

PIEZOCONE PENETROMETER TESTING AND DIMENSIONLESS EXCESS PORE PRESSURE

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Introduction

The use of the piezocone (CPTU) probe has become increasingly popular and is currently one of the most widely used *in situ* investigation devices. The addition of a pore pressure measuring system to the cone penetration test (CPT) provides much more information about the *in situ* soil and thus enables a much clearer picture of the subsurface soil conditions to be obtained.

The pore pressure measured during a CPTU test in a saturated soil consists of two principal components. Firstly, the hydrostatic pore pressure, u_0 , and secondly a component, Δu , generally termed the excess pore pressure, that represents the change in water pressure caused by penetration of the instrument. This excess pore pressure is a function of the soil permeability and drainage, and therefore its grain size, as well as the mechanical characteristics of the soil, in particular, the density and dilatancy characteristics. Interpretation of excess pore water pressure is complicated by the fact that it is also affected by the drainage conditions, soil consolidation behaviour, and the rate of loading during the test.

Berrill et al. (1992) proposed a simple non-dimensional form for excess pore pressure in an attempt to minimise the effect of differing soil drainage conditions and rate of loading. With these factors eliminated the resulting dimensionless excess pore pressure, ΔU , is intended to provide a better indication of the *in situ* state of the soil than does the raw excess pore pressure, Δu , and thus enable better interpretation of piezocone results. The dimensionless form of excess pore pressure is given by:

$$\Delta U = \frac{\Delta u}{\gamma_w v_f t_{50}}$$

In this expression, Δu is the raw excess pore pressure, γ_w is the unit weight of water, v_f is the penetration rate, and t_{50} is the time for half of the excess pore pressure to dissipate.

The initial intention of this project was to test this expression for the normalisation of excess pore pressure. However the investigation became sidetracked into a technical problem which arose from a combination of the modification of the *in situ* soil state and the clogging of the piezocone filter element.

Observations

The results of a series of CPTU tests carried out using differing penetration rates, at the St Johns Street Water Pumping Station in Christchurch are shown in the plots of point resistance (q_c), friction ratio (R_f), and pore pressure (u) against depth of penetration in Figure 1 to 4. The subsurface material at the site is interpreted to consist of a large cohesive layer up to three metres thick overlying dense sand.

The Fugro piezocone appears to provide reliable data for q_c and R_f ; however the values for pore pressure are somewhat uncertain. Of particular interest is the zone of extremely high negative excess pore pressures from approximately 2.6 m through to about 3.6 m below the ground surface. These negative pore pressures are particularly strange since they follow a region of large positive pore pressures in apparently the same material (based on the similar q_c and R_f values). The change in behaviour follows the rod change and dissipation test at approximately 2.6 m for tests SJS003, SJS004, and SJS005.

Originally the high negative pore pressures were thought to be due to inadequate saturation of the hydraulic circuit of the piezocone. Test SJS006 was performed following the use of an extremely rigorous deairing procedure to ensure complete saturation. The results of this test (Figure 4) indicate that inadequate saturation was not a primary factor contributing to the unusual pore pressure records.

Inspection of the filter used for test SJS006, and subsequently that used for the previous tests, shows that clogging of the filter in the fine-grained layer is the principal cause of the spurious pore pressure records (Figure 5). A soil sample of the fine-grained layer from a depth of 2.2 m was tested in the laboratory. A summary of the test results and a grain size distribution are shown in Table 1 and Figure 6 respectively. The soil consists predominantly of silt material with a minor clay fraction (approximately 15%). The filter element used in these tests has a pore opening of approximately 150 μm . The average particle size of the soil (13 μm) is therefore considerably finer than the pore size of the filter element and clogging is therefore possible and likely to occur.

Table 1: Results of the laboratory tests performed on a soil sample from a depth of 2.2 m at the St Johns Street Water Pumping Station site.

d_{30}	6 μm
d_{50}	13 μm
d_{60}	17 μm
I_L	33
I_p	23
Unified Classification	ML, clayey silt

It is interesting to note that for tests SJS003, SJS004, and SJS005 the filter clears itself and the pore pressures measured in the clean sand layer seem to be accurate. However for SJS006 the filter is much more clogged than for the previous three tests (Figure 5) and does not clear itself at any point during the test. Furthermore, there does not appear to be any consistency between the three tests in the point at which the filter appears to clear itself.

Interpretation

This apparently anomalous behaviour may be explained as follows. The large positive excess pore pressures measured at the beginning of penetration in the fine silt layer are as expected for this type of loose, estuarine material. The large negative pore pressures measured following the first rod change and dissipation test are not expected. When penetration is stopped at this first rod change and the large positive excess pore pressures allowed to dissipate, the soil surrounding the tip of the piezocone will consolidate as the local effective stresses increase. This consolidation will result in the soil being more dense than its original *in situ* state.

As penetration resumes, movement of the cone causes dilation of the now dense material and generation of negative excess pore pressures. Cavitation may also occur within the pore pressure transducer if the pore pressure decreases sufficiently. These negative excess pore pressures lead to a tendency for outflow from the (now imperfectly?) saturated pore water pressure system. As the cone passes through the consolidated region and into virgin material (in a matter of centimetres of movement) the excess pore pressure becomes positive again and therefore leads to an inflow into the pore water pressure system and a corresponding clogging of the filter by the fine silt particles.

Conclusions

The problems of filter saturation and clogging cast doubt on the accuracy of the recorded values of Δu . Until this doubt is removed it is difficult to draw any conclusions about the correctness of the relationship for the normalisation of excess pore pressure.

This investigation highlights the importance of complete saturation of the pore water pressure system of the piezocone in order to obtain accurate and significant results. It appears that the procedure currently in use at the University of Canterbury for deairing the Fugro piezocone is inadequate for testing in fine-grained soils and should therefore be modified.

Filter pore size has a significant effect on the reliability of pore pressure records. If the pores of the filter element are large relative to the soil particles at the site to be tested than clogging of the filter may occur and the pore pressure measurements will be adversely affected. On the other hand, too fine a filter may adversely affect response time in free-draining soils. Thus special consideration needs to be given to the pore size of the filter and the filter material used when performing CPTU tests.

The problem of filter clogging that occurred during piezocone testing at the St Johns Street Water Pumping Station site clearly adversely affected the pore pressure records. To further investigate the proposed normalisation of excess pore water pressure, either a sandy site free from overlying silt should be sought, or alternatively, more tests should be carried out at the present site using filters with finer pore sizes that will not clog during the test.

Reference

Berrill, J.B., Canou, J., Foray, P. and Pautre, J.-L. (1992) "Piezocone testing of liquefaction sites: Normalisation of excess pore pressure", Proc. 10th World Conference on Earthquake Engineering, Madrid, pp 1421-1424.

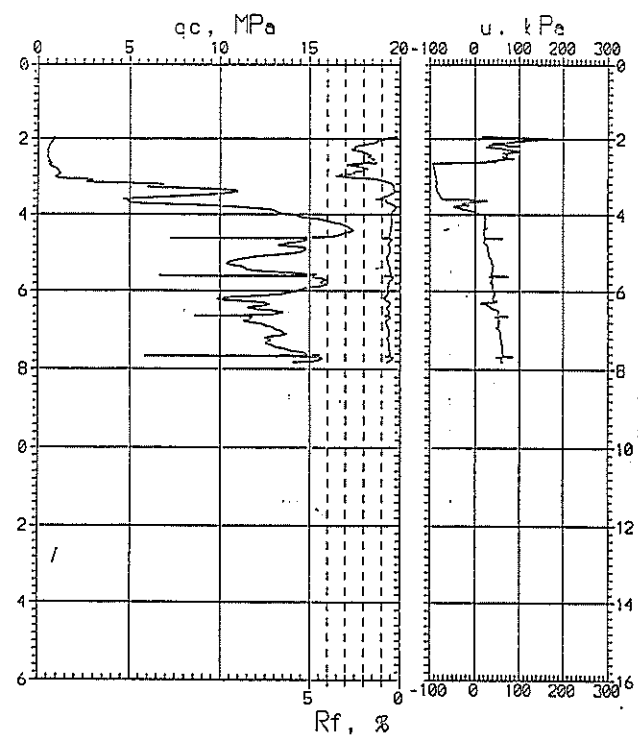


Figure 1: CPTU Test SJS003 with 10 cm² Fugro cone at St Johns St Water Pumping Station, Christchurch, New Zealand. $v_t = 20$ mm/s.

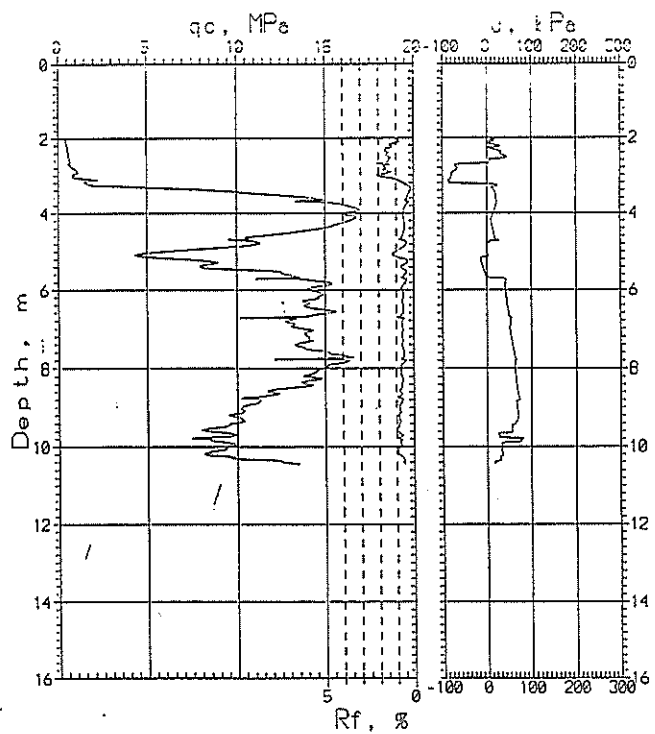


Figure 2: CPTU Test SJS004 with 10 cm² Fugro cone at St Johns St Water Pumping Station, Christchurch, New Zealand. $v_t = 40$ mm/s.

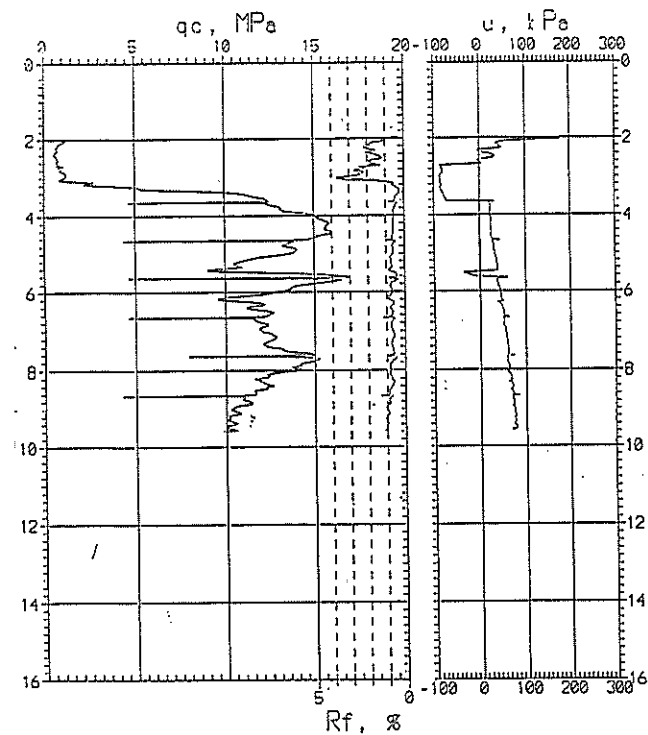


Figure 3: CPTU Test SJS005 with 10 cm² Fugro cone at St Johns St Water Pumping Station, Christchurch, New Zealand. $v_t = 10$ mm/s.

