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THE USE OF AUGER-TYPE DEVICES FOR THE IN-SITU TESTING OF SOFT SENSITIVE CLAYS

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SYNOPSIS

This technical note discusses the use of devices such as screw plates and helical augers for the in-situ testing of soft clays. Attention is focussed on theoretical developments which are necessary to evaluate elementary deformability and shear strength characteristics of the soil from the measured load-displacement response.

INTRODUCTION

Extensive regions of glacially derived marine and lacustrine silts and clays are encountered in regions of Eastern Canada, the Scandinavian countries and in South East Asia (EDEN and CRAWFORD, 1957; BJERRUM, 1973; MITCHELL, 1976; BRAND and BRENNER, 1982). The accurate estimation of the mechanical properties of these soft clays is in itself an important aspect of geotechnical engineering. It is well documented that routine sampling techniques introduce considerable disturbance effects in any laboratory estimation of the deformability and strength characteristics of such soft clays. Extensive accounts of the factors which contribute to the disturbance effects have been presented by Crawford and Burn (1962), Bjerrum (1964), Soderman et al. (1968), Hanna and Adams (1968), Eden (1970), LaRochelle and Lefebvre (1970), Raymond et al. (1971). The studies by Eden (1970) indicated that the disturbance effects can be minimized by the use of laboratory samples derived from large block samples. The procurement of block samples is however a difficult and time consuming exercise. Such block sampling techniques can be appropriately classified as research class sampling (see e.g. DOMASCHUK, 1977 and LEFEBVRE and POULIN, 1979). It must also be appreciated that although physically the sample may exhibit intact undisturbed qualities, hidden factors such as stress relief, pore pressure changes etc., can induce effects which are tantamount to sample disturbance. For this reason, where possible, recourse must be made to calibrate the laboratory parameters for strength and deformability with equivalent results derived from in-situ tests. In recent years several researchers have attempted to use in situ techniques such as the pressuremeter test, the borehole shear test

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and the screw plate test to determine the deformability and strength characteristics of soft sensitive clays (see e.g. JANBU and SENNEST, 1973; ROY et al., 1975; SCHWAB, 1976; SCHWAB and BROMS, 1977; BERG and OLSSEN, 1978; SELVADURAI et al., 1980; EDEN and LAW, 1980; BAUER et al., 1980; SELVADURAI and NICHOLAS, 1981; SELVADURAI, 1983).

This paper focusses on the use of screw plate type auger devices for the measurement of undrained deformability and shear strength characteristics of soft sensitive clays.

THE SCREW PLATE TEST

In its earlier applications the screw plate test was primarily used as a device for the estimation of deformability, and density characteristics of granular soil deposits (see e.g. KUMMENEJE and EIDE, 1961; GOULD, 1967; SCHMERTMANN, 1970; DAHLBERG, 1975). The methods used for the interpretation of these results involved assumptions of an empirical nature. These empirical assumptions were very similar in character to those which formed the basis for the estimation of in situ settlement and deformations of foundations resting on granular soil media (see e.g. SUTHERLAND, 1975; BURLAND, 1977; WINTERKORN and FANG, 1975). When screw plate tests are conducted on cohesive soils it is instructive to assess the performance of the test by appeal to relatively simplified theories of material behaviour such as linear elasticity and ideal plasticity. These theories are by no means complete descriptions of the complex mechanical characteristics of naturally occurring soils but they provide useful first approximations of the mechanical response of soils at working stress and ultimate stress levels respectively. The theoretical response of the screw plate test can also be examined by appeal to more sophisticated theories of material behaviour which incorporate non linear and irreversible phenomena such as those proposed in recent research on constitutive modelling of geological materials (see e.g. DESAI and CHRISTIAN, 1977; GUDEHUS, 1977; COWIN and SATAKE, 1979; VERMEER and LUGER, 1982; CHEN and SALEEB, 1982). It, however, seems unlikely that the non linear material functions which characterize these non linear stress strain phenomena can be completely determined from the results of a single load displacement response. The theoretical assessment of the screw plate test therefore focussed on the development of theoretical relationships which can be used to estimate undrained deformability and shear strength characteristics of soft cohesive soils. To this end the theoretical assessment of the screw plate test was

