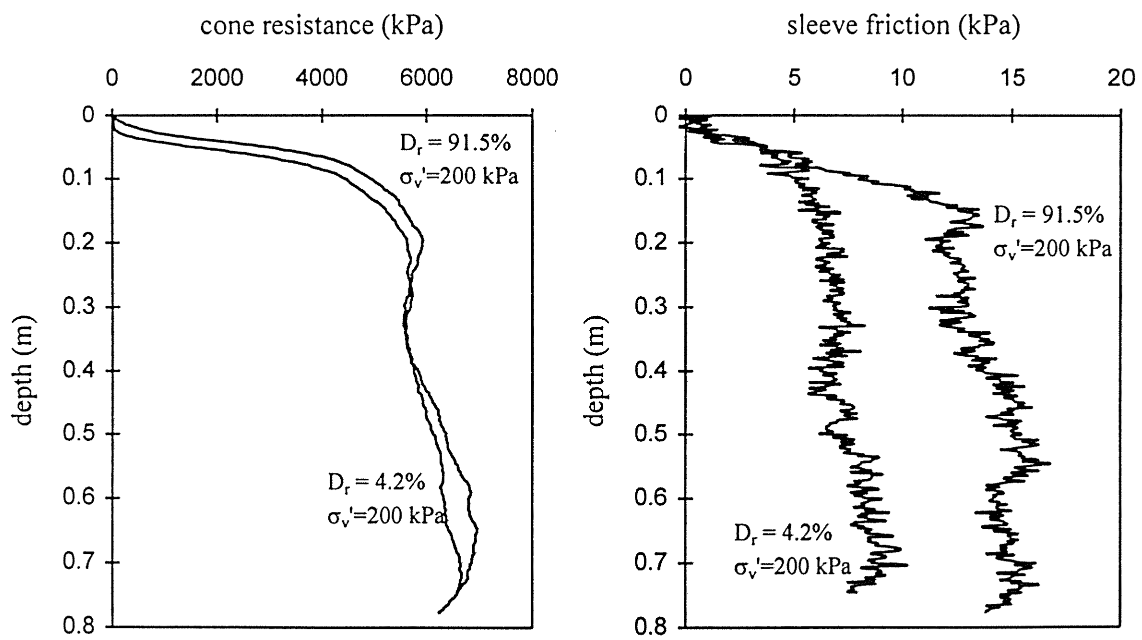

Figure 8. Typical results for the pumice sand.