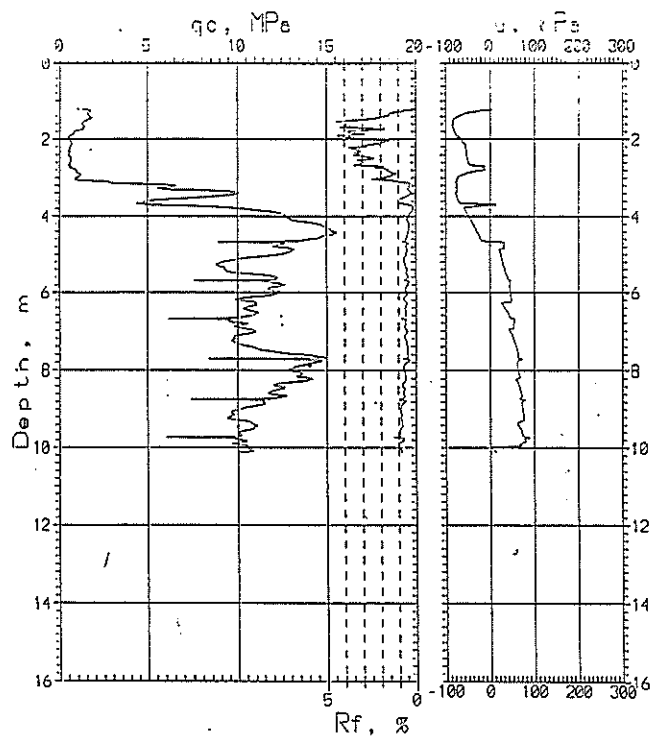


Figure 4: CPTU Test SJS006 with 10 cm² Fugro cone at St Johns St Water Pumping Station, Christchurch, New Zealand. $v_t = 20$ mm/s.

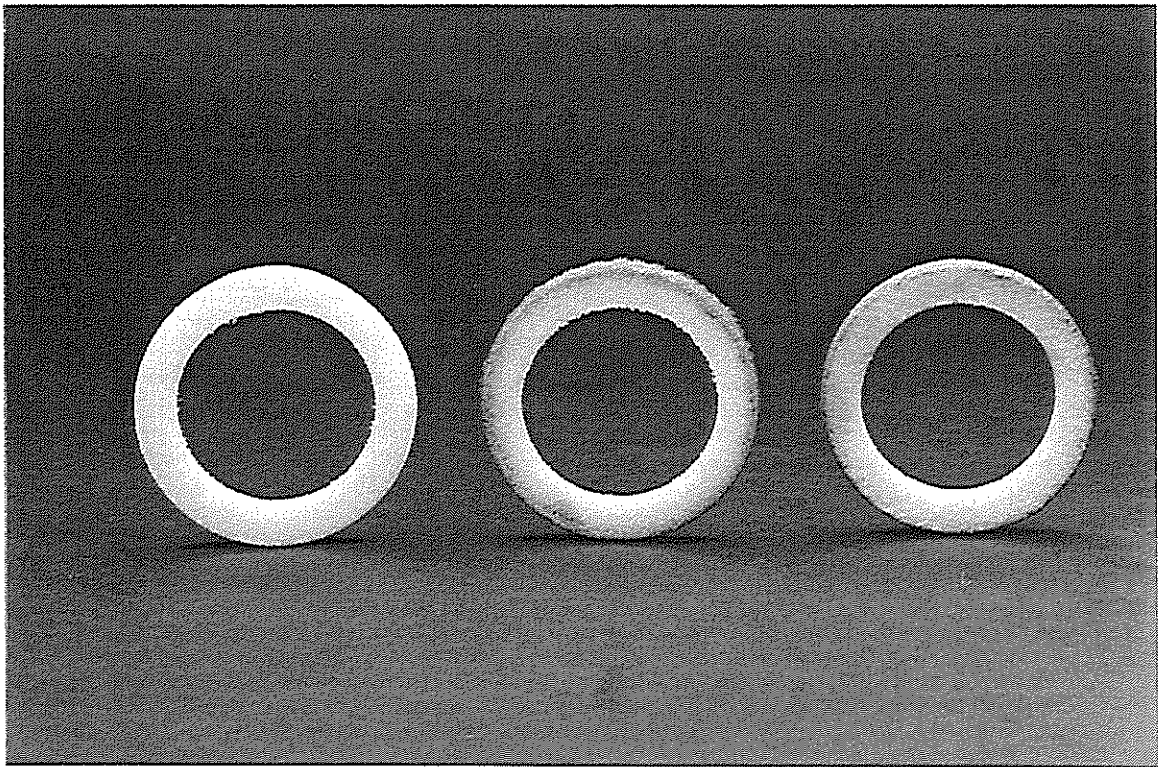


Figure 5: The filters used in the CPTU tests at the St Johns Street Water Pumping Station site. From left to right these are (1) an unused filter, (2) the filter used in for test SJS006, and (3) the filter used for tests SJS003, SJS004, SJS005.