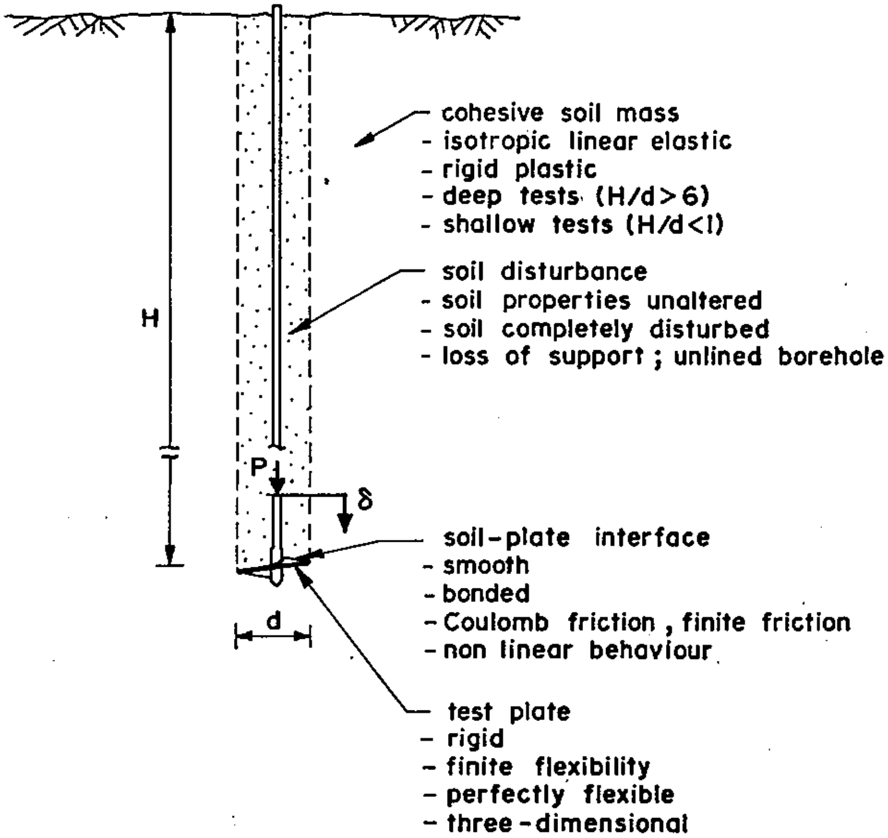

Fig. 1. The screw plate test.

conducted by Selvadurai and Nicholas (1979) and Selvadurai and Szymanski (1980). These investigations took into consideration the influence of a number of salient parameters in the estimation of the theoretical relationships as indicated in Figure 1. These included (i) the soil disturbance induced during installation of the screw plate, (ii) the geometry of the screw plate auger, (iii) the flexibility of the screw plate, (iv) the bond conditions at the auger-soil interface. The details of the theoretical developments can be found in the references cited previously. The analysis was restricted to soil masses which exhibit isotropic and homogeneous characteristics at the local region in which the screw plate test is conducted. The analytical results were presented in a form such that the undrained elastic modulus (E_u) and the undrained shear strength (c_u) of the tested soil could be deduced from initial slope and the ultimate load measured in the screw plate test. Using the load (P)—displacement (δ) response in the initial (linear) range the undrained elastic modulus can be deduced from the relationship

$$E_u \simeq \left\{0.06 \text{ to } 0.75\right\} \left\{\frac{2P}{\pi a \delta}\right\} \qquad \ldots\ldots\ldots\ldots\ldots\ldots \text{(1)}$$

where d is the diameter of the screw plate and
δ is the rigid displacement of the plate.

The range of values presented in Equation 1 take into consideration plausible conditions that can exist in an actual testing situation.

Similarly, the undrained shear strength (c_u) can be determined from the ultimate failure load (P_{ult}) observed in a screw plate test, via the relationship

$$c_u \simeq \frac{4P_{ult}}{\left\{9.00 \text{ to } 11.35\right\} \pi d^2} \qquad \ldots\ldots\ldots\ldots\ldots\ldots \text{(2)}$$

Again, the bounds in Equation 2 take into account plausible failure and interface conditions that can exist in a screw plate test.

These theoretical results were used to examine experimental data derived from in situ test conducted at the Gloucester test fill site (see e.g. SELVADURAI and NICHOLAS, 1981). The material parameters derived from the in situ screw plate tests compared favourably with equivalent material parameters derived from other in situ tests and laboratory tests (see e.g. BOZOZUK and LEONARDS, 1972) conducted with high quality samples.

The results of this research programme indicates that the screw plate test and the attendent theoretical developments can be used quite successfully to determine in situ deformability and strength characteristics of soft cohesive soils. The primary drawback of the method is the relatively cumbersome techniques that are employed for the application of the test load. The success of the use of screw plate testing as a viable (and certainly an inexpensive) alternative to devices such as the pressuremeter, rests on the development of an efficient loading system. These features are currently under investigation and it is hoped that the use of a mobile testing facility can be viewed as a suitable option where data acquisition and processing facilities should enable the rapid in situ determination of the required parameters.

THE HELICAL AUGER TEST

The helical auger test is a further in situ test which has been developed by the author at the Geotechnical Engineering Laboratories at Carleton University. The test itself is an extension of the basic principles of screw plate testing. The development of the test was motivated by recent theoretical studies which were conducted to estimate the elastic stiffness and load carrying capacity of ground anchors. The dimensions of the helical auger are organized in such a way that the introduction of the auger into the soil mass creates little or no disturbance in soil regions outside the cylindrical driven path. The auger is manually inserted into the soil mass. When the auger is driven to the desired depth a tensile load is applied to the drive rod. The load is measured both at the ground level and at a location close to the auger. This allows for the estimation of any shaft friction. The effective displacements of the auger are estimated by using the displacement of the torsion rods at the ground level and the shaft compression caused by friction. The objective of the test is to estimate the undrained deformability and strength characteristics of the soft cohesive soil by making use of the measured load-displacement results. As in the theoretical assessment of the screw plate test the undrained deformability is estimated by appeal to isotropic linear elasticity and the undrained shear strength is estimated by appeal to ideal (rigid) plastic behaviour. In the theoretical assessment of the auger test several factors have to be taken into consideration. These include (i) soil disturbance induced during installation of the auger test, (ii) the geometry of the auger, (iii) the flexibility of the auger and (iv) the bond conditions at the effective soil-auger interface as depicted in Figure 2. The details of these theoretical developments will be presented elsewhere (SELVADURAI, 1984). It is sufficient to note some salient results of the theoretical modelling.

In developing theoretical results for the load-displacement response of the auger, the soil filled auger region is modelled as a rigid cylindrical inclusion. In the extreme case where the soil is completely disturbed along the driven path of the auger, the load displacement characteristics can be assessed by appeal to the models shown in Figures 3 b and 3 d. The other extreme situation where the insertion of the auger induced no soil disturbance, the theoretical modelling can be approached via examples shown in Figures 3a and 3c. In the first example (Figure 3a) the auger region is modelled as a cylindrical inclusion in perfect bonding with the surrounding soil mass. In the second example (Figure 3c) the auger region is modelled as a rigid prolate spheroidal

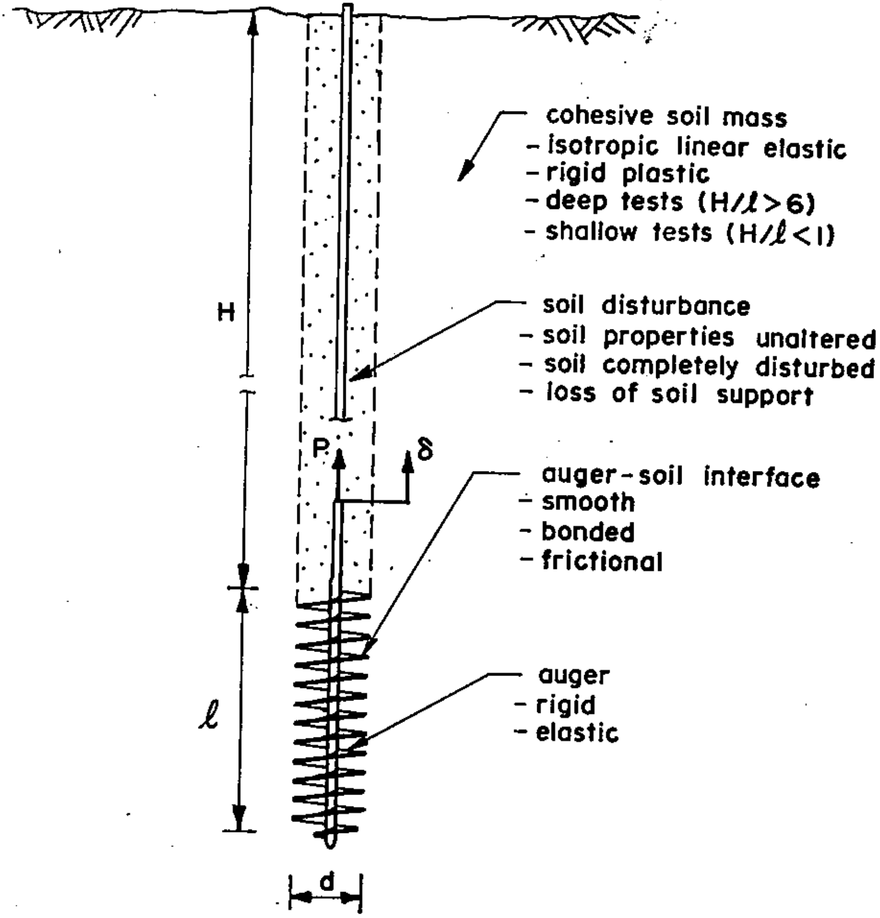

Fig. 2. The helical auger test.

