Fifth Australia-New Zealand
Conference on Geomechanics
Sydney, 22-23 August 1988

# Some Aspects of the Design of a Friction Cone Penetrometer

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SUMMARY: The performance of two penetrometers of different structural stiffness has been compared in the Monash sand calibration chamber. Individual reading of the strain gauges shows that penetrometers are subject to oscillating lateral forces, which may be due to an unsteady failure mode around the tip. This could add to the uncertainties in interpreting friction measurements, but the provision of a stiffer core appears to be beneficial. Consideration is also given to the interpretation of cone and friction resistance in layered sands.

## 1. INTRODUCTION

The value of information derived from a cone penetrometer depends on its reliability and sensitivity. This requires that the instrument should respond only to the vertical force acting on the cone and the friction force acting on the sleeve.

Because the load cells are designed for maximum sensitivity within the design load range, they are usually rather thin (especially for the sleeve), and can be subject to appreciable bending in penetration tests, leading to errors in the recorded resistances. Hence this paper examines the behaviour of a conventional 10 cm$^2$ penetrometer and compares it with another penetrometer of stronger internal construction.

Whilst conventional penetrometers are valuable reconnaissance devices where they can be correlated against other test information, they cannot provide unique values of soil engineering parameters through not reading sufficient independent information. Consideration is also given to special difficulties of interpretation in non-homogenous deposits, wherein it is shown that the cone tip resistance is more meaningful than the friction resistance.

## 2. EQUIPMENT AND TEST CONDITIONS

Two penetrometers were used to examine the influence of bending on penetration resistance. One is essentially the same as a standard CRB (now RCA Vic.) penetrometer (Fig. 1a), as built by Chapman and Donald (1981), with cone and sleeve load cell capacities of 20 kN and 3 kN. For the examination of bending, the load cell strain gauges must be wired for individual reading, but, because of the limited space available, it was only possible to do this on the sleeve load cell, which is the weaker of the two and therefore more sensitive to bending.

The other penetrometer (Fig. 1b) has a stiffened body, and load cell capacities increased about 4 times. A teflon ring supports the sleeve, with a small clearance to allow for thermal expansion. This stronger construction was expected to reduce significantly bending and load transfer between the cone and sleeve.

For testing, large samples (1.22 m dia. by 1.83 m high) of dry sand were prