Some Residual Strength Measurements on New Zealand Soils

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SUMMARY

The results of residual strength measurements on some New Zealand soils are presented. The soils tested consisted mainly of weathered Waitemata sandstones, weathered volcanic ash, Pleistocene material, and Onerahi Chaos. The results show that while most soils conform to the pattern of behaviour of overseas soils, the range of ϕ'_r values within any group is large. The volcanic ash soils show consistently high ϕ'_r values and do not conform to conventional soil behaviour.

1. INTRODUCTION

The residual strength of soils is important in geotechnical engineering in relation to the stability of existing land slides and the stability of deposits which contain shear surfaces or similar discontinuities. It is also of importance in understanding or evaluating the risk of progressive failure in certain materials. In this paper the results of a series of residual strength measurements on a number of New Zealand soils are presented.

2. TEST PROCEDURES

The tests have been carried out in a Bromhead ring shear apparatus (Bromhead, 1979). This device is much simpler than the original ring shear apparatus described by Bishop et al (1971); the most important difference between the two devices is in the constraints placed upon the location of the shear surface within the ring sample. The design of the original apparatus is such that the shear surface forms at the centre of the samples with approximately equal thicknesses of soil above and below the shear plane. In the Bromhead apparatus, the shear surface invariably forms close to the top of the sample, and in most cases appears to be right at the interface with the upper platen. Despite this important difference, the test results from the two devices appear to be very similar (Bromhead, 1979).

The tests have been carried out at a rotation rate of 0.024 or 0.12°/min; this corresponds to displacement rates of 0.018 and 0.09mm/min. These rates were chosen for convenience; the higher rate was generally used during working hours, and the lower rate outside these times. While this rate is slightly faster than displacement rates normally used in ring shear tests, the influence on measured strengths is negligible (Skempton 1985). The normal stress range used in the tests was from 25kPa to 500kPa.

The actual procedure for setting up the samples and conducting the tests was to first adjust the water content of the soil so that it was a little wetter than the plastic limit, and then to press it into the annular slot in the apparatus. Loads were then added to consolidate the sample to the maximum normal stress to be used in the test, and then unloaded to the minimum stress to be applied. The test was then carried out using a sequence of increasing normal stresses. By using this procedure the amount of soil lost by "squeezing" out through the small gap at the edge of the upper platen was minimised.

In addition to the ring shear tests, measurements were made of natural water content, Attenberg limits and particle size.

3. SOILS TESTED

The samples tested came from the upper half of the North Island and belonged mainly to the following geological groups:

Weathered Waitemata series sandstone and siltstone
Weathered Pleistocene deposits in the Auckland area
Weathered volcanic ash
Weathered Onerahi Chaos sandstone or siltstone.

No attempt has been made to systematically obtain representative samples from each of these groups; tests have simply been carried out as time and samples have been available. Nearly all the samples used were obtained as part of site investigations for other purposes, and no claim is made that they are necessarily typical or representative of the geological groups they come from.

The location of the samples, together with descriptions and geological origin, is given in Table 1. Also included among the volcanic ash samples are four samples from Indonesia. This has been done partly because of an interest in volcanic ash soils on the part of the writer, and partly to check some residual strength measurements made earlier on these soils (Wesley, 1977). These earlier measurements on samples from Indonesia gave ϕ'_r values in the range of

