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23. Interpretation of piezocone soundings in clay – a case history

R. G. CAMPANELLA, J. P. SULLY and P. K. ROBERTSON, University of British Columbia

Lower 232nd Street in Langley, British Columbia, is one of several research sites used by the In Situ Testing Group of the University of British Columbia (UBC). With emphasis on the presentation of data the paper considers the results obtained from piezocone soundings carried out at the site and interpretation methods used to evaluate soil response and associated geotechnical parameters.

INTRODUCTION

1. The site is located at the 232nd Street exit of the Trans Canada Highway in Langley, B.C. The Quaternary sequence at the site consists of marine silt to clay deposited during the glacial regressions and is occasionally interbedded with minor sand layers. The slightly organic silts and clays are underlain by dense glaciomarine sands and gravels. Subsequent to deposition the fine grained soils have been subjected to leaching initiated by isostatic uplift and/or receding sea levels. The soils are overconsolidated at the surface due to dessication.

2. Piezocone data has been obtained using several UBC designed cones (UBC4, UBC6, UBC7) and also the Hogentogler "supercone" each of which permit pore pressure measurement at several locations along the cone (refs 1, 2). Two different filter thicknesses were used (5 mm and 2.5 mm) with the Hogentogler cone for the location behind the tip.

3. In situ vane tests were performed using a Nilcon portable apparatus to determine both peak and remoulded undrained shear strengths.

4. Continuous undisturbed sampling was performed using a GMF (Dutch) wireline sampler operated from the UBC Research Vehicle.

TESTING PROCEDURES AND EQUIPMENT

5. Details of the piezocones used in this study have been presented elsewhere (ref. 3) and will not be considered here suffice to say that test procedures and equipment characteristics are in accordance with the ASTM (1986) and ISSMFE (1977) standards.

6. Microcomputer software is used extensively for data acquisition, reduction and interpretation using empirical correlations developed through comparisons of field and laboratory performance (ref. 4).

INTERPRETATION OF PIEZOCONE DATA

7. Cone data is presented graphically using the IBM-PC compatible program CONEPLOT available from Hogentogler and Co. Figure 1 shows the profile of piezocone parameters obtained with the UBC7 cone for the pore pressure measuring location behind the friction sleeve. Superimposed on the profile are the results from the Hogentogler "supercone" at the same site but with the pore pressure measured behind the tip. The two soundings are separated laterally by 3 m. The variations in the measured parameters will be discussed later.

8. The results of in situ vane tests carried out over the past four years are shown in Fig. 2 where the relative uniformity of the clay is evident. The figure also indicates the undrained shear strength profile used in the analyses for determination of cone factors. The sensitivity of the clay as determined by the ratio of peak to remoulded s_u from the in situ vane test was around 12 with a more sensitive layer ($S_t = 25$) between 8.5 m and 13.5 m.

Comments on measured cone data

9. The cone bearing profile in Fig. 1 again demonstrates the uniformity of the soil at the site and the repeatability of the results using two different piezocones even in soils where bearing measurements are prone to substantial errors (bearings <1% of full scale, ref. 5).

10. The sleeve friction and consequently friction ratio (friction/bearing stress ratio as a percent) profiles are in good agreement below 10 m. Above this depth a substantial difference exists which can be attributed tc temperature effects. The UBC7 results have been corrected for temperature. Shear wave velocities were also measured at 1 m intervals during testing so that the cone was in equilibrium with the ground temperature (shear wave velocity profiles are not presented in this paper). The Hogentogler "supercone" which does not have a temperature sensor, however, was penetrated at the standard rate of 2 cm/s with no stops for shear wave velocity determinations. It is apparent that only at about 10 m depth does the cone arrive at temperature equilibrium.

