Friction and Cohesion Parameters for Highly and Completely Weathered Wellington Greywacke

M. J. PENDER
Senior Lecturer in Civil Engineering, University of Auckland

SUMMARY Data from five site investigations in central Wellington are pooled. Results of more than 190 consolidated undrained triaxial tests on highly and completely weathered greywacke are analysed statistically. The analysis shows the effective stress cohesion parameter is highly uncertain.

1 INTRODUCTION

Between 1969 and 1973 the Central Laboratories of the New Zealand Ministry of Works and Development were involved in five site investigations in the central Wellington area. At all the sites profiles of greywacke, weathered in situ, were encountered. The strength parameters for the completely and highly weathered material were of importance for the structures under design, which included multi-storey buildings, bridge foundations and cut slopes. Specific investigation work was done at each site. Subsequently the opportunity was taken to examine the results of all the laboratory tests on the material.

The properties of the weathered greywacke encountered at one site and the method of classification are described by Pender (1971). Both completely weathered and highly weathered greywacke have a buff brown colour, the relict joint surfaces are evident by the presence of a deposit of black manganese dioxide. The completely weathered material is easily crumbled to sand and silt sizes under finger pressure. The highly weathered material is more difficult to crush under finger pressure and at least some of it cannot be crushed to sand and silt sizes.

The various sites are fairly close, as shown in Figure 1. From the point of view of visual classification the material at all the sites was similar. Thus all the data were pooled and analysed as a group. No detailed statistical analysis was done comparing the strength parameters from one site with another, there was not enough data for this. No site appears to have test results greatly different from others, Figures 2 to 7.

Continuous cores, 100 mm in diameter, were recovered with a triple tube rotary coring barrel. This gives good quality undisturbed core. A total of 193 triaxial tests were done on 100 mm diameter specimens from the five sites. The tests were all consolidated undrained with pore water pressure measurement.

The earlier paper (Pender, 1971) provided a detailed examination of the results from the Public Trust Office Site in Lambton Quay. This suggested that the void ratio of the weathered material was a useful independent variable for correlating the values of various physical properties.

The results of the statistical analysis show that the effective stress friction angle is a most reliable parameter, the 95% confidence limits on ϕ' are close to the best estimate of ϕ'. On the other hand the cohesion intercept is a much more variable parameter. The 95% confidence limits are very wide and in all cases the lower confidence limit on c' is zero.

2 REGRESSION ANALYSIS

A complete tabulation of the individual triaxial test results is given by Pender (1977) as well as the output from the statistical analysis. The data were pooled and sorted into common void ratio ranges. The test results subjected to a linear regression analysis to give best fit values of c' and ϕ'. The 95% confidence limits for the predicted shear stress at each normal effective stress were also calculated. The correlation coefficient for the best fit line is very close to unity. This has the consequence that the 95% confidence limit values also suggest a straight line. Thus further linear regression analyses were done on the 95% confidence values to

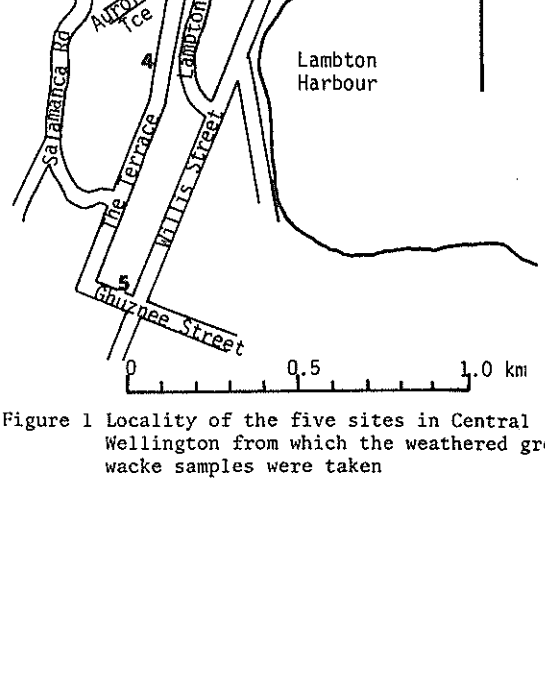

Figure 1 Locality of the five sites in Central Wellington from which the weathered greywacke samples were taken

give 95% confidence limits for ϕ' and c'. The results of this analysis are given in Table I.