region (see e.g. SELVADURAI, 1976). The cylindrical interface between the auger and the soil mass is assumed to be intact (or continuous) whereas the base of the auger can exhibit debonding. Considering these features it is possible to obtain an expression for the linear elastic shear modulus derived from an auger test in te following form

$$G = \frac{2C(\lambda, \nu)P}{\delta d} \qquad \text{........................ (3)}$$

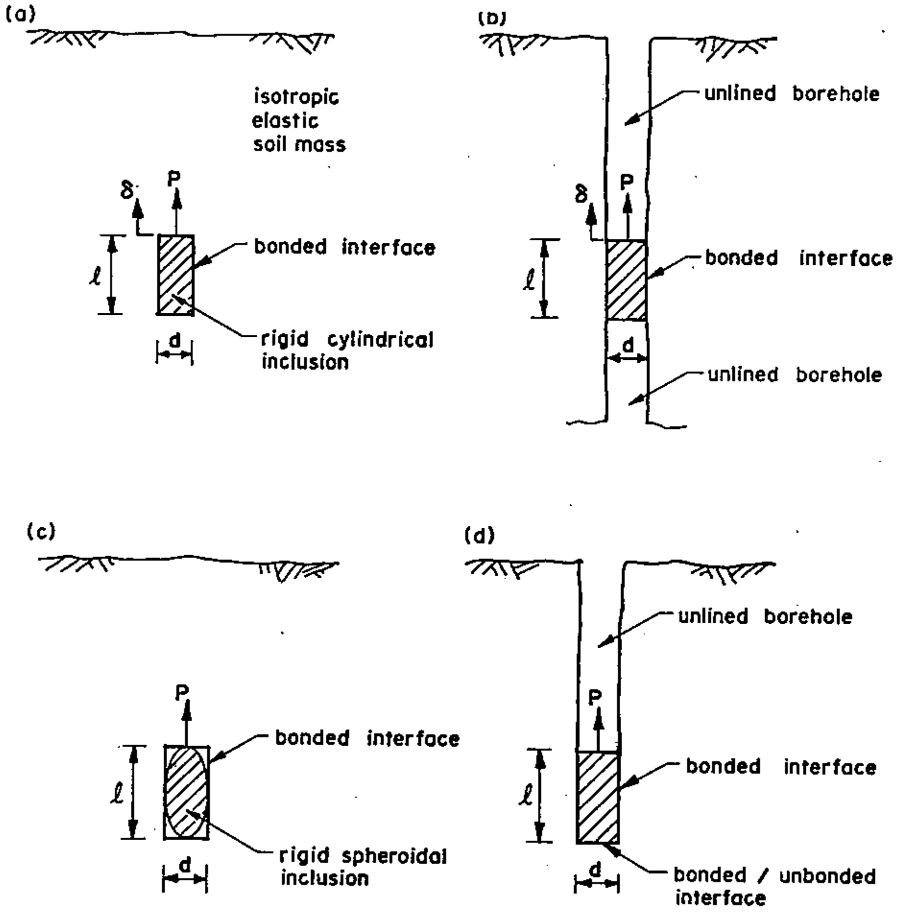

Fig. 3. Theoretical models of the auger test response.

where $\lambda = l/\mathrm{d}$;

l is the length of the auger;

d is the diameter of the auger;

P is the load in the elastic (linear) range;

δ is the corresponding displacement and

$C(\lambda, \nu)$ is a constant which depends on the aspect ratio of the auger and the Poisson's ratio.