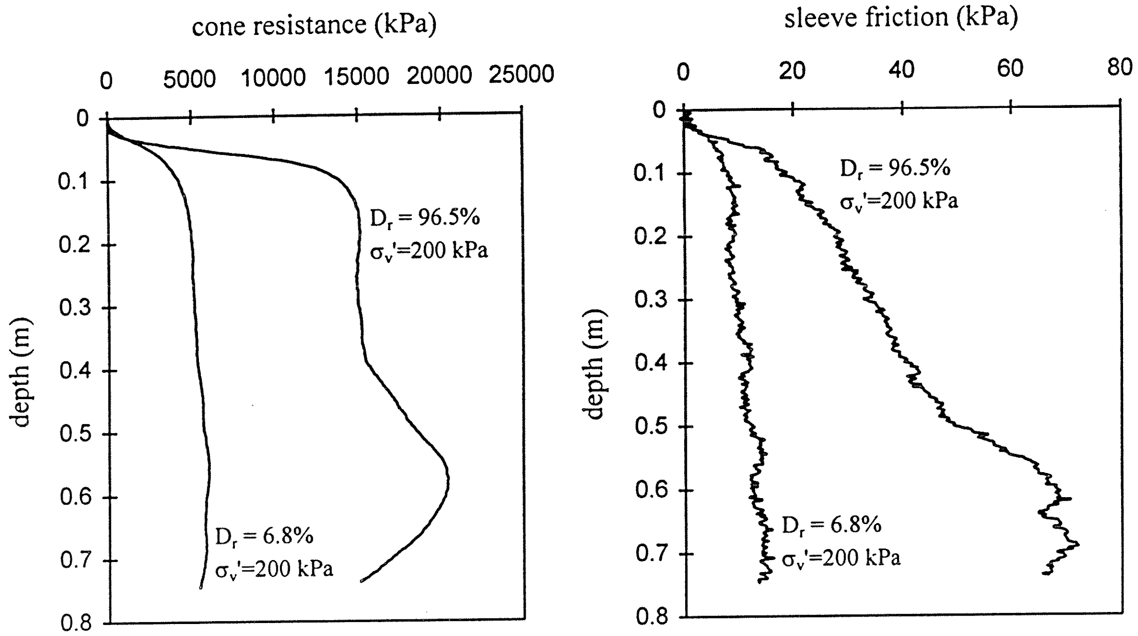

Figure 9. Typical results for the quartz sand.

proved to be rather problematical. The initial intention was to follow overseas practice and use a "pluviation" process which rains the sand into the chamber. This was found to be satisfactory for loose specimens but not for dense specimens. After trying various alternatives, it was found that manual placing in thin layers and tamping produced the densest samples.

4.3 Test Results

The test results are summarised in Figs. 8 to 11. Figs. 8 and 9 show typical results from the pumice and quartz sand respectively, in the loose and dense states. Fig. 10 shows the cone resistance only from the same tests plotted on one graph. Fig. 11 illustrates all the results on a graph of the usual type relating cone resistance to relative density and effective vertical stress.

The results show a dramatic difference in behaviour between the two sands. The quartz sand behaves as expected, showing large differences in cone resistance between the loose and dense states, and steadily increasing values with confining stress. The pumice sand, on the other hand, behaves quite differently, with the following surprising characteristics:

1. Its penetration resistance is a little higher than the quartz sand when both are in the loose state.
2. There is very little change in cone resistance between its loose and dense states, and the increase in resistance with confining stress is less pronounced than with the quartz sand.

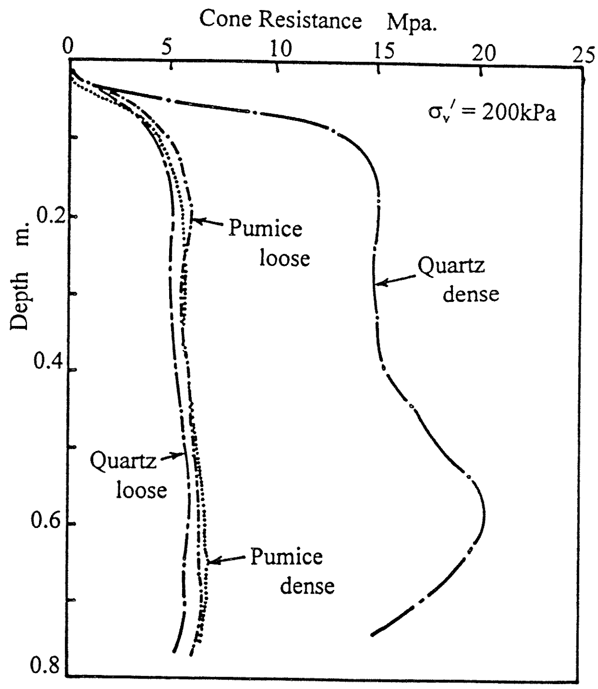

Figure 10. Comparison of typical results.

3. Despite little difference in cone resistance with relative density, there is a substantial difference in sleeve friction, as Figure 8 clearly shows.