11. The pore pressure measured behind the tip, u_2, is higher than the pore pressure measured behind the friction sleeve, u_3. The units of pore pressure are in meters of water

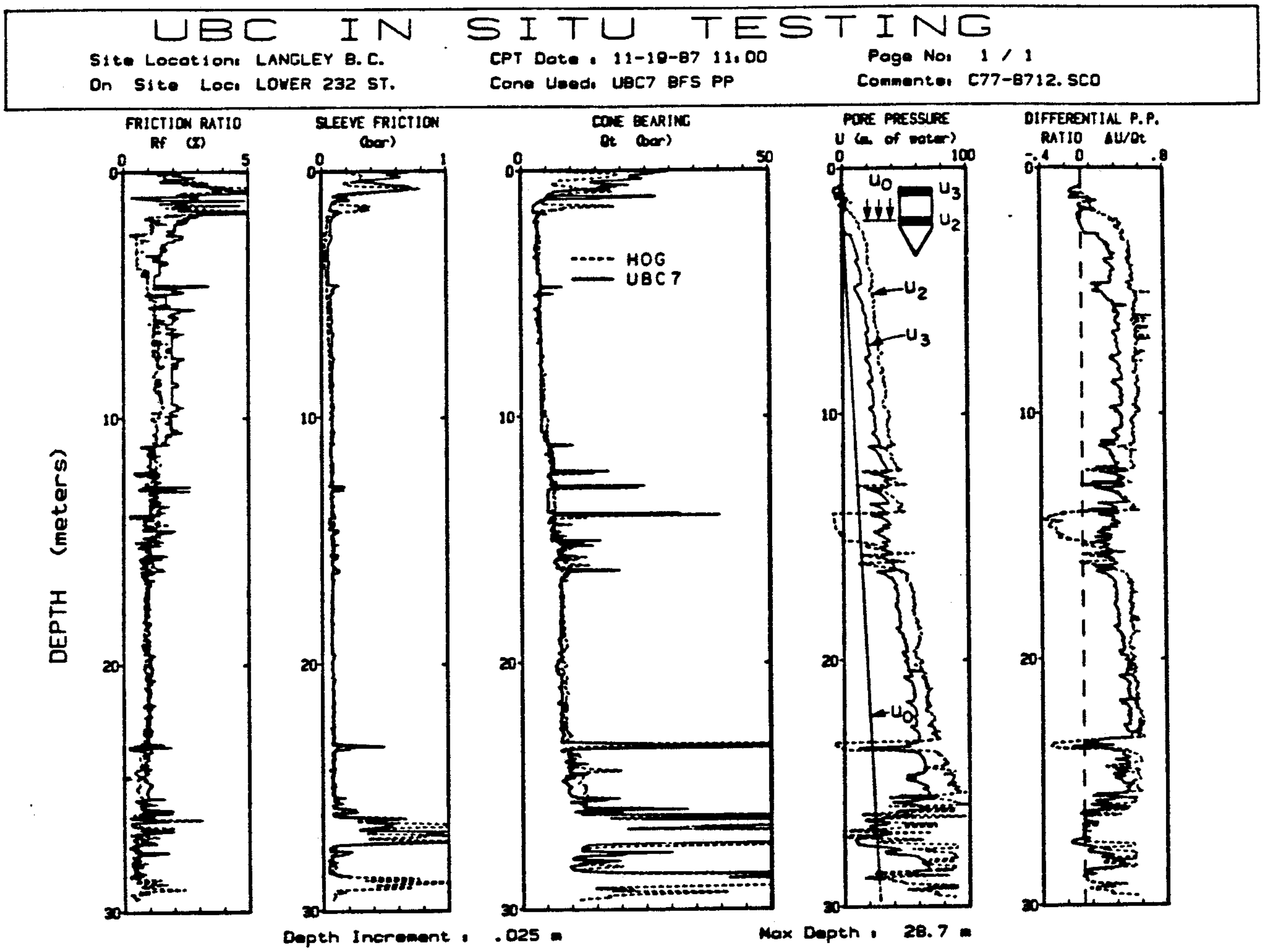


Fig. 1. Piezocone profile for Lower 232nd Street

head for easy reference to depth of sounding. The almost constant value of differential pore pressure ratio with depth in the clay is a good indicator of the complete saturation of the measuring system. The magnitude of the pore pressures measured at three locations around the cone is shown in Fig. 3.