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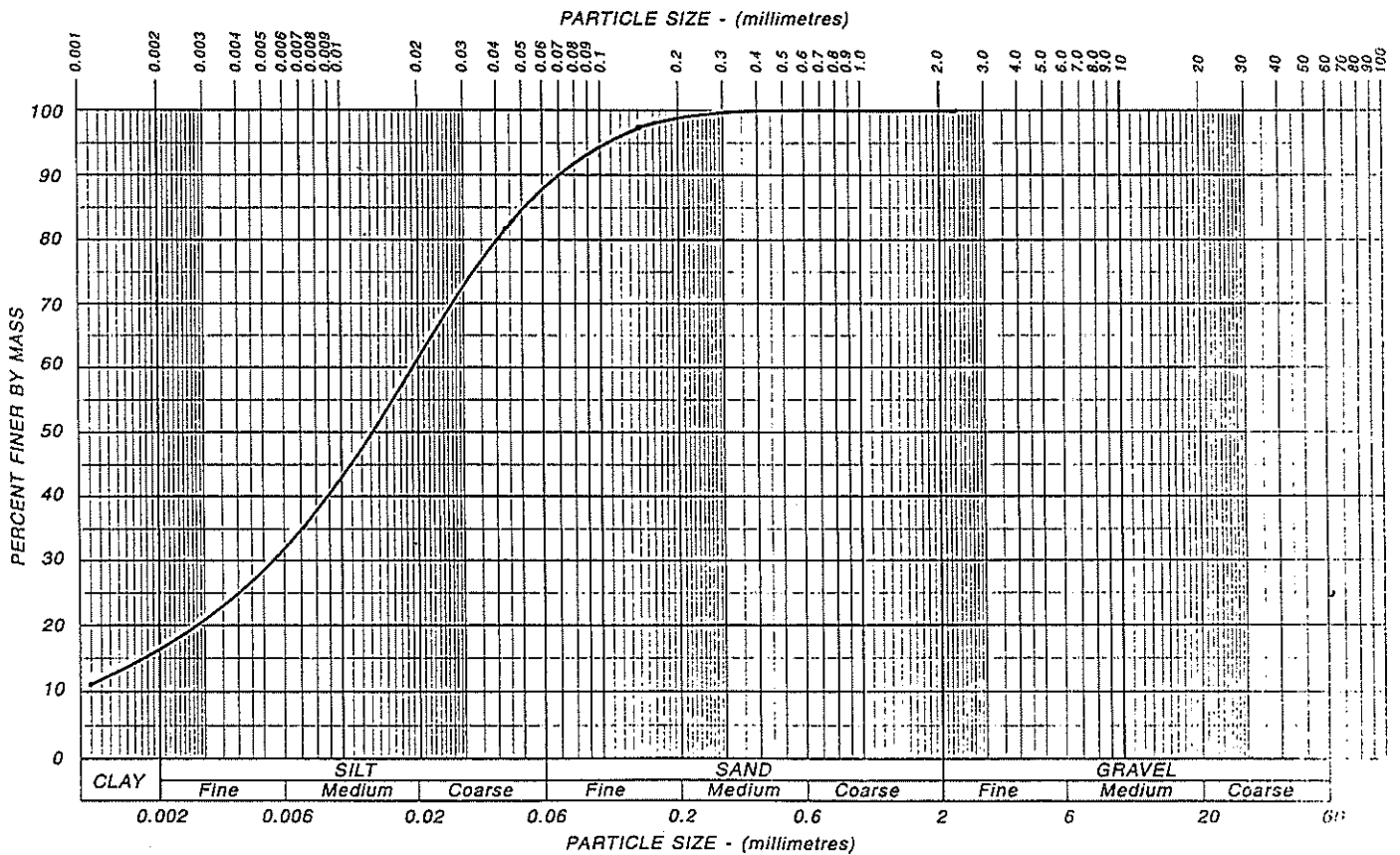


Figure 6: Grain size distribution curve for a soil sample from a depth of 2.2 m at the St Johns Street Water Pumping Station site.