XIII ICSMFE, 1994, New Delhi, India XIII CIMSTF, 1994, New Delhi, Inde

RELATING CONE AND PRESSUREMETER TESTS TO ASSESS PROPERTIES AND STRESSES IN SAND

CORRELATION ENTRE CONES EPROUVETTES ET ESSAIS AU PRESSIOMETRE EN VUE DE DETERMINER CARACTERISTIQUES ET CONTRAINTES DANS LES SABLES

Fernando Schnaid

Lecturer in Civil Engineering, Universidade Federal do Rio Grande do Sul, Porto Alegre - RS - Brazil

SYNOPSIS: A new approach for assessing soil properties and in situ stresses in sand has been recently developed from cone-pressuremeter tests. This paper intends to demonstrate the suitability of this approach to field and calibration chamber data. In particular, an attempt is made to demonstrate that correlations established from the cone-pressuremeter test can be extended by making use of limit pressure values obtained from the self-boring pressuremeter combined with independent measurements of cone resistance. A documented set of data from three different uncemented sands is referenced that confirms the validity of the approach to predict density and horizontal stress.

INTRODUCTION

The cone penetrometer is a well established in situ test technique which provides a reliable information of soil profile and an assessment to strength parameters in either sands or clays. Given the limitations of the assessment of soil deformation parameters from cone tests, the determination of the shear modulus by pressuremeter tests is considered of great practical interest.

A new site investigation device has been developed by Withers et al (1986) in which a pressuremeter module is incorporated behind a standard cone penetrometer tip. The pressuremeter module is similar to the Cambridge self-boring pressuremeter, differing on its capability of large radial membrane expansions. The small strain analyses developed for the self-boring pressuremeter are therefore not appropriate for the cone-pressuremeter test.

An analysis of the cone-pressuremeter test in clay has been proposed by Houlsby and Withers (1988) and has been applied successfully to derive values of undrained strength and shear modulus, but failed on deriving realistic values of horizontal stress. In sand, analytical and numerical methods of interpretation are not yet suitable to determine strength parameters (Withers et al, 1989; Yu, 1990) and interpretation has to relay on semi-empirical relationships. The interpretation of the test was then developed on the basis of calibration chamber tests (Schnaid, 1990; Schnaid and Houlsby, 1990, 1991). Since there is no large body of field data available for cone-pressuremeter tests in sand, validation of proposed cone-pressuremeter correlations are explored by making use of limit pressure values obtained from the self-boring pressuremeter combined with independent measurements of cone resistance.

CALIBRATION CHAMBER TESTS

Calibration chamber tests on the cone-pressuremeter give measurements of limit pressure ψ_ℓ and cone resistante q_c under conditions of controlled density, vertical stress and horizontal stress. Test results clearly showed that for a given density of sand it is horizontal effective stress and not the vertical effective stress which controls the behaviour of both q_c and ψ_ℓ (Houlsby and Hitchman, 1988, Schnaid and Houlsby, 1990, 1991).

It was therefore considered useful to explore the relationship between the ratio $(q_c - \sigma_h)/(\psi_\ell - \sigma_h)$ against relative density, R_d, which is presented in Figure 1. The ratio is sensitive to the relative density and the results can be approximated by a linear equation:

$$R_d = 9.0 \frac{(q_c - \sigma_h)}{(\psi_\ell - \sigma_h)} - 30 \qquad [1]$$

which is applicable for cone-pressuremeter tests carried out on Leighton Buzzard sand with values of $(q_c - \sigma_h)/(\psi_\ell - \sigma_h)$ in the range of 6 to 14.

The validity of the proposed correlation between density and the ratio $(q_c - \sigma_h)/(\psi_\ell - \sigma_h)$ can be further explored by making use of limit pressure values obtained from the self-boring pressuremeter combined with independent measurement of cone resistance. Calibration chamber tests carried out on Ticino sand (Ghionna et al, 1990) provide a database for such comparison, in which values of q_c and ψ_ℓ measured under the same stress conditions and about same density are presented. However to an adequate comparison of data it is necessary to account for the length to diameter L/D ratio effects of geometry on limit pressure, as suggested by Schnaid (1990).