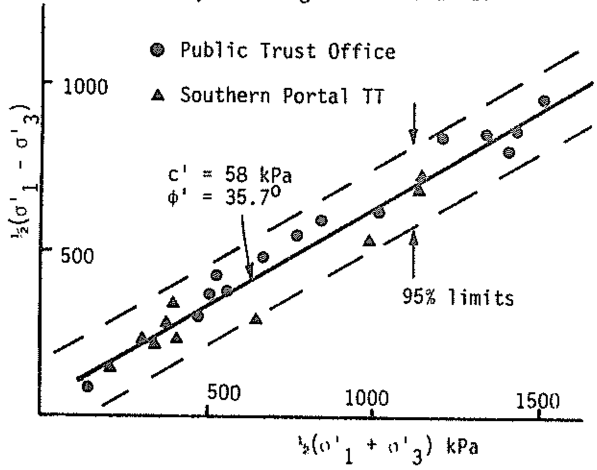

Figure 2 Triaxial results for the void ratio range 0.25-0.40

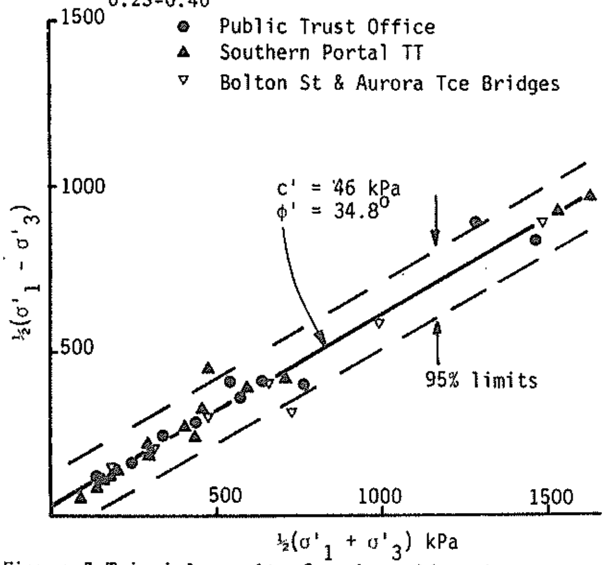

Figure 3 Triaxial results for the void ratio range 0.40-0.50

The lower 95% confidence limit value calculated for c' by this process was always negative. An additional option available in the statistical package used was the ability to perform a linear regression analysis in which the best fit straight line was forced through the origin. This option was tried with the intention that a more realistic lower limit for c' might be given. The result is shown in Figure 8. The lower 95% friction angle then diverges from the data. Thus the unconstrained option was adopted for the calculation of the lower 95% limits. The resulting ϕ' values appear in Table I, the c' values are assumed to be zero.

Careful examination of the data in Figures 2 to 7 shows, that at the low normal stress end of the data, all the data points lie on or beneath the best fit line. This suggests that the linear approximation for the failure envelope may no longer be valid at low normal stresses. In this region the failure envelope may curve down towards the origin. As insufficient data are available in this range the possibility cannot be investigated further.

In Figures 9 and 10 the results given in Table I are plotted. It is clear from Figure 10 that there