12. At several depths in the profile substantial reductions in pore pressures are generated which correspond to dense sand/silt layers of high bearing. Recovery of the pore pressure is especially sluggish when these pressures are negative and probably result from partial loss of saturation and in some cases cavitation. The delay in recovery to the maximum value depends on the ease with which water can flow back into the measuring system as evidenced by comparing the response of 5 mm and 2.5 mm high filters placed behind the tip (Fig. 4). The 5 mm filter recovers very rapidly suggesting that the 2.5 mm filter may suffer from partial pore blockage. Except for that difference, the response of the two filter sizes was essentially identical for this site. Figure 3 shows that the face and behind friction sleeve pore pressures rapidly return to the maximum value once the dense layers are penetrated.

Interpreted soil profile

13. Soil behaviour type has been determined using the charts presented by Robertson et al

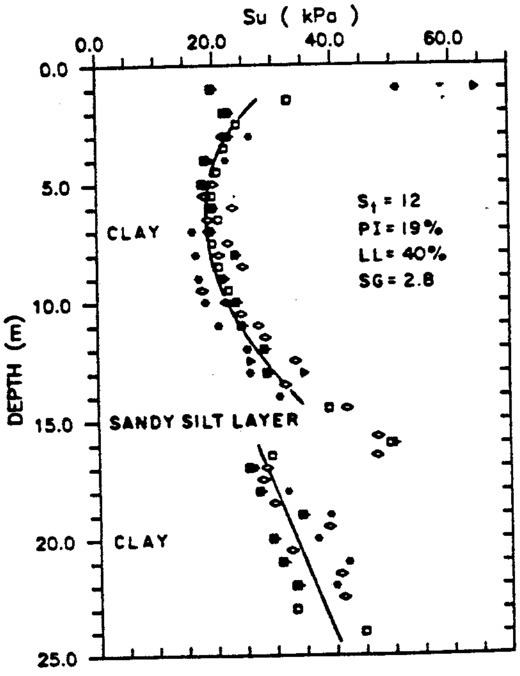


Fig. 2. Undrained shear strength profile - Lower 232nd Street

(ref. 5) using cone bearing with both friction ratio (R_f) and pore pressure parameter Bq (Fig. 5). The q_c-R_f% correlation is performed by the program CPTINTR1 developed at UBC (ref. 4). A more versatile interpretation

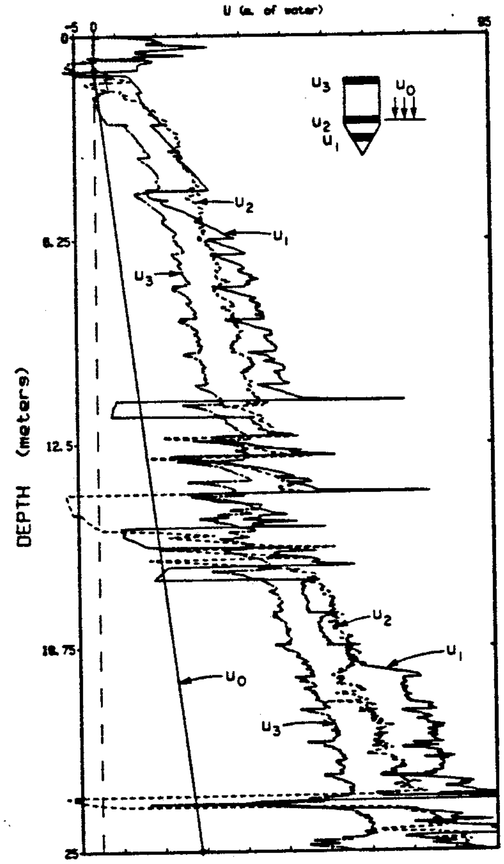


Fig. 3. Pore pressures measured at three locations around the cone for Lower 232nd Street

