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Piezocone testing of liquefaction sites: Normalization of excess pore pressure

J.B.Berrill
University of Canterbury, Christchurch, New Zealand
J.Canou
Ecole Nationale des Ponts et Chaussées, CERMES, France
P.Foray
Institut de Mécanique, Grenoble, France
J.-L.Pautre
Bouygues Offshore, Paris, France

ABSTRACT: A non-dimensional form is presented for excess pore pressure recorded by piezocone penetrometer. The normalization is prompted by dimensional analysis and allows for the effects of penetration rate and soil drainage conditions. The proposed expression for dimensionless excess pore pressure is supported by field and calibration chamber tests using both full-sized and miniature piezocones.

1. INTRODUCTION

Excess pore pressure measured during a piezocone (CPTU) probe should give an indication of the state of density of the soil and its dilatancy characteristics. But these pressures are difficult to interpret in a quantitative manner because they are also influenced by the drainage conditions and consolidation characteristics of the soil and the rate of loading during the test, as well as by properties of the cone itself, especially the filter position.

In this paper, we present a simple non-dimensional form for excess pore pressure, suggested by dimensional analysis and confirmed by test data, that allows for drainage conditions and rate of loading. The resulting dimensionless excess pore pressure, ΔU, should be more closely related to the state of the soil and its volume-change characteristics than the raw excess pore pressure, Δu. It should thus lead to better interpretation of piezocone results, especially in fine-grained, liquefiable sands, where drainage conditions lie somewhere between fully drained and fully undrained.

2. NON-DIMENSIONAL EXCESS PORE PRESSURE

Drainage conditions during a CPTU probe can be characterised by the parameter t_{50}, the time required for dissipation of 50 percent of initial excess pore pressure in a dissipation test made when piezocone penetration is stopped. The value of t_{50} depends on both the permeability of the soil and on boundary conditions, as must the value of excess pore pressure, Δu, during penetration. Measured pore pressure must also depend on the rate of pore pressure generation, which should be proportional to the rate at which pore water mass is displaced during the probe; that is, proportional to $(\pi/4)nd_c^2\rho_w v_f$, where n is porosity, d_c is the cone diameter, ρ_w the mass density of water and v_f the penetration rate.

Noting that porosity and permeability appear explicitly in the coefficient of consolidation c we have the six parameters: Δu, d_c, v_f, t_{50} c and γ_w, where for convenience γ_w the unit weight of water replaces ρ_w. These parameters contain three independent dimensions, and dimensional analysis yields the three dimensionless numbers:

$$\pi_1 = \frac{\Delta u}{\gamma_w\ v_f\ t_{50}}$$

$$\pi_2 = \frac{ct_{50}}{d_c^2}$$

and

$$\pi_3 = \frac{t_{50}v_f}{d_c}$$

The first grouping interests us since it gives a dimensionless measure of excess pore pressure

$$\Delta U = \frac{\Delta u}{\gamma_w v_f t_{50}} \quad \text{.........} (1)$$

We note in passing, however, that π_2 gives the well-known expression for dimensionless time. (Torstensson, 1977).

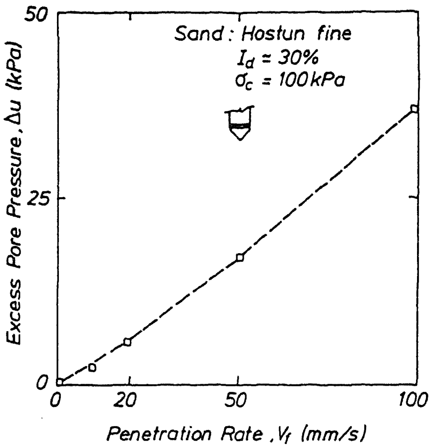

Figure 1. Influence of Penetration Rate on Δu, Observed with the Mini-Piezocone in the CERMES Calibration Chamber (Canou, 1989).

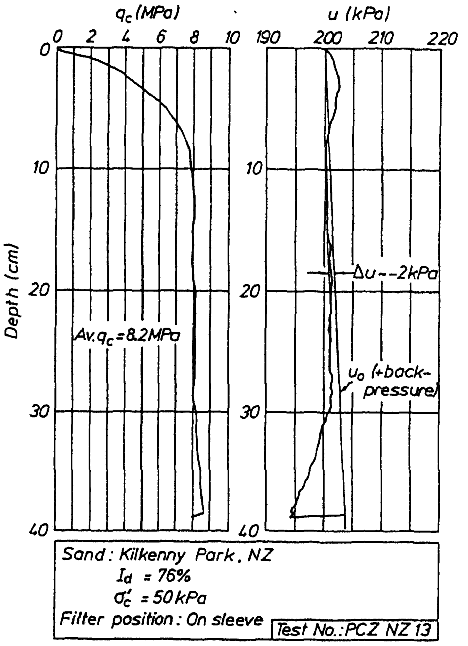

Figure 2. Mini-piezocone Test on Kilkenny Park, New Zealand sand in the CERMES Calibration Chamber.

3. COMPARISON WITH TEST RESULTS

To test he effectiveness of the dimensionless form given in equation (1), we use results from a joint French-New Zealand piezocone project. As part of this project, tests were carried out with a mini-piezocone (M-CPTU) having a cross-sectional area of 1 cm^2 in a small calibration chamber at CERMES in Paris, and with a 15 cm^2 Parez cone in the 1.2 m diameter chamber at the IMG in Grenoble. Field tests were made with the Parez cone at a number of sites that had liquefied in New Zealand during the 1968 M7.1, Inangahua earthquake. Sand from one of these sites, Kilkenny Park, Westport, was shipped to France for use in the calibration chambers. Although the calibration chamber tests with Kilkenny Park sand have not yet been completed, we do have some preliminary results, together with results from an exhaustive series of tests with the mini-cone using Hostun RF sand. These, and the CERMES test setup, are described by Canou (1989). The field testing has been described briefly by Berrill et al. (1987) and more fully by Ooi(1987).