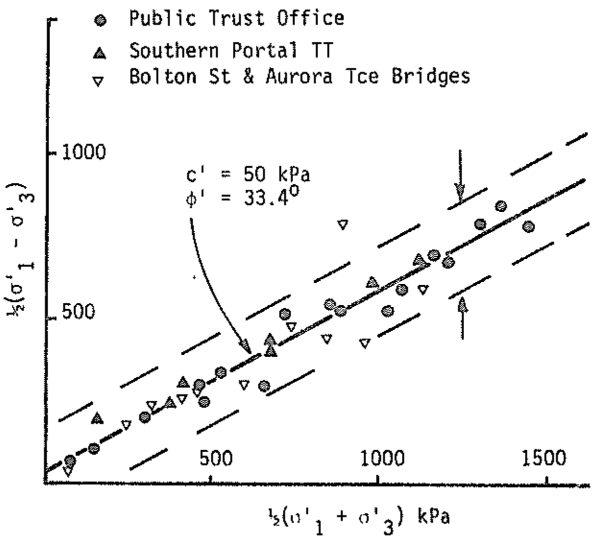

Figure 4 Triaxial results for the void ratio range 0.50-0.60

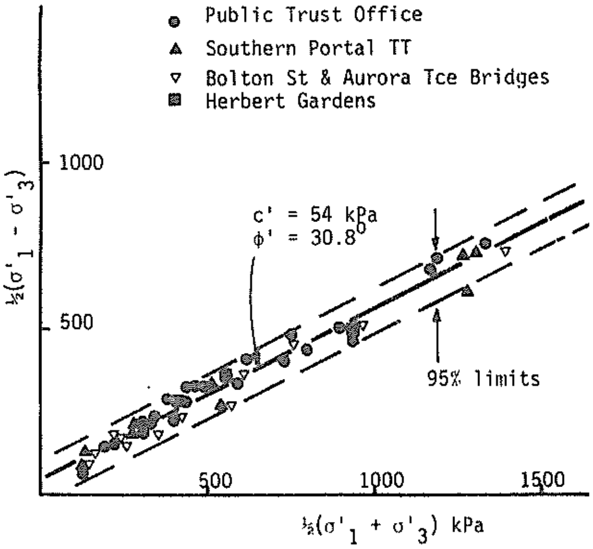

Figure 5 Triaxial results for the void ratio range 0.60-0.70

is a good correlation (although nonlinear) between void ratio and the effective friction angle. On the other hand the effective cohesion, Figure 9, is much less reliable.

3 DISCUSSION

In Figure 7, for the void ratio range 0.80-0.90, there are only seven data points. As a consequence the confidence limits are wide. Figure 5, for the void ratio range 0.60-0.70, has sixty data points. In this case the 95% confidence limits are much narrower, but even so the limits on the cohesion are still rather wide. Figure 7 then raises a query about the conventional testing procedures that are used to determine c' and ϕ'. A typical number of test results on which c' and ϕ' would be determined is 4, 5 or 6. A worthwhile procedure would be to evaluate the 95% confidence limits on c' and ϕ' as a routine matter in soil testing. This would lead to a rather more caution in choosing cohesion values for analyses.

The fact that no data points are found in the very low normal stress range in Figures 2 to 7 is a consequence of performing consolidated undrained

TABLE I

SUMMARY OF REGRESSION ANALYSIS

Void Ratio Range	Number of Specimens	Best Fit Straight Line			95% Confidence Limits		
					Upper		Lower
		φ' (Degrees)	c' (kPa)	Regression Coefficient	φ'	c'	φ'
0.250-0.400	24	35.7	58	0.979	35.8	201	34.5
0.400-0.500	32	34.8	46	0.984	35.0	162	34.6
0.500-0.600	39	33.4	50	0.968	33.5	39	33.2
0.600-0.700	60	30.8	54	0.986	30.9	128	30.7
0.700-0.800	31	28.6	48	0.969	28.7	132	28.5
0.800-0.900	7	27.1	36	0.907	27.3	209	26.8

triaxial tests on material that would be classed as dense or heavily overconsolidated. Because of the negative pore water pressure response of such material the effective stress path approaches the failure envelope by moving up to the right. Thus even with a very low initial effective consolidation pressure there is a large increase in normal stress before failure is reached. For a cut slope problem the long term stress path approaches the failure envelope by moving to the left. Thus a drained constant axial stress triaxial test might be more appropriate for the determination of strength parameters for the long term stability of cut slopes.

The degree of saturation of the specimens before testing was generally high (greater than 90%). For some of the specimens saturation was ensured by the application of back pressure but generally no special measures were taken to ensure saturation. Saturated behaviour represents the worst possible condition in situ. Using the values for c' and φ' quoted in this paper it would be possible to show that many apparently stable cuttings around Wellington should have failed. This is probably because the material is not saturated, the suction in the pore water gives a larger effective stress and hence strength. During wet conditions this suction is relieved leading to greatly increased numbers of failures.