TABLE 1. SAMPLE DETAILS AND TEST RESULTS

Sample No	Location	Description: Soil Type	Description: Geological Origin	Natural Water Content %	Atterberg Limits: LL	Atterberg Limits: PL	Atterberg Limits: PI	Particle Size: <.06	Particle Size: <.002	Residual Angle ϕ'_r
1	Symonds St, Auckland	Stiff grey clay	Waitemata Siltstone	-	77	40	37	92	35	19.3
2	"	Pale yellow silt	"	43.0	52	33	19	56	20	27.5
3	"	Hard grey clay	"	51.5	89	29	60	98	45	14.0
4	"	Firm yellow clay	"	51.9	80	40	40	93	52	20
5	Redoubt Rd, Manukau	Grey clay	"	51.2	97	47	50	92	59	9.9
6	Takapuna	Highly plastic grey clay	"	46.8	118	35	83	100	76	7.4
7	Sunset Rd, North Shore	Pale yellow clay	"	45.9	89	39	50	87	57	13.1
8	Omata 1 New Plymouth	Pale brown clayey silt	Volcanic ash	99.6	108	72	36	82	41	24.5
9	" 2	"	"		103	60	43			31.0
10	" 3	"	"	-	151	83	68	100	f	18.1
11	Morrinsville 1	Pale brown clayey silt	"	51.7	115	68	36	66	28	28.0
12	" 2	"	"	71.0	113	67	46	65	f	34
13	Mangamahoe Dam New Plymouth	Pale yellow clayey silt	"	72.4	93	84	9	65	22	35
14	Minden, Tauranga	Light brown clayey silt	"	47.6	54	33	21	65	39	26
15	Ruahihi,Tauranga 1	Orange brown silty clay	"	90.5	104	74	30	56	f	35
16	" 2	Orange silty clay	"	137.8	140	84	56	45	f	37
17	Darajat,Indonesia 1	Brown silty clay	"	162.0	183	112	71	96	77(f)	35
18	" 2	"	"	166.5	197	120	77	100	f	31
19	" 3	"	"	153.3	183	140	43	100	f	37
20	Kamojang,Indonesia	Yellowish brown silty clay	"	135.6	175	133	42	100	f	36
21	Takapuna	Highly plastic grey clay	Pleistocene deposits	38.9	129	40	89	99	91	8.1
22	Takapuna	Greyish white clay	"	42.1	89	42	47	100	72	10.0
23	Takapuna	Grey clay	"	-	39	20	19	83	40	25.6
24	angarei	Yellow clay	Onerahi chaos	56.4	88	43	45	98	52	15.9
25	hangarei	Hard grey clay	"	-	64	29	35	90	30	13
26	Bay of Plenty (Wirihana Quarry)	Yellowish brown silty clay	Weathered ignumbrite	46.9	71	40	31	78	34	23.5
27	Bay of Plenty (Camerons Quarry)	Brown silty clay	Weathered greywacke	25.2	38	28	10	58	13	25.0

f indicates flocculation during sedimentation.

24° to 39°; these were from samples with clay contents in the range of 65% to 83% where ϕ'_r values would typically be less than 10°.

Two of the weathered Waitemata series samples, Nos 5 and 6, were taken from clearly identified shear zones where slipping had taken place at some time in the past. Investigations were being carried out at both these sites because of stability concerns associated with these shear zones.

4. TEST RESULTS

The results of the tests are summarised in Table 1 and presented graphically in the figures that follow. The values of ϕ'_r have been calculated for an effective normal stress of 200kPa and an assumed cohesion intercept of zero. This stress level is thus a little lower than the mid range value of the normal stresses used in the tests.

It is clear from Table 1 that the soils tested cover a fairly wide range of soil types. Plasticity indicies range from 9 (Sample 13) to 89 (Sample 21) and clay fractions from 13% (Sample 27) to 91% (Samples 21). It should be noted that clay fractions for some of the volcanic ash samples are not given; this is due to flocculation occurring during the sedimentation process, a phenomenon not uncommon with such soils.

The position occupied by the soils on the plasticity chart is shown in Fig.1. On the basis of their relative distribution, the soils divide themselves into two groups, namely the non volcanic ash soils ("normal" soils) and the volcanic ash soils. The former group tend to lie close to the A-line, in accordance with conventional soil behaviour, while the volcanic ash soils lie well below the A-line in a zone typical of such soils (Wesley 1974). This natural division of the soils into two distinct groups will be used as a basis for presenting the results of the ring shear tests.

