

EFFECT OF LATERAL STRESS ON CPT ~~CONE~~ PENETRATION PORE PRESSURES

by

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INTRODUCTION

Cone penetration testing with associated pore pressure measurement is widely acknowledged as the optimum in situ test method for providing stratigraphic detail in subsoil investigations. However, in recent years the trend has been towards the interpretation of more sophisticated soil parameters with increased experience using piezocones (Campanella and Robertson, 1988). Many of the derived soil properties are often dependent on empirical correlations, ideally based on some theoretical framework (Wroth, 1984). In general, normalized CPTU parameters based on total cone resistance, q_t , excess pore pressure due to penetration, Δu , or a combination of both are used as indicators to which changes in soil behaviour can be correlated. This paper considers the pore pressure distribution around a penetrating cone in cohesive soils and how the measured values can be related to changes in the lateral stress condition.

The development of penetrometers with multiple piezometers has supported the idea that the pore pressures measured at differing locations can be related to changes in stress history. Konrad and Law (1987) presented a combined cone resistance and pore pressure method to evaluate the preconsolidation pressure in normally consolidated to lightly overconsolidated clay. The

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method assumes a constant ratio between the pore pressure measured on the face of the cone and that measured behind the tip. Incorporation of actual measured pore pressures at both locations may enhance the correlations especially for soils with higher overconsolidation ratios (OCR) where this assumption does not generally hold. The method proposed by Sully et al. (1988a) relates the OCR of the soil to a normalized pore pressure difference parameter, PPD, defined as:

$$PPD = \frac{u_1 - u_2}{u_0} \quad (1)$$

where

u_1 = penetration pore pressure measured on face of the cone

u_2 = pore pressure measured behind the cone tip

u_0 = equilibrium in situ pore pressure.

Due to the interdependence of K_0 and OCR in non-cemented soils, similar type correlations may be expected between a pore pressure parameter and K_0 .

Penetration Pore Pressures and K_0

Pore pressures measured during penetration are known to be a function of both soil characteristics and probe geometry. It is thought that the use of the pore pressure difference technique accounts to a great extent for this dependence (Sully et al., 1988b).

Experience at the University of British Columbia (UBC) and at other centres has shown that the excess pore pressure, Δu , measured at any location on or behind the cone tip during CPTU can be expressed as a function of the cone resistance:

$$\Delta u_1 = f_1(q_t) \quad (2)$$

$$\Delta u_2 = f_2(q_t) \quad (3)$$

$$\Delta u = u - u_0 \quad (4)$$

where the functions f_1 and f_2 vary according to the characteristics and stress history of the soil (see for example, Mayne and Holtz, 1988).

It follows then, that the pore pressure gradient around the tip ($\Delta u_1 - \Delta u_2 = u_1 - u_2$) is also some function of q_t . Furthermore, the acceptance that the cone resistance in clay is related to the horizontal effective stress, as has been shown to be the case for sands tested in calibration chambers, leads to the conclusion that:

$$u_1 - u_2 = f_4(q_t) = f_5(\sigma'_h) \quad (5)$$

Normalizing the pore pressure difference with respect to the vertical effective stress gives:

$$\text{PPSV} = \frac{u_1 - u_2}{\sigma'_v} = f_6(K_0) \quad (6)$$

EVALUATION OF FIELD DATA

Very little chamber test data exists for undrained penetration in clays; that which does exist is inadequate to provide sufficient data to evaluate the suggested dependence of PPSV on K_0 . Consequently, it has been necessary to use field data to evaluate the basis of eqn. (6).

Initially, lateral stress measurements at two sites in the Lower Mainland of British Columbia were correlated with the results of piezocone soundings (Sully and Campanella, 1990). To amplify the data base, published data from recognized research centres around the world were also incorporated. Table 1 lists the soils deposits that have been used and provides information concerning the types of measurement performed at each. The results of the study are shown on Fig. 1, which indicates the existence of a definite trend between the normalized pore pressure parameter, PPSV, and the lateral stress coefficient, K_0 .