As the highly and completely weathered greywacke can be crumbled under finger pressure, stability analysis based on soil behaviour is appropriate, despite the presence of the relict joints in the material. It is difficult to decide how to handle the uncertainty in the cohesion parameter, particularly as the conventional limiting equilibrium stability analyses show that cohesion has a great effect on the maximum stable slope height. For an important structure one could argue that cohesion should be neglected and the slope designed on the basis of frictional behaviour only. Slopes steeper than the friction angle then require a support system such as ground anchors. Alternatively the large variations in c' can be

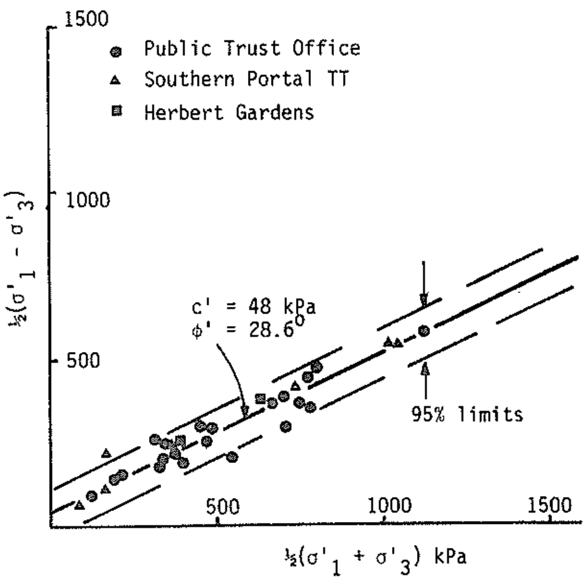

Figure 6 Triaxial results for the void ratio range 0.70-0.80

considered by conducting a probabilistic analysis to find the probability of failure rather than the factor of safety. To simplify the calculations several assumptions are required about the variation of soil properties through the soil mass. Nevertheless the insight gained is sufficiently different from that given by the factor of safety approach to make the analysis of considerable interest. Such a series of calculations was done for the Southern Portal of the Terrace Tunnel (Pender 1976) which was constructed in a soil profile consisting mainly of greywacke weathered in situ.