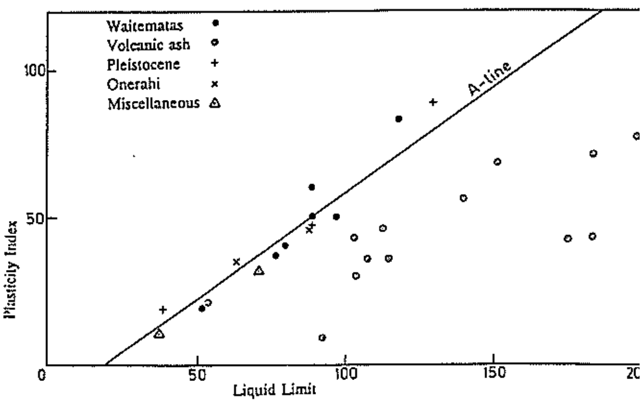

Fig 1 Position on Plasticity Chart

A typical result for tests on the non volcanic ash soils is shown in Fig.2. These soils all tended to behave in a conventional manner, as described for example by Lupini et al (1981) or Skempton (1985). The strength envelope is slightly curved, so that the value of τ/σ_n is somewhat higher at lower stress levels and then falls to an approximately constant value at higher stress levels. The values of shearing resistance at any particular stress level tend to be quite constant, especially for the high plasticity materials which have low ϕ'_r values. For the low plasticity materials the residual strength tends to be rather less constant and varies somewhat at any particular stress level. This variation, however, is still very small, and has an almost negligible effect on the ϕ'_r value. Tests were carried out on some soils in this group using a sequence of both increasing and decreasing normal stress; it was found that almost identical readings were obtained in each case.

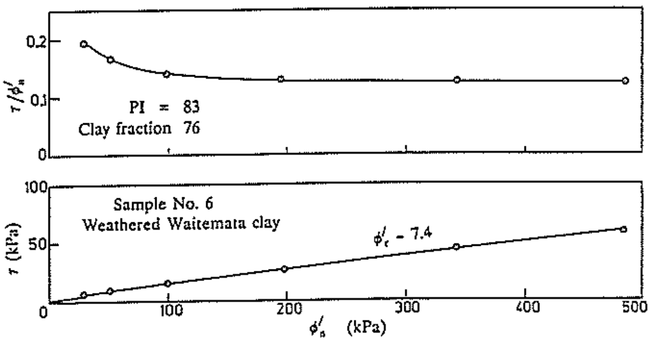

Fig 2 Ring shear result from Sample 6

For the volcanic ash group, a typical result is shown in Fig.3. With these soils, the residual strength was generally high but was less well defined as readings tended to fluctuate considerably at each normal stress. Also, when tests were carried out using both increasing stress and decreasing stress sequences, there tended to be significant variations in the readings. However there did not appear to be a consistent pattern to these variations. The result in Fig.3 shows the ϕ'_r value to be generally lower for the unloading sequence than for loading, but this was not a uniform pattern in all tests.

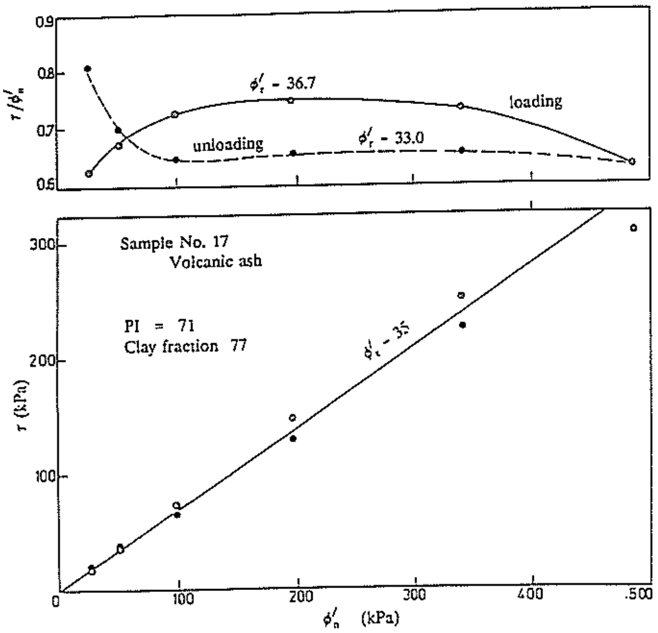

Fig 3 Ring shear result from Sample 17

In Fig.4 the residual strength values are plotted against plasticity index; this is done separately for the two soil groups. Also shown on these graphs is a line which represents the approximate upper limit of ϕ'_r values obtained from sedimentary soils overseas. This line (and the similar line in Fig.5) has been deduced from the data summarised by Lupini et al (1981). This line is not a well defined line (nor is the lower limit line) and is introduced here only for the purpose of comparing results from New Zealand soils with those obtained overseas (mainly in the United Kingdom). The behaviour of the non volcanic ash soils appears to generally conform to "normal" soil behaviour, while that of the volcanic ash samples is quite different.