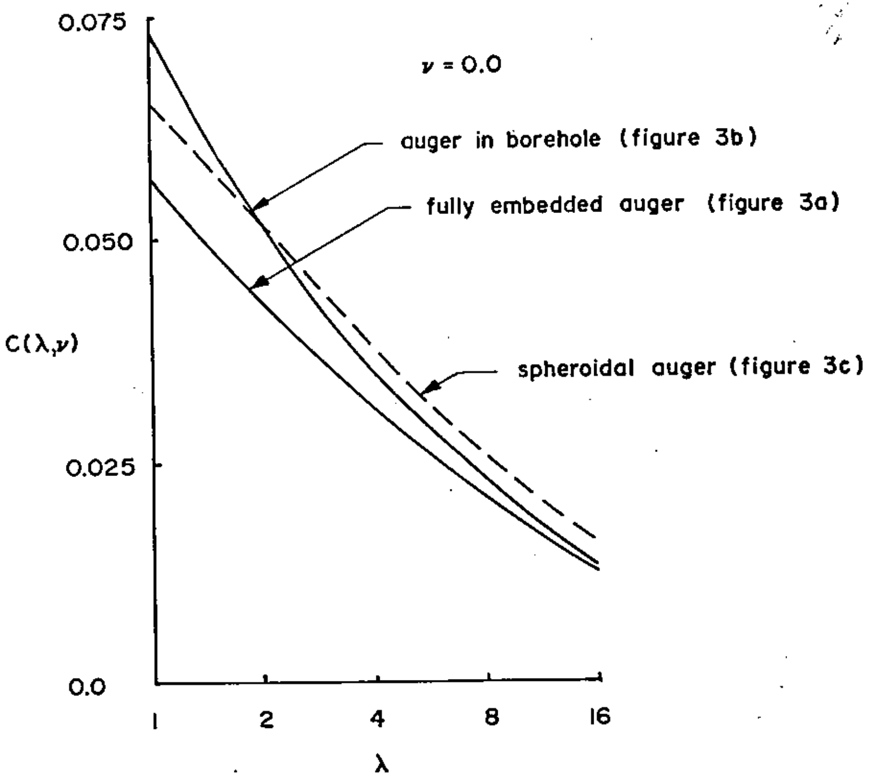

Fig. 4. Stiffness parameters for the auger test.

Figures 4-6 illustrate the variations in C(λ, ν) for various values of λ and ν, for the models presented in Figure 3. Figure 5 also contains certain analytical results developed by Luk and Keer (1980) for the embedded cylindrical inclusion problem. The results presented for the cases 3a and 3b were developed by using a boundary element approach. It is sufficient to note that as λ increases the discrepancy beyond an auger aspect ratio of $l/d > 10$, the value of C(λ, ν) does not vary significantly for the models given in Figures 3a and 3b. The discrepancy between the cylinder model and the spheroid model stems from the reduction in effective volume contained within the inscribed spheroid with the same aspect ratio. Further refinements to these models will be given in future studies (SELVADURAI, 1984) and for the purposes of the present paper we note that the value of C(λ, ν) can be evaluated analytically. The result from Equation 3 therefore serves as the mathe-

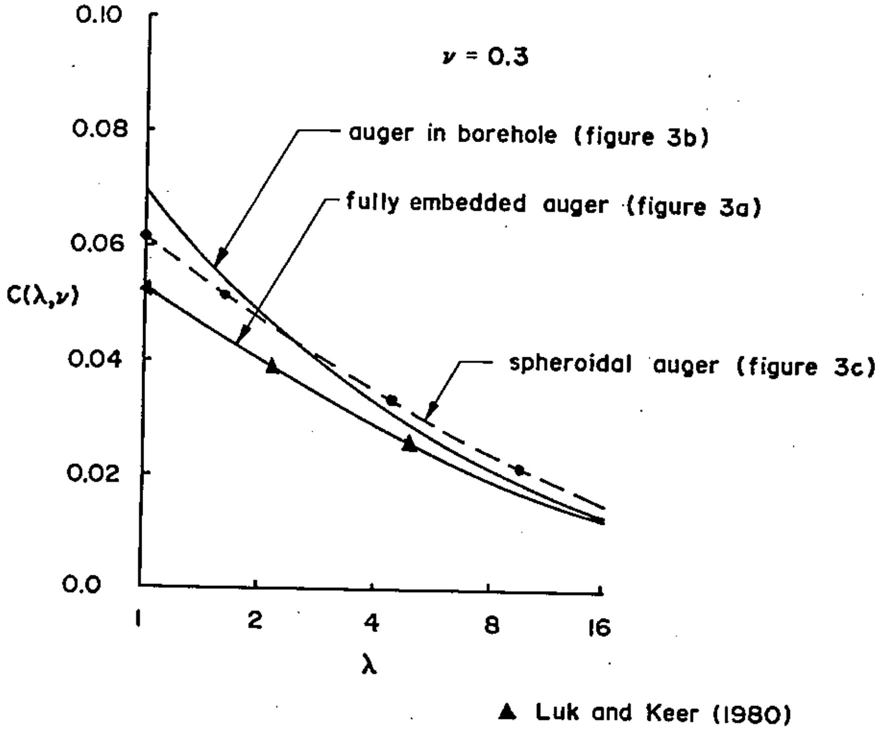

Fig. 5. Stiffness parameters for the auger test.