Each test result plotted in Figures 2 to 7 represents

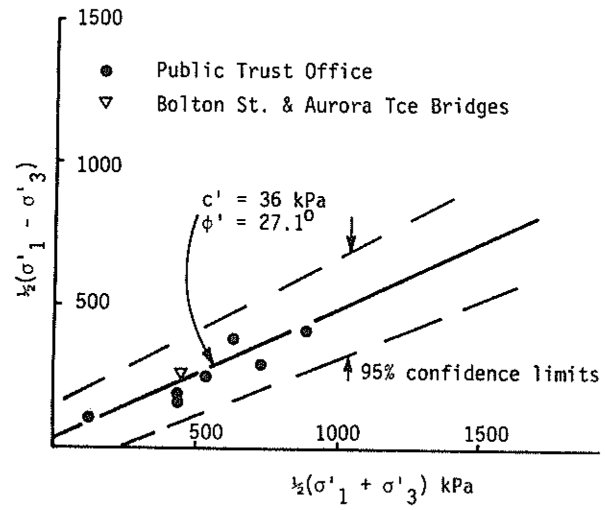

Figure 7 Triaxial results for the void ratio range 0.80-0.90

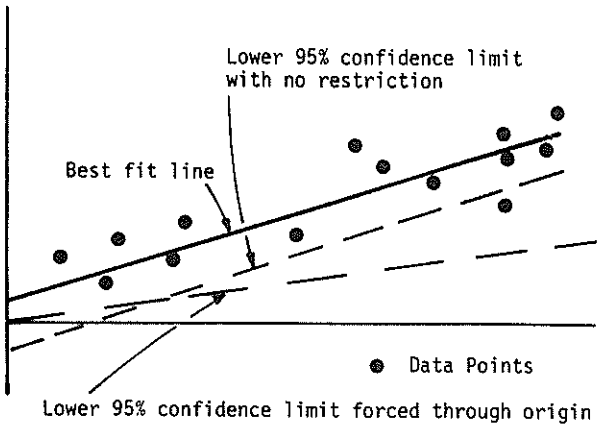

Figure 8 Regression analysis for lower 95% confidence limit on cohesion

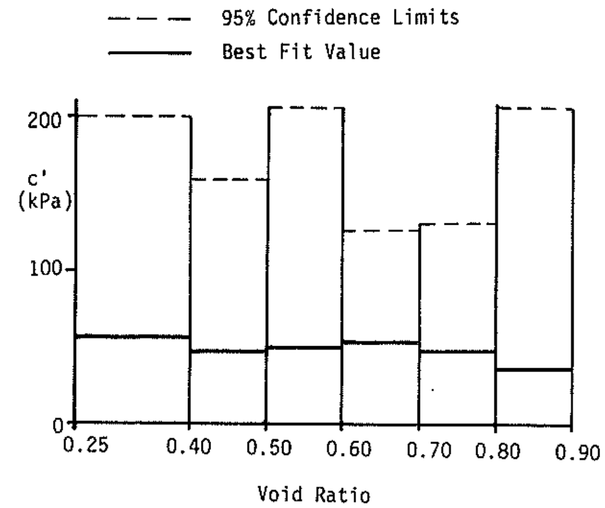

Figure 9 Variability of the effective stress cohesion parameter as a function of void ratio

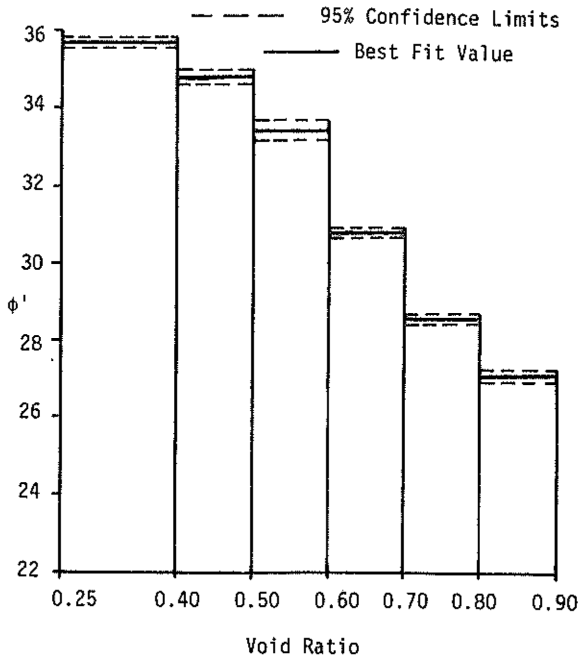

Figure 10 Variability of the effective stress friction angle as a function of void ratio

the behaviour of a volume of material that is small in relation to the volume of soil mobilised in civil engineering projects. Is the soil mass in situ to be modelled as a large number of small units about the size of a triaxial specimen all having different properties? Or is it to be regarded as a large mass of homogeneous material with an uncertain cohesion? The first of these possibilities would seem to be more likely, the second provides a simpler model for the purposes of the probabilistic analysis mentioned above. If the first of these ideas is correct it suggests that the appropriate cohesion for the completely and highly weathered greywacke is the best fit value obtained from a large number of tests. The cohesion for some elements of the soil mass will be greater than this and the cohesion for others less. However with such a distribution of cohesion values it is not necessary that the best fit or average value would control the strength of the soil mass. Perhaps a 'weakest link' mechanism operates leading to a type of progressive failure. The apparent cohesion would then be less than the best fit value.

4 CONCLUSIONS

The results plotted in Figures 2 to 7 suggest that the properties of the completely and highly weathered greywacke from the five central Wellington sites are a function more of void ratio than locality in the city. Figure 10 then provides a ready means of predicting the likely friction angle for the material if the void ratio is known. However, Figure 9 does not provide a similar means of estimating the effective cohesion of the material.

The statistical analysis of the test results emphasizes very clearly the uncertain nature of the effective cohesion parameter. The test results show that the cohesion can be expected to vary between wide limits from point to point in the soil mass. The choice of the appropriate cohesion value, even with the benefit of a large number of test results, is not a simple matter.

5 REFERENCES

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