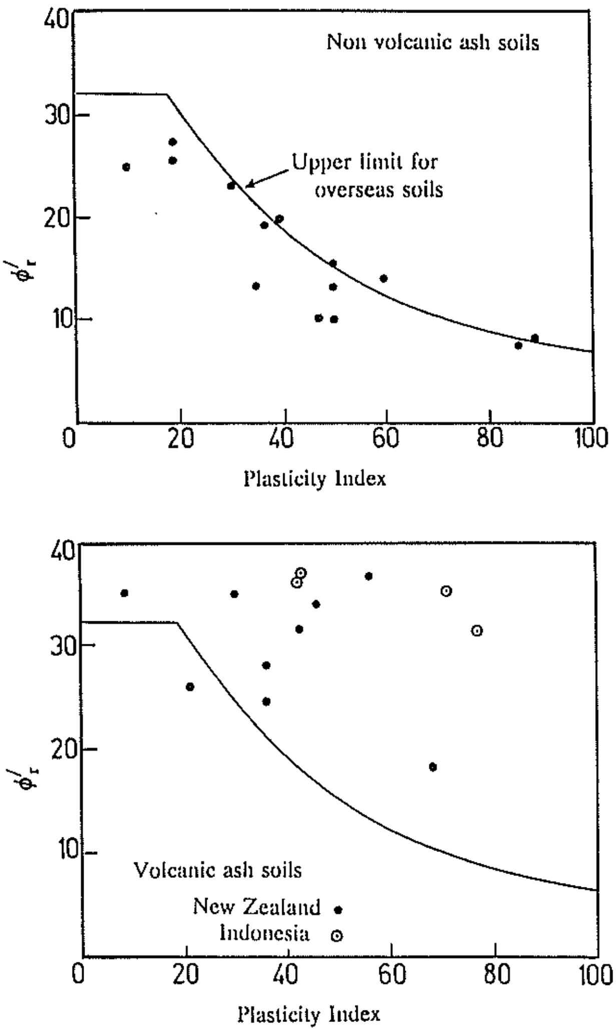

Fig 4 ϕ'_r versus Plasticity Index

The ϕ'_r values from the volcanic ash samples are much higher than for "normal" soils, and do not appear to be related to plasticity index. The highest ϕ'_r values are from Indonesian samples, which are believed to have higher allophane contents than the New Zealand ash samples.