$$\frac{\psi_\ell}{\psi^{L/D=10}} = 0.69 + \frac{3.1}{L/D} \qquad [2]$$

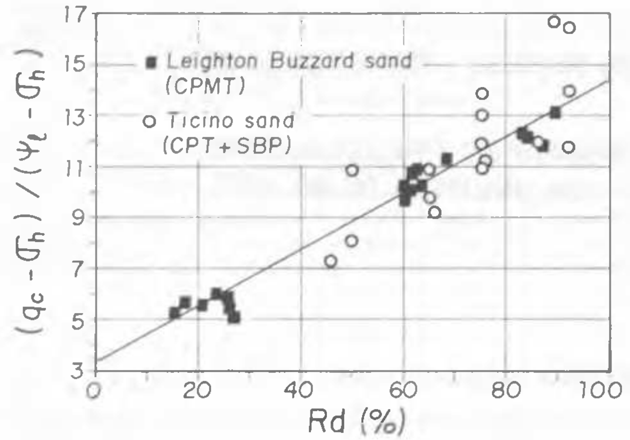

Figure 1 - Ratio of cone resistance to limit pressure against relative density (Calibration chamber tests).

in which $\psi_\ell^{L/D=10}$ is the limit pressure measured with L/D equal to 10. Results are also presented in Figure 1, in which the expression derived from cone-pressuremeter tests is shown to produce a generally good agreement with data obtained from self-boring pressuremeter tests.

Recalling that the cone resistance is primarily controlled by the horizontal stress and density, it is found that cone resistance measurements in the calibration chamber can be reasonably approximated by the expression:

$$R_d = \frac{1}{3} \frac{(q_c - \sigma_h)}{\sigma_h'} + 10 \qquad [3]$$

It is important to observe that equation [3], in contrast to equation [1], is expected to be influenced by chamber size effects (Parkin and Lunne, 1982; Schnaid and Houlsby, 1991). Neglecting the effects of chamber size leads to an overestimation of the density values in the field, and the coefficients in equation [3] would change for field tests.

As previously discussed q_c and ψ_ℓ are both controlled by the horizontal stress, and an alternative approach is to reverse the process to estimate σ_h'. The combination of equations [1] and [3] gives σ_h' as a function of q_c and ψ_ℓ expressed as the root of a quadratic equation. Figure 2 shows the comparison between σ_h' estimated from the measured values of q_c and ψ_ℓ and σ_h' applied in the calibration chamber. A generally good agreement is observed in the predictions for the range of conditions tested, the horizontal stress being estimated within a factor of approximately 1.3.

Calibration chamber tests carried out on Ticino sand using a self-boring pressuremeter proble (Ghionna et al, 1990) were again used, this time to validate predictions of σ_h' (see Figure 2). The expression derived from cone-pressuremeter tests overestimates σ_h', the disagreement being partially explained by different soil stress path generated by the self-boring and cone-pressuremeter tests, as well as the validity of the assumptions regarding geometry.

Although some scatter is observed in Figures 1 and 2, calibration chamber data seem to confirm the validity of the proposed method of interpretation since density and σ_h' are clearly expressed as a function of the combined values of q_c and ψ_ℓ for both cone-pressuremeter and

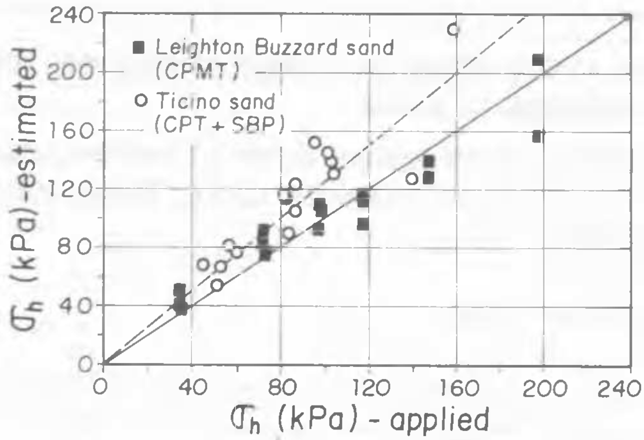

Figure 2 - Estimated an applied horizontal stress values (Calibration chamber tests).

self-boring pressuremeter.

FIELD DATA

The validity of proposed calibration chamber correlations to field data is based on results obtained on the PO River silica sand deposit (Bruzzi et al, 1986; Lancellotta, 1990). Results of in situ tests are presented in Figure 3 in which cone resistance and self-boring limit pressure are plotted against depth.