Assuming a linear variation between the parameters, the correspondence of K_0 with PPSV is given by:

$$K_0 = a + b(\text{PPSV}) \quad (7)$$

where a and b are constants. In the ideal case the coefficient ' a ' would be equal to the normally consolidated value of K_0 with a corresponding PPSV value of around 0.75. The second coefficient, b , averages 0.11. For many of the sites used to produce Fig. 1 this approximation is fairly realistic (for comparison with the data trends of individual sites, the dotted line on Fig. 1 has a gradient of 0.11). At other sites, notably St. Albans and Lr 232 St., both comprising sensitive clay silts, this simplification does not hold; however, the variation between K_0 and PPSV essentially remains linear. The results for Brent Cross would also appear to be anomalous. The methods employed for the measurement of lateral stress at St. Albans and Brent Cross may suggest an explanation for the discrepancy (Table 1) since at most of the other sites either self-boring pressuremeter (SBPM) or total stress cell (TSC) results form the reference for K_0 . At Lr 232 St. the overconsolidated

Table 1. Details of in situ measurements for evaluation of K_0 and PPSV parameters

Site location and soil type (1)	Methods used for lateral stress determination ^a (2)	Brief details of piezocone measurements ^b (3)	Reference (4)
Brent Cross, London (London clay)	LAB, PBPM	D	Powell et al. (1988) Powell and Uglow (1986)
Cowden, U.K. (Glacial clay till)	PBPM, SBPM, TSC	D	Powell et al. (1983) Lunne et al. (1986b)
Drammen, Norway (Sensitive silty clay)	HF, SBPM	D	Lacasse and Lunne (1982) Ghionna et al. (1981)
Emmerstad, Norway (Quick clay)	FV	D	Aas et al. (1985) Aas (1985) Aas et al. (1986)
Grangemouth, U.K. (Soft alluvial clay)	SBPM, TSC	D	Powell et al. (1988) Powell and Uglow (1986)
Haga, Norway (Lean marine clay)	FV, HF, SBPM	D	Aas et al. (1986) Lunne et al. (1986a)
Lr. 232 St., Langley (Sensitive clay silt)	TSC	D	Sully and Campanella (1990) Gillespie (1990) Campanella et al. (1988)
Madingley, U.K. (Gault clay)	SBPM, TSC	D	Lunne et al. (1986b) Powell and Uglow (1986)
Onsoy, Norway (Soft sensitive clay)	HF, SBPM, TSC	D	Lacasse and Lunne (1982) Ghionna et al. (1981)
Rio de Janeiro, Brazil (Guanabara Bay clay)	No information given	S	Sills et al. (1988) Soares and Dias (1989)
Saugus, MIT (Boston Blue clay)	HF, SBPM	D	Levadoux and Baligh (1980) Ladd et al. (1979)
St. Albans, Quebec (Champlain Sea clay)	HF	D	Tavenas et al. (1974) Roy et al. (1982a,b)
Strong Pit, B.C. (Stiff clay silt)	TSC	D	Sully and Campanella (1989)
McDonald Farm, Vancouver (Soft clay silt)	SBPM	D	Konrad et al. (1985) Gillespie (1990)
Calib. Chamber, Oxford (Speswhite kaolin)	Transducers on CC boundaries	S	May (1987)

(a) FV = Field vane
 HF = Hydraulic fracturing
 LAB = Laboratory data
 PBPM = Prebored pressuremeter
 SBPM = Self bored pressuremeter
 TSC = Total stress cells
 (push-in type)

(b) S = Simultaneous measurement of u_1 and u_2 pore pressures in one sounding
 D = Dual (adjacent) soundings to independently measure u_1 and u_2