Although these test programmes were not designed with the proving of (1) in mind, they do include a study of the effect of penetration rate on Δu, and certain other pairs of tests which enable the validity of the Δu - t_{50} relationship to be examined.

Firstly, Canou (1989) carried out a number of M-CPTU tests over a range of penetration rates in Hostun RF sand under similar conditions of density and confining stress. The results given in Figure 1 show a near-linear relation between Δu and v_f.

Secondly, to test the relationship between t_{50} and Δu, we use values of Δu and t_{50} recorded with the mini piezocone (M-CPTU) and those recorded with a full-sized cone in Kilkenny Park sand under similar conditions of density and confining stress. Results from comparable tests are shown in Figures 2 and 3. In both cases, the filter was in the common position at the base of the sleeve. A feature of the field tests at Kilkenny Park was the negative excess pore pressure recorded throughout the 10 m sand layer, even in sand that had liquefied in the M = 7.1 Inangahua earthquake. The M-CPTU test, shown in Figure 2, employed a confining pressure of 50 kPa and registered a cone resistance of $q_c \approx 8.2$ MPa, together with $\Delta u \approx -1.5$ to - 2.0 Kpa and $t_{50} \approx 0.2$ seconds. Thus, for the comparison, we sought a field record which had yielded a q_c of about 8 MPa at a depth of around 5 m, to have the effective overburden stress in the field similar to the confining pressure in calibration chamber as well as similar relative density. These conditions were fulfilled in test KPK007 whose log is shown in Figure 3, taken from Ooi (1987). Here we have $\Delta u \approx -10$ to - 15 kPa, with values of $t_{50} \approx 1.35$s and 1.26s recorded in dissipation tests at z = 5.36 m and 6.36 m respectively. Thus from the mini-cone in the laboratory we have

$$\Delta U_{mini} = \frac{-2}{\gamma_w v_f 0.2} = \frac{-10}{\gamma_w v_f}$$

Table 1. Results from Parez cone tests in the field at Kilkenny Park, New Zealand and Mini cone tests in the CERMES calibration chamber on the Hostun RF sand.

Test No.	Sand	I_D	σ'_c	Δu	t_{50}	ΔU
NZ 18	Kilkenny Park, NZ	49%	400 kPa	7.6 kPa	0.45	950
MPC	Hostun RF	29%	100 kPa	4.4 kPa	0.2s	1100

and with the Parez cone in the field,

$$\Delta U_p \approx \frac{-12}{\gamma_w v_f 1.3} \approx \frac{-9}{\gamma_w v_f}$$

The same penetration rate of 20 mm/s was used in both cases. The agreement is remarkable.

It is worth noting that the drainage conditions were markedly different in the two cases. In the field, the dissipation test took place in the middle of a fairly homogeneous layer about 10 m thick. In the laboratory, drainage occurred at the two ends of the 200 mm diameter cylindrical sample whose length was 400 mm. This supports the assertion that the parameter t_{50} characterises the overall drainage conditions, boundary conditions included.

A third comparison can be made between the two different sands tested at roughly comparable relative densities, I_D. Test conditions and results are shown in Table 1.

Here, the trends are as one would expect: The cleaner, coarser Hostun RF sand (D_{50} = 0.32 mm, C_U = 1.70) generates smaller absolute excess pressures, which dissipate more quickly, than does the Kilkenny Park sand (D_{50} = 0.27, C_U = 2.1). Yet the dimensionless excess pore pressure is greater for the Hostun sample, consistent with its looser state.

4. CONCLUSIONS

Dimensional analysis yields an expression for dimensionless excess pore pressure normalised by the half-dissipation time, t_{50}, and penetration rate, v_f.

The expression proposed for non-dimensional pore pressure is well-supported by available field and laboratory results. Furthermore, the near identical dimensionless pore pressures yielded by the second comparison above, comparing field results from the full-sized Parez cone with laboratory results from the mini-cone in the same sand in the same state but with quite different drainage boundary conditions, suggests that t_{50} does indeed characterize the overall drainage condition, including boundary effects.

It is expected that this normalization will allow for the effects of penetration rate and drainage on the pore pressure measurements, thus minimizing or eliminating completely the uncertainty in piezocone pore pressure readings due to unknown drainage conditions and non-standard penetration rates.

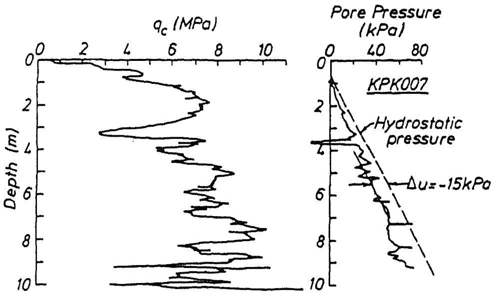

Figure 3. CPTU Test with 45 mm diameter Parez Cone at Kilkenny Park, New Zealand (Ooi, 1989).

This development has implications for the more precise empirical use of the piezocone, especially in identifying potentially liquefiable sand deposits and it may also lead to more fundamental applications through, for example, the *parameter of state* of Been and Jefferies (1985).

5. ACKNOWLEDGEMENTS

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