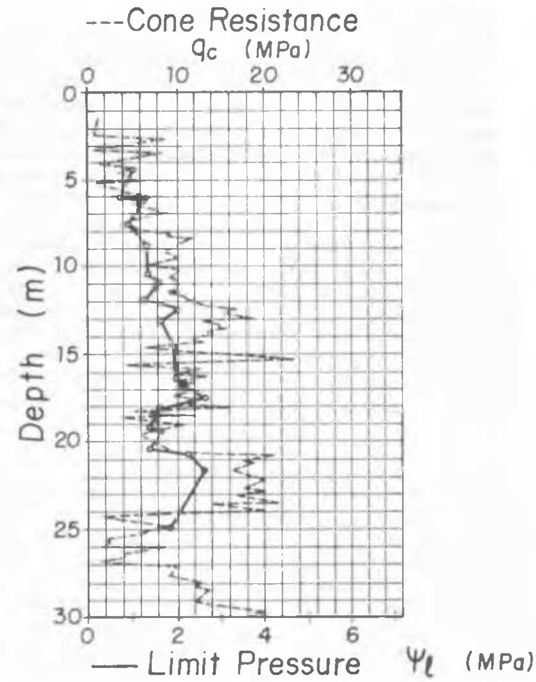

Figure 3 - Comparison of limit pressure (ψ_ℓ) and cone resistance (q_c) in PO river sand.

Interpretation of field data is analogous to that performed previously on calibration chamber data. Self-boring tests were corrected to account for the effect of geometry on limit pressure by making use of equation [2]. The above mentioned $R_d \times q_c$ correlation (equation [3]) is modified to allow q_c measured in the calibration chamber to be corrected from chamber size effects, as proposed by Schnaid and Houlsby (1991).

First the horizontal stress is predicted as a function of measured values of q_c and ψ_ℓ. Results are presented in Figure 4 in terms of the earth pressure coefficient K_o, defined as the ratio σ'_h/σ'_v. The vertical stress was obtained adopting γ=18.2 kN/m³, and is used together with the estimated horizontal stress to compute the K_o values. The water table was assumed to be at 2.0m below ground level (Bruzzi et al, 1986).

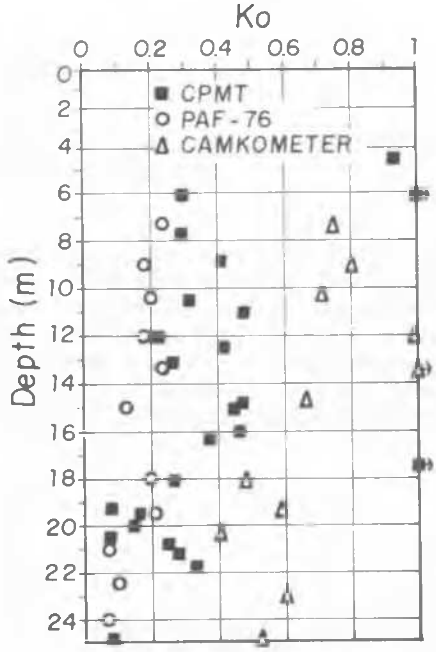

Figure 4 - Predictions of K_o values in PO River sand

The results of horizontal stress yielded from q_c and ψ_ℓ produced highly scattered values of derived K_o. An average value of about K_o=0.32 was obtained, K_o values being about 20% to 50% lower than Bruzzi's best estimate of K_o in situ.

Predicted data showed some agreement with σ'_h values derived from the self-boring lift-off pressure. K_o values were lower than those predicted from Camkometer data, which are reported to significantly overestimate K_o, and are higher than PAF-76 data, which are consistently too low in comparison with what was considered the best estimate of K_o.

Finally the estimated horizontal stress was used in equation [1] to calculate relative density. Figure 5 gives the values of R_d for PO River sand yielded from combined values of q_c and ψ_ℓ as well as R_d obtained by means of standard R_d x q_c correlations (Lancellotta, 1983; Schmertman, 1976). The proposed method is in good agreement with Lancellotta's correlation, except for a depth between 14m and 18m. Schmertman's method significantly overestimates R_d in comparison with the two other formulations.

CONCLUSIONS

A new approach for deriving soil properties and in situ stresses in sand has been presented. The approach is based on the combined values of tip cone resistance and pressuremeter limit pressure. Cone-pressuremeter data and self-boring pressuremeter data from both calibration chamber tests and field tests were used in the analysis. The usefullness of the predictions justifies its application but until a comprehensive field investigation is carried out the proposed method is still open to criticism.