matical relationship which may be used to estimate the deformability characteristics of the soil medium. It is also important to note that when $\lambda > 10$ the predominant mechanism in the transfer of the applied force P is the development of shear along the cylindrical surface.

In the estimation of the undrained shear strength characteristics, the loaded auger may be visualized as the base region of a cylindrical pile which counteracts the ultimate load (P_{ult}) by both base resistance and side shear. Again as λ increases, the relative contribution from side shear becomes appreciable. As a first approximation the undrained shear strength can be estimated from relationships of the type

$$c_u \simeq \frac{P_{ult}}{\pi d^2}\left[\frac{4}{4\lambda + \phi}\right] \qquad \text{.........................} \quad (4)$$

where the factor ϕ varies with the mode of shear failure that may be generated at the "end bearing" region of the auger. When shearing failure

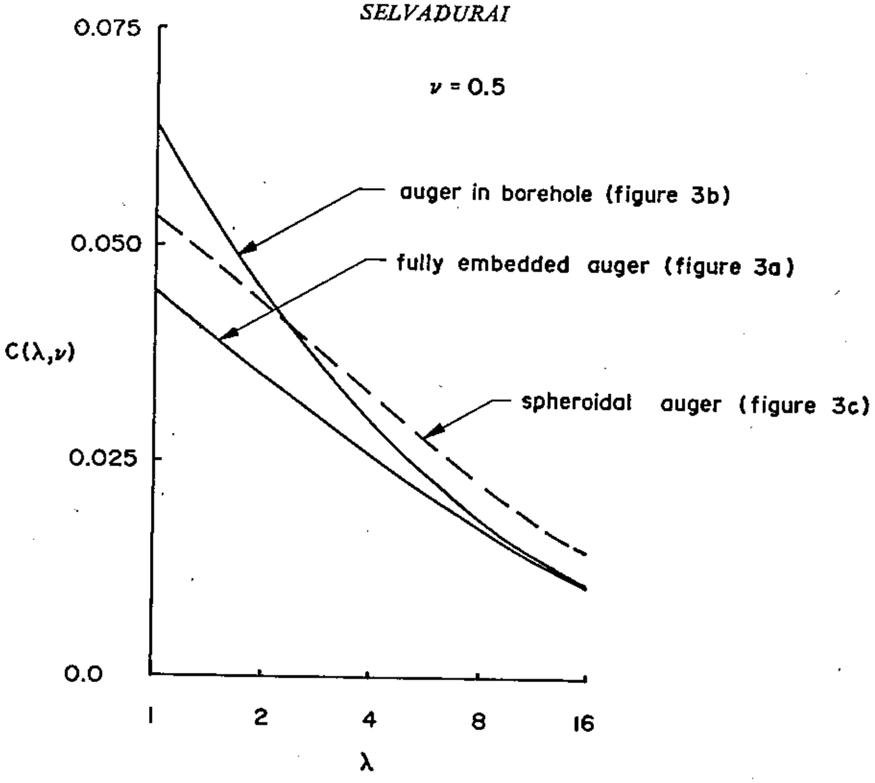

Fig. 6. Stiffness parameters for the auger test.

in the end bearing region takes place in a manner similar to that developed at the base of a circular area embedded in an ideal plastic material, $\phi \simeq 9$. When the end bearing region exhibits localized interface shearing failure over a spherical surface, $\phi \simeq \pi/2$. Alternative estimates for c_u can be obtained by making use of numerical techniques such as the finite element method to model the elasto-plastic response of the embedded auger. Detailed account of these developments will be presented elsewhere (SELVADURAI, 1984).

CONCLUSIONS

The determination of the in situ undrained deformability and strength properties of soft clays constitute an important aspect of geotechnical engineering. A number of in situ testing devices have been used for the determination of these in situ characteristics. These devices introduce disturbance effects of varying magnitude. For this reason it is desirable to employ a variety of testing techniques to assess the efficiency of each in situ technique. This paper discusses the use of auger type tests for the estimation of the determination of in situ properties of soft clays. The screw plate test and the auger test are convenient testing schemes which can be used to estimate the undrained deformability and strength characteristics of soft cohesive soils. In this paper we have presented a brief account of the theoretical performance of the auger test. The accuracy and reliability of the theoretical modelling can be assessed only by recourse to an in situ testing programme which involves a number of in situ testing devices.