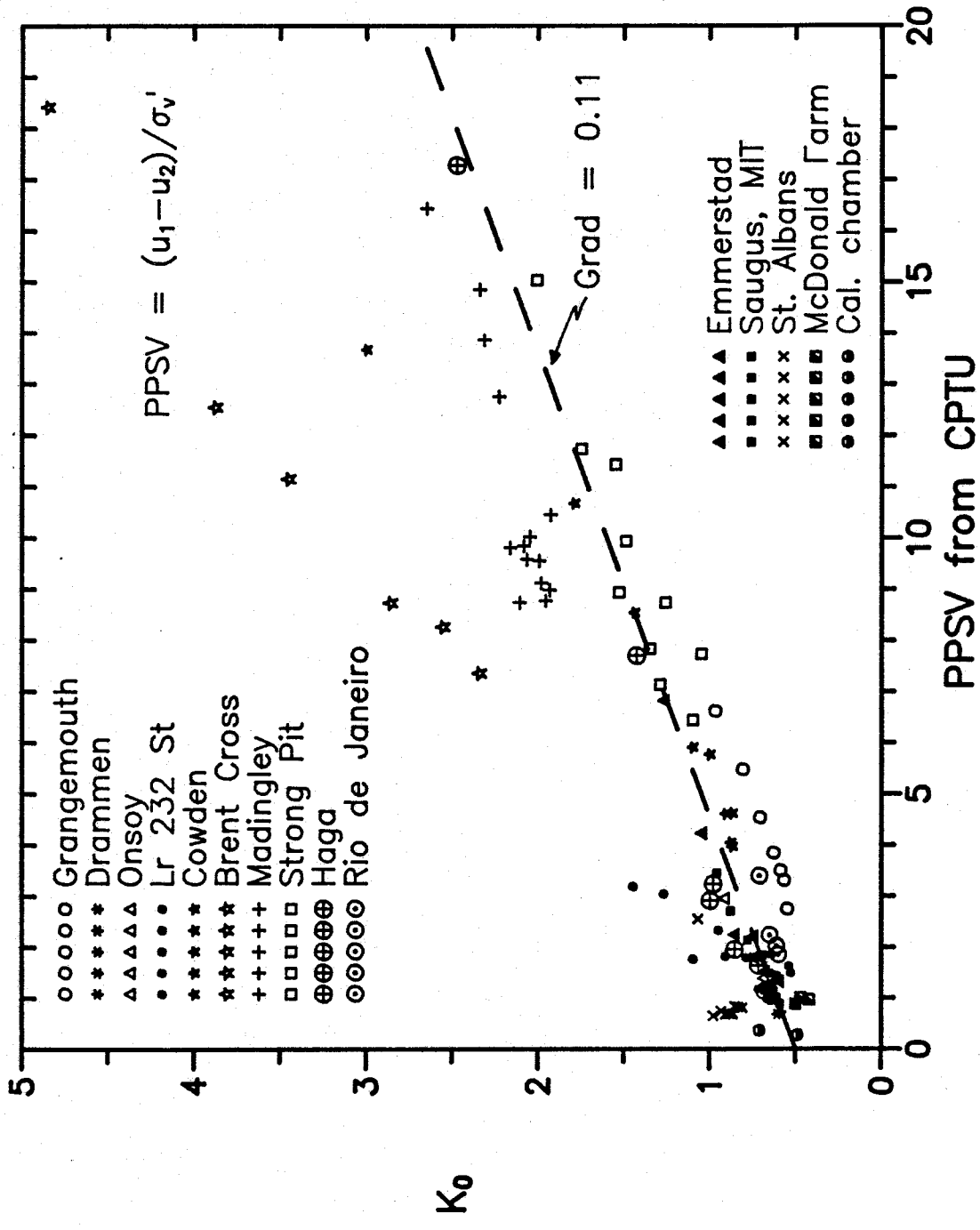


Fig. 1 PPSV- K_0 correlation for clays from published field data.

crust is riddled with open mineralized root holes which definitely influence the excess pore pressures measured during cone penetration; as would be expected, it is the pore pressure measurements on the face of the cone that are most affected, probably resulting in low estimates of PPSV.

DISCUSSION AND CONCLUSION

This paper has briefly presented the reasoning why a correlation might be expected between a defined pore pressure parameter, PPSV, and K_0 . Qualitative theoretical confirmation of the suggested correlations can be obtained by examination of both cavity expansion theories and the more rigorous strain path method approaches (Levadoux and Baligh, 1980; Teh, 1987). Based on the ideas presented, it is also logical to conclude from the relationship given by eqn. (5) that a similar correlation might be expected between a normalized cone resistance parameter and K_0 . This is outside the scope of this Technical Note, but data obtained at UBC suggest that q_T/σ'_{v0} is also a reasonable indicator of the K_0 conditions.

Evaluation of field data from fourteen sites and one calibration chamber study suggests that an approximately linear relationship exists between PPSV and K_0 for any particular site. The scatter in the data precludes the use of a generalized relationship. However, the advantage of this type of approach may be in the evaluation of K_0 for moderately to heavily overconsolidated clays; these materials present problems for lateral stress measurement using any of the methods listed in Table 1 (Jamiolkowski et al, 1985). The normally consolidated value of K_0 may be estimated from an empirical relationship with PI (Brooker and Ireland, 1960) and the overconsolidated value obtained based on pore pressure measurements during CPTU and the correlations shown in Fig. 1. Confirmation of the evaluated K_0 profile by other methods, including direct measurement, would be prudent considering the preliminary nature of the correlation shown in Fig. 1.

ACKNOWLEDGEMENTS

The authors are grateful to Tom Lunne (Norwegian Geotechnical Institute, Norway) and John Powell (Building Research Establishment, U.K.) for providing some of the data presented here and for their comments on the text.

Financial support by Natural Sciences and Engineering Research Council of Canada is also gratefully acknowledged.

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