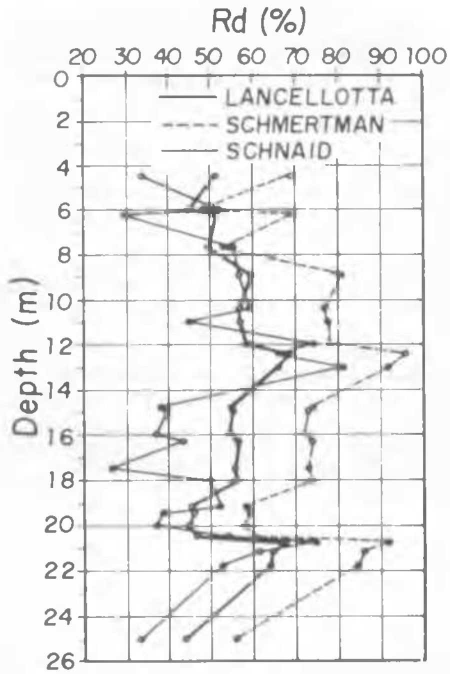

Figure 5 - Predictions of relative density in PO River sand

ACKNOWLEDGEMENTS

The author is grateful for the support and contributions from Prof. G.T.Houlsby. The generosity of the Italian research group in making available the results of their testing programmes is much appreciated.

REFERENCES

Bruzzi, D., Ghionna, V.N., Jamiolkowski, M., Lancellotta, R. and Manfredini, G. (1986) - Self-boring pressuremeter tests in PO River sand. The pressuremeter and its marine applications, II Int. Symp., ASTM STP 950, Texas A&M University.

Ghionna, V.N., Jamiolkowski, M. and Manassero, M. (1990) - Limit pressure in expansion of cylindrical cavity in sand. Proc. of the Third Int. Symp. on Pressuremeters, British Geotechnical Society, Oxford, 149-158.

Houlsby, G.T. and Hitchman, R.C. (1988) - Calibration tests of a cone penetrometer in sand. Géotechnique, Vol. 38, Nº 1, 39-44.

Houlsby, G.T. and Withers, N.J. (1988) - Analysis of the cone pressuremeter test in clay. Géotechnique, Vol. 38, Nº 4, 575-587.

Houlsby, G.T. and Schnaid, F. (1992) - Interpretation of shear moduli from cone-pressuremeter tests in sand. Geotechnique, in press.

Lancellotta, R. (1983) - Analisi di affidabilita in ingenieria geotecnica. Atti Insituto Scienza Costruzioni, Nº 625, Politecnico di Torino.

Lancellotta, R. (1990) - Section Report - Proc. of the Third Int. Symp. on Pressuremeters, British Geotechnical Society, Oxford. Verbal presentation.

Parkin, A.K. and Lunne, T. (1982) - Boundary effects in the laboratory calibration of a cone penetrometer for sand. Proc. 2nd European Symp. Penetration Testing.

Schmertmann, J. (1976) - An updated correlation between relative density, Dr, and Fugro-type eletric cone bearing, q_c. Waterways Experimental Station, Contract Report DACW 39-76M6646.
Schnaid, F. (1990) - A study of the cone-pressuremeter test in sand. D.Phil Thesis. Oxford University.
Schnaid, F. and Houlsby, G.T. (1990) - Calibration chamber tests of the cone-pressuremeter in sand. Proc. of the Third Int. Symp. on Pressuremeter, British Geotechnical Society, Oxford, 263-272.
Schnaid, F. and Houlsby, G.T. (1991) - An assessment of chamber size effects in the calibration of in situ tests in sand. Geotechnique, Vol 41, Nº 2.
Schnaid, F. and Houlsby, G.T. (1991) - Measurement of the properties of sand by te cone pressuremeter test. Geotechnique, in press.
Withers, N.J., Schaap, L.H.J. and Dalton, C.P. (1986) - The development of a full displacement pressuremeter. Proc. Symp. on Pressuremeter and its Marine Applications. ASTM SPT 950, 38-56.
Withers, N.J., Howie, J., Hughes, J.M.O. and Robertson, P.K. (1989) - Performance and analysis of cone pressuremeter tests in sands. Géotechnique, vol.39. Nº 3, 433-454.
Yu, H.S. (1990) - Cavity expansion theory and its application to the analysis of pressuremeters. D. Phil. Thesis, Oxford University.