REFERENCES

BAUER, G.E., SELVADURAI, A.P.S. and DEMARTINECOURT, J.P. (1980). Measurement of the In Situ Strength Properties of a Champlain Sea Clay with the Modified Borehole Shear Device, *Proc. 33rd Canadian Geotech. Conf.*, 11.5.1-11.5.9.

BERG, G. and OLSSEN, O. (1978). Screw Plate Loading Tests on Gothenberg Clays-Deformation and Strength Properties under Static and Repeated Loading, Chalmers Tekniska Hogskola, Tech. Rep. G72/2.

BJERRUM, L. (1964). Observed Versus Computed Settlement of Structures on Clay and Sand. Presented at M.I.T., Cambridge, Mass (Unpublished Lecture Summarized by Ladd).

BJERRUM, L. (1973). Problems of Soil Mechanics and Construction on Soft Clays and Structurally Unstable Soils, General Report Session 4, *Proc. 8th Int. Conf. Soil Mech. Fdn. Eng.*, 3, pp. 11-159.

BOZOZUK, M. and LEONARDS, G.A. (1972). The Gloucester Test Fill, *Specialty Conf. on Performance of Earth and Earth-Supported Structures*, ASCE, Purdue University, Lafayette, Ind., Vol. 1, pt.1, pp. 299-317.

BRAND, E.W. and BRENNER, R.P. (1982). Soft Clay Engineering, Developments in Geotechnical Engineering, 20, Elsevier Scientific Publ. Co., Amsterdam.

BURLAND, J.B. (1977). Settlement of Granular Materials, *Proc. 9th Int. Conf. Soil Mech. Found. Eng.* 2, pp. 517-518.

CHEN, W.F. and SALEEB, A.F. (1982). Constitutive Modelling for Engineering Materials, Volume 2, Elasticity and Modelling, John Wiley, New York.

COWIN, S.C. and SATAKE, M. (Editors) (1978). Continuum Mechanics and Statistical Approaches in the Mechanics of Granular Materials, *Proceedings of the U.S. Japan Seminar*, Sendai, Japan, Gakujutsu Bunken Fukyu-Kai, Tokyo.

CRAWFORD, C.B. and BURN, K.N. (1962). Settlement Studies on the Mount Sinai Hospital, *Toronto. Eng. Jour.* 45, pp. 31-37.

DAHLBERG, R. (1975). Settlement Characteristics of Preconsolidated Natural Sands, National Swedish Institute for Building Research, Stockholm, Sweden. Report ISBN 91-540-2410-2.

DESAI, C.S. and CHRISTIAN, J.T. (1977). Numerical Methods in Geotechnical Engineering, McGraw-Hill, New York.

DOMASCHUK, L. (1977). Soil Block Sampler, *Can. Geotech. Jour.*, 14, pp. 262-265.

EDEN, W.J. (1970). Sample Trials in Over-consolidated Sensitive Clay, ASTM *Special Tech. Publ.* 438, pp. 132-142.

EDEN, W.J. and CRAWFORD, C. (1957). Geotechnical Properties of Lada Clay in the Ottawa Area, *Proceedings of the 4th Int. Conf. Soil Mech. Fdn. Eng.*, Vol.1, pp. 22-27.

EDEN, W.J. and LAW, K.T. (1980). Comparison of Undrained Shear Strength Results Obtained by Different Test Methods in Soft Clays, *Can. Geotech. Jour.*, Vol.17, pp. 369-381.

GOULD, J.H. (1967). The Comparative Study of Screw Plate and Rigid Plate Bearing Tests, M.S. Thesis, University of Florida, Gainesville, Fl.

GUDEHUS, G. (ed) (1977). Finite Elements in Geomechanics, John Wiley, New York.

HANNA, T.H. and ADAMS, J.I. (1968). Comparison of Field and Laboratory Measurements of Modulus of Deformation of Clay. *Highway Res. Rec.*, p. 243.

JANBU, N. and SENNESET, K. (1973). Field Compressometer: Principles and Applications, *Proc. 8th Int. Conf. Soil Mech. Found. Eng.*, Vol. 1, pp. 191-198.