The difference in behaviour can only be attributed to the different particle strength of the two sands. The initial interpretation put on the results was that with the quartz sand failure occurred by shear displacement, while with the pumice sand failure

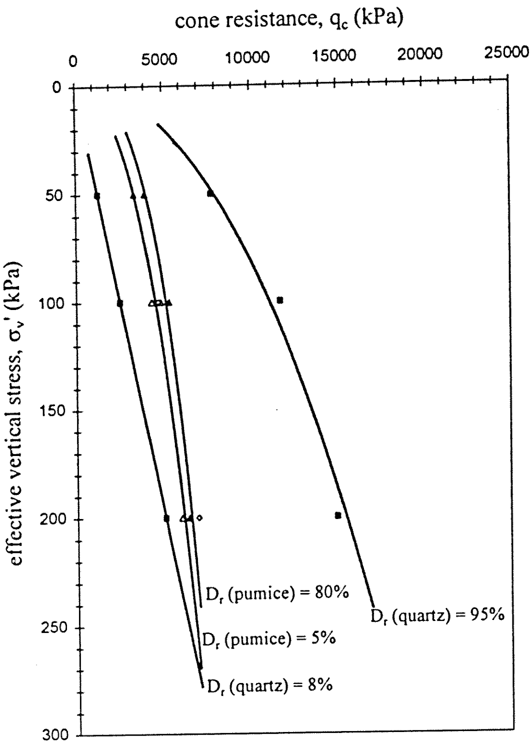

Figure 11. Summary of penetrometer test results.

occurred predominantly as a result of particle crushing. To investigate the extent of particle crushing, samples were taken from the immediate vicinity of the cone when emptying the chamber, and particle size measurements made. The results, which are illustrated in Fig.12, show a surprising amount of crushing with both sands, especially in the dense states, and the crushing is only marginally higher with the pumice sand than the quartz sand. The comparison is qualitative as it was not possible to be sure that the size and location of the samples was the same in each case.

It should be noted that the results from the quartz sand, as shown in Fig.11 do not conform very well to established correlations of this sort published by overseas researchers. The reason for this is uncertain; it may be because the chamber used was somewhat smaller than that needed to eliminate size effects, and possibly because of differences between the quartz sand used here and that used overseas. The quartz sand used here was not pure quartz.

5. DISCUSSION AND CONCLUSION

The results clearly illustrate that the soft particles of the pumice sand have a marked influence on its geotechnical properties. The main points to come out of the laboratory tests are the following:

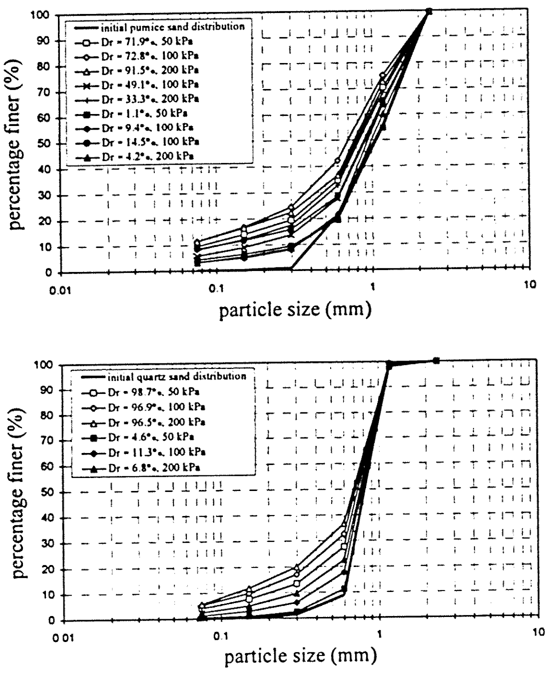

Figure 12. Particle size measurements made after testing showing extent of particle crushing.

1. The peak strength of the pumice sand is very similar to that of the quartz sand, but the strain to failure is much greater.
2. The pumice sand is much more compressible than the quartz sand.

The results of the chamber tests are not good news for geotechnical engineers interested in evaluating the properties of pumice sands. The cone resistance values do not sufficiently distinguish between loose and dense states of the sand for these to be used as a means of determining relative density, and current relationships between cone resistance, relative density, and confining stress are not valid for the pumice sand. One of the aims of this research programme was to establish alternative correlations specifically for pumice sands. The results suggest that this is not feasible, although the difference in skin friction values may provide an alternative basis for such a correlation. Insufficient data exists at present to know whether this is feasible.

6. ACKNOWLEDGEMENT

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