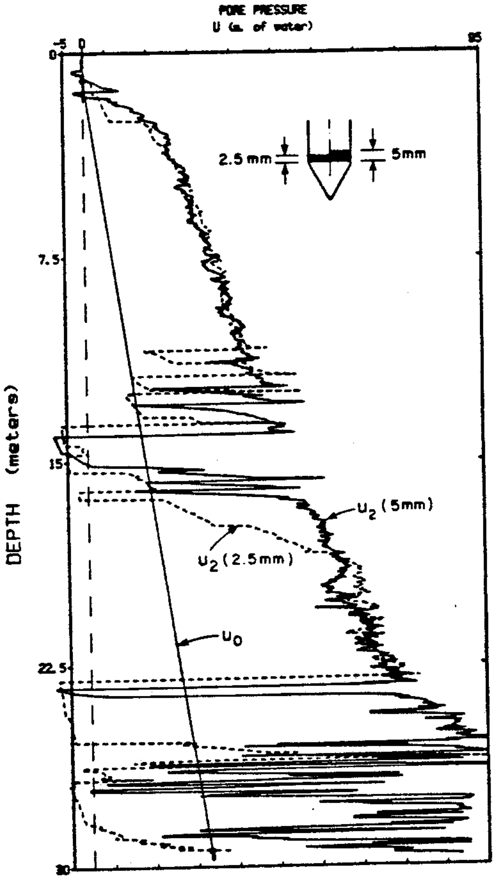
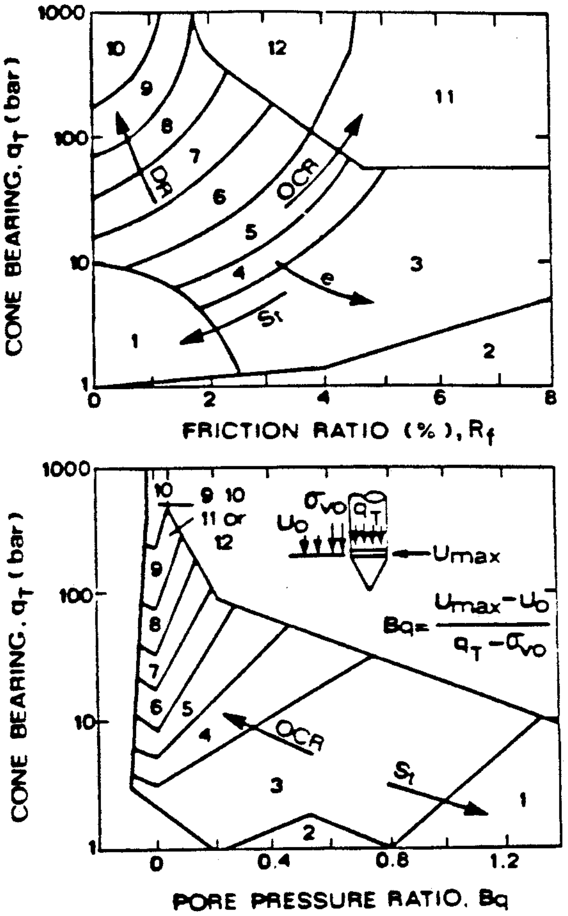


Fig. 4. Effect of filter size on pore pressure response - Lower 232nd Street



Zone	q_T/N	Soil Behaviour Type
1)	2	sensitive fine grained
2)	1	organic material
3)	1	clay
4)	1.5	silty clay to clay
5)	2	clayey silt to silty clay
6)	2.5	sandy silt to clayey silt
7)	3	silty sand to sandy silt
8)	4	sand to silty sand
9)	5	sand
10)	6	gravelly sand to sand
11)	1	very stiff fine grained (*)
12)	2	sand to clayey sand (*)

(*) overconsolidated or cemented

Fig. 5. Soil behavior type from CPT and CPTU (Robertson et al, 1986)

program which incorporates both correlations is presently being installed (ref. 4).

14. Both charts gave good agreement on the soil type which fell in the range sensitive fine grained (Zone 1) to clay (Zone 3). The soil types obtained using Fig. 4 were confirmed by inspection of the recovered undisturbed samples.

Undrained strength and cone factors

15. The average undrained shear strength profile shown in Fig. 2 was used to evaluate the cone factors N_{kt} and $N_{\Delta u}$ as given by:

$$N_{kt} = (q_t - \sigma_v)/s_u \qquad (1)$$

$$N_{\Delta u} = \Delta u/s_u \text{ where } \Delta u = u - u_o \qquad (2)$$

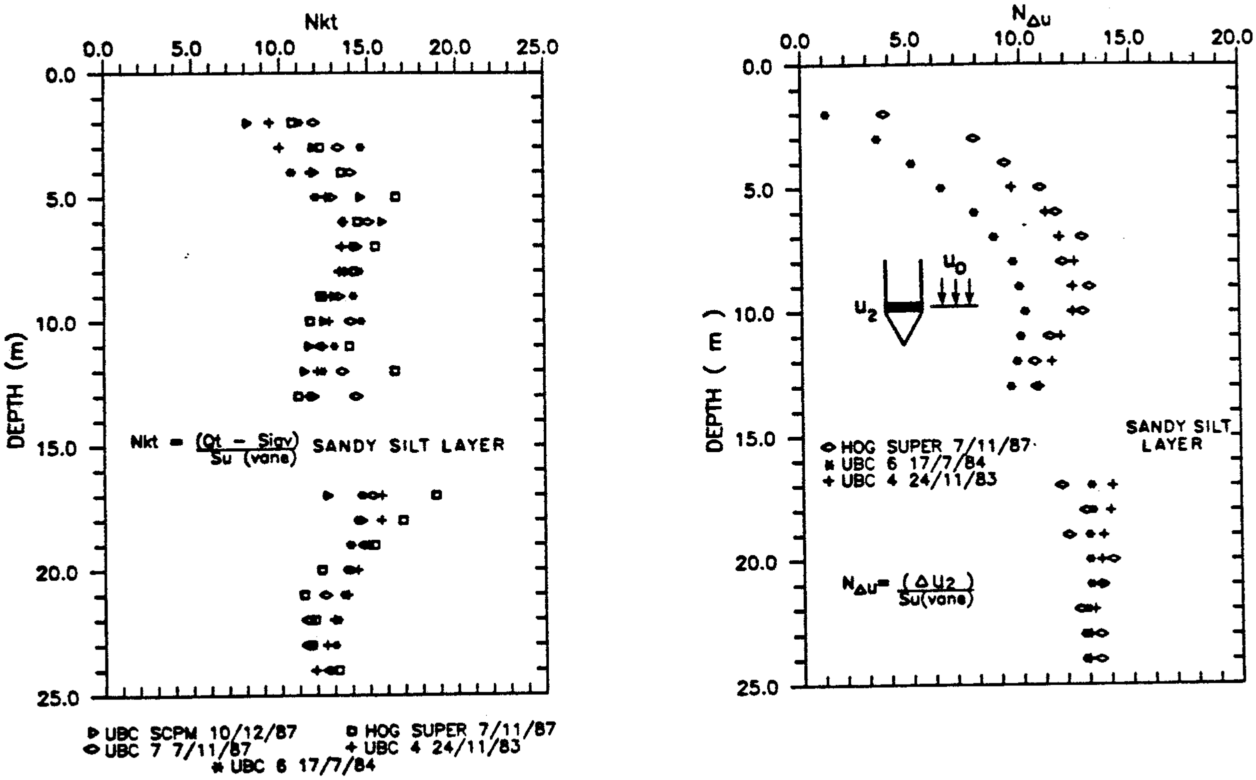


Fig. 6. Cone factors (a) N_{kt} and (b) $N_{\Delta u}$ determined from in situ vane data - Lower 232nd Street

The results are presented in Figs 6(a) and (b). Regarding the variation in N_{kt} values given in Fig. 6(a) the following comments can be made:

- the average values for tests performed in 1983/4 and 1987 are similar. Errors in the measurement of s_u may be the principal reason for the difference as well as natural soil variability.
- full scale and low range calibration of the piezocones used in the study confirmed the measured bearings.

16. For the $N_{\Delta u}$ values in Fig. 6(b) calculated using the pore pressure measured behind the tip (u_2) a similar variation also exists in the lower part of the profile. However, above 13 m the values of UBC6 are somewhat lower suggesting that the filter may not have been completely saturated. Except for these lower values the results are very consistent. Since the pore pressure transducer is operating at 40% to 50% full output the measurements are considered to be reliable. It appears that neither N_{kt} nor $N_{\Delta u}$ are constant over the depth of 25 m at this site.

17. Figure 7 compares the $N_{\Delta u}$ values for the three measuring locations around the cone. For determining an s_u profile it would appear that the best location for the pressure to be measured is behind the friction sleeve since the obtained $N_{\Delta u}$ value is essentially constant within a particular stratum. High pore pressure gradients near the tip (refs 2, 5) complicate the measurement of a true pore pressure which may be overly sensitive to equipment characteristics.