KUMMENEJE, O. and EIDE, O. (1961). Investigation of Loose Sand Deposits by Blasting, *Proc. 5th Int. Conf. Soil Mech. Found. Eng.*, Paris, Vol. 2, pp. 491-497.

LAROCHELLE, P. and LEFEBVRE, G. (1970). Sampling Disturbance in Champlain Clays, ASTM *Special Tech. Publ.* 482, pp. 143-163.

LEFEBVRE, G. and POULIN, C. (1979). A New Method of Sampling Sensitive Clay. *Can. Geotech. Jour.*, Vol. 16, pp. 226-233.

LUK, V.K. and KEER, L.M. (1980). Stress Analysis of a Deep Rigid Axially Loaded Cylindrical Anchor in an Elastic Medium, *Int. J. Num. Anal. Meth. Geomech.*, Vol. 4, pp. 215-232.

MITCHELL, J.K. (1976). Fundamentals of Soil Behaviour, John Wiley, New York.

RAYMOND, G.P., TOWNSEND, D.L. and LOJKASEK, M.J. (1971). The Effect of Sampling on the Undrained Soil Properties of a Leda Soil, *Can. Geotech. Jour.* Vol. 8, pp. 546-557.

ROY, M., JUNEAU, P., LAROCHELLE, P. and TAVENAS, F.A. (1975). In situ Measurement of Sensitive Clays by the Pressuremeter Test, *Proc. Conf. In Situ Measurement of Soil Properties*, Rayleigh, N.C., Vol. 2, pp. 350-357.

SCHMERTMANN, J.H. (1970). Static Cone to Compute Static Settlement over Sand, *Jour. Soil Mech. Fdn. Div.*, ASCE, Vol. 97 (SM3), pp. 1011-1043.

SCHWAB, E.F. (1976). Bearing Capacity, Strength and Deformation Behaviour of Soft Organic Sulphide Soils, Dept. Soil Mech. and Rock Mech., Royal Institute of Technology, Sweden.

SCHWAB, E.F. and BROMS, B.B. (1977). Pressure-settlement-time Relationship by Screw Plate Tests In Situ, *Proc. 9th Int. Conf. Soil Mech. Found. Eng.* Tokyo, Vol. 1, pp. 281-288.

SELVADURAI, A.P.S. (1976). The Load-Deflexion Characteristics of a Deep Rigid Anchor in an Elastic Medium, *Geotechnique*, Vol. 26, pp. 603-612.

SELVADURAI, A.P.S. and NICHOLAS, T.J. (1979). A Theoretical Assessment of the Screw Plate, *Proc. 3rd Int. Conf. Num. Methods in Geomech.*, Aachen, Germany, Vol. 3, pp. 1245-1252.

SELVADURAI, A.P.S. and SZYMANSKI, M.B. (1980). The Bearing Capacity of Rigid Circular Anchor Plates Embedded in an Ideal Cohesive Soil (unpublished).

SELVADURAI, A.P.S., BAUER, G.E. and NICHOLAS, T.J. (1980). Screw Plate Testing of a Soft Clay, *Can. Geotech. Jour.*, Vol. 17, pp. 465-472.

SELVADURAI, A.P.S. and NICHOLAS, T.J. (1981). Evaluation of Soft Clay Properties by the Screw Plate Test, *Proc. 10th Int. Conf. Soil Mech. Found. Eng.*, Stockholm, Vol. 2, pp. 567-572.

SELVADURAI, A.P.S. (1983). On the Screw Plate and Auger Testing of Soft Clays, *Proceedings Int. Symp. In Situ Testing*, Paris, Vol. 3, pp. 379-384.

SELVADURAI, A.P.S. (1984). A Theoretical Assessment of a Helical Auger Test Used for the In Situ Measurement of Properties of Soft Clays (unpublished).

SODERMAN, L.G., KIM, Y.D. and MILLIGAN, V. (1968). Field and Laboratory Studies of the Modulus of Elasticity of a Clay Till, *Highway Res. Rec.*, 243, pp. 1-11.

SUTHERLAND, H.B. (1975). Granular Materials: Review Paper, *Proc. Conf. Settlement of Structures*, Cambridge, pp. 473-499.

VERMEER, P.A. and LUGER, H.J. (Eds.) (1982). Deformation and Failure of Granular Materials, *Proc. IUTAM Symposium*, Delft University of Technology, A.A. Balkema, The Netherlands.

WINTERKORN, H.F. and FANG, H.Y. (1975). Foundation Engineering Handbook, Van Nostrand Reinhold, New York.