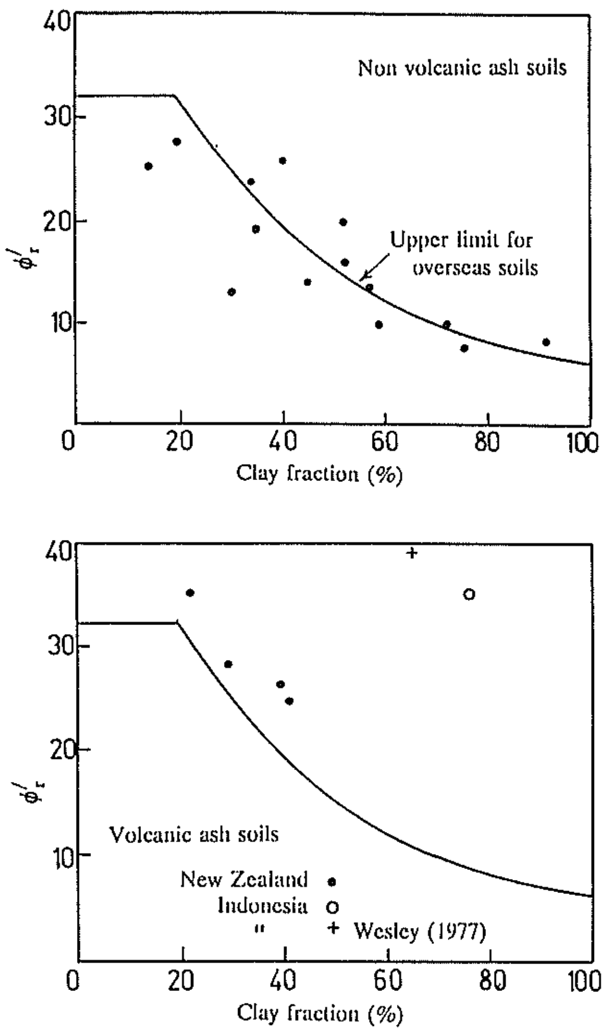

Fig. 5 ϕ'_r versus clay fraction

In Fig.5, the results are re-plotted against clay fraction using a similar format to Fig.4. This emphasises similar trends to those shown in Fig.4, although the plot of ϕ'_r against clay fraction for the non volcanic ash soils shows greater scatter than the similar plot against P.I. Also, a number of points be significantly above the upper limit line.

5. DISCUSSION OF RESULTS

5.1 Normal (Non Volcanic Ash) Soils.

Not surprisingly, the behaviour of these soils conforms fairly well to that of overseas soils, as summarised by Lupini et al (19081). Perhaps the most significant feature to emerge from the tests is the wide range of values obtained within particular soils groups. For examples, in the Waitemata series samples, values of ϕ'_r ranged from 7.4° to 27.5°. In the Pleistocene materials, the ϕ'_r values ranged from 8.1° to 25.6°. However, this range of values is not surprising in view of the similar wide range in P.I. values and clay fractions.

As mentioned earlier, two of the Waitemata samples were from pre-existing shear zones, which were associated with stability concerns at their respective sites. The very low ϕ'_r values from these samples (7.4° and 9.9°) are a salutary reminder that zones of very low strength materials can be found within what are otherwise quite competent materials. Geotechnical engineers are sometimes tempted (or forced) to adopt "typical" values for properties of commonly occurring materials such as weathered Waitemata clays; this is no doubt unavoidable to some extent but the results presented here highlight the risks associated with this approach. Regardless of whether such an approach is adopted, or a detailed investigation carried out, there is still the risk that the detailed investigation may not identify these low strength zones.

It will be apparent to the reader that the number of tests for soil groups other than the Waitematas is too few to be able to draw any general conclusions.

5.2 Volcanic Ash Soils

The ϕ'_r values from the soils are unusual, firstly because they are very high and secondly because they do not appear to be related to either plasticity index or clay fraction. The reason for this is not known exactly, but appears to be due to the unusual characteristics of the amorphous clay mineral allophane. There is something about this material which gives it high frictional resistance when sheared, and the absence of plate-like particles presumably means that particle reorientation leading to lower frictional resistance does not occur in these soils. As mentioned above, the measured shearing resistance in the ring shear tests tended to vary somewhat at any particular normal stress. The precise reason for this is not known, although it is believed to be due to the nature of the shear surface which forms during the test. In tests on volcanic ash samples carried out in the Imperial College ring shear apparatus, it was observed that a number of shear planes developed, and shearing probably switched from plane to plane in a random manner, with associated variations in readings. This is in contrast to sedimentary clays where the formation of a shear surface results in a drop in strength and thus a natural tendency for only one plane to form.

6. CONCLUSION

The main points of interest which emerge from this study are as follows:

1. Apart from the volcanic ash samples, the behaviour of the soils in ring shear tests is similar to that recorded overseas with sedimentary soils.

2. The range of ϕ'_r values is very large, even within a particular geological soil group.

3. Very low ϕ'_r values obtained from two samples of Waitemata series clays emphasise the risk that local low strength zones may exist within what are otherwise quite competent materials.

4. Results from the volcanic ash samples are very distinctive; the ϕ'_r values are very high and do not appear to be related to either plasticity index or clay fraction.

7. ACKNOWLEDGEMENTS

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