Evaluation of stress history

18. The stress history of the soil has been evaluated using both the vane and piezocone data (refs 6, 7) to estimate overconsolidation ratios (Fig. 8). The two methods are correlated with the results of preliminary laboratory data also shown on Fig. 8. OCR's obtained from DMT testing are also shown for comparison. The estimated OCR profiles from the vane and piezocone bracket the laboratory data.

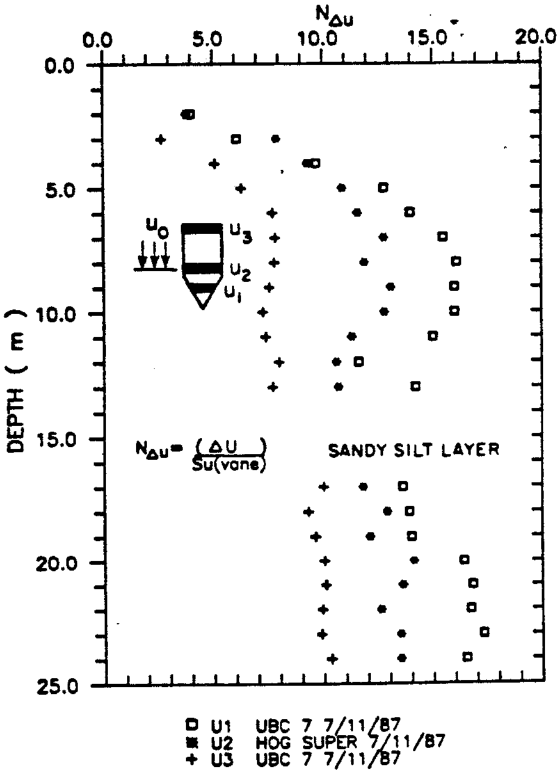


Fig. 7. $N_{\Delta u}$ for three measuring locations - Lower 232nd Street

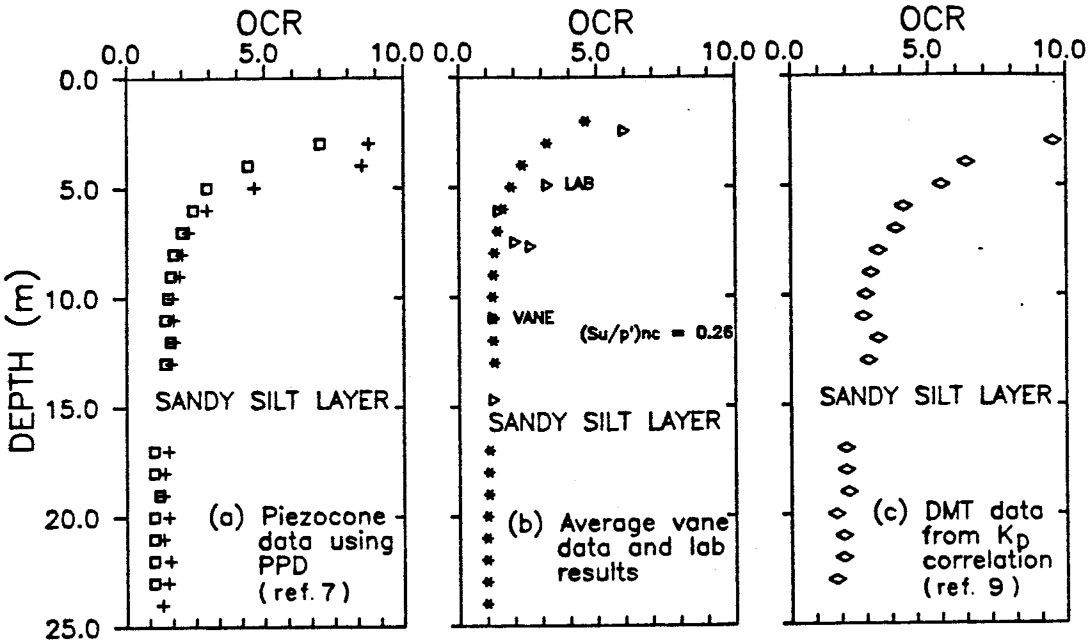


Fig. 8. Stress history from vane, piezocone and dilatometer results - Lower 232nd Street

Assessments of flow characteristics

19. At various stages during the soundings the excess pore pressures generated during penetration were allowed to dissipate in order to estimate the flow characteristics of the soils. Typical dissipation curves in a heavily overconsolidated clay for the various filter locations are shown in Fig. 9. The data shown is for the clay in the Strong Pit, about 10 km from Lower 232nd Street site.

20. Pore pressure gradients near the cone tip may modify the dissipation curves so that after commencement of the period for dissipation the pore pressure actually increases first before decaying. This behavior is very pronounced in overconsolidated soils due to the larger gradients that exist (refs 2, 8). Under these circumstances the available theories for interpreting dissipation data cannot be applied and little analytical benefit results. In overconsolidated soils the best location for the filter is probably on the face of the tip if dissipation tests are required since the excess pore pressure is highest at this point and hence always decays during stops in penetration. However, unloading of the bearing stress when penetration stops may cause a sudden decrease in the measured pore pressure. Normally and lightly overconsolidated clays give pore pressure decays behind the tip and behind the friction sleeve which are not affected by unloading and for which available theories can be used for interpretation to estimate the coefficient of consolidation, c_h, as was the case at Lower 232nd below 5 m. Whether or not the data can be interpreted to give quantitative estimates of flow parameters depends on the form of the normalized dissipation curve. If not, the time for 50% dissipation, t_{50}, can always be used as an aid for soil classification purposes.

CONCLUSIONS

21. Piezocone testing can produce reliable and repeatable data provided adequate consideration is given to the factors which affect the quality of the data, i.e., measurement errors, temperature variations, saturation of filters, etc. Furthermore, the effect of the inherent errors on interpreted soil parameters should be considered when characterizing a site.

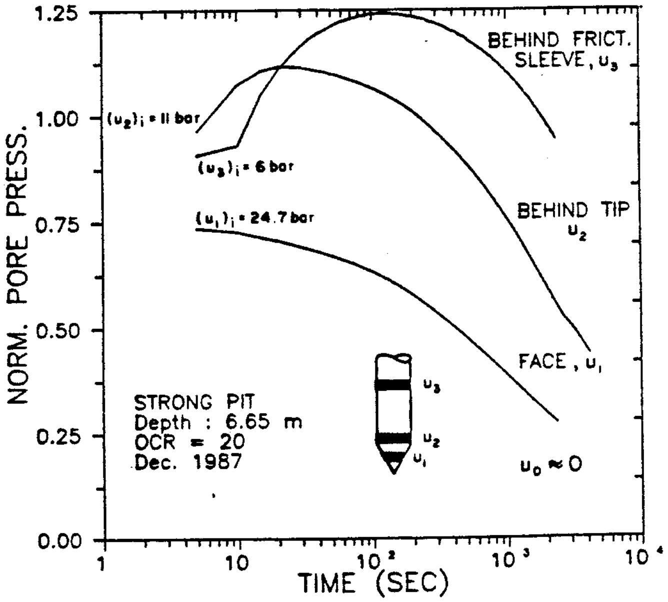


Fig. 9. Dissipation curves for the various filter locations in heavily overconsolidated clay - Strong Pit

22. Various locations on the cone exist for measuring pore pressures during penetration. The data presented confirms that no one location is best suited to all problems; rather the measuring location(s) should be selected so as to provide the most useful data. For the Lower 232nd Street site pore pressures measured behind the tip gave better definition of material type whereas in the overconsolidated part of the profile and at the Strong Pit the best dissipation data was obtained with the filter located on the face of the tip. However, if unloading of the tip occurs during stops in penetration the dissipation curves can be substantially affected.

23. Examples have been given in which it appears to be more reliable to measure pore pressure response either on the face of the cone tip or behind the friction sleeve. Unfortunately, practical problems like excessive wear and damage of face filter elements and initial saturation difficulties behind the friction sleeve make these locations much less desirable. Unfortunately, immediately behind the tip large stress and pore pressure gradients exist which complicate the measurement of a true response in overconsolidated clay. The trend in design of in situ devices currently in use at UBC requires that all three pore pressure locations be monitored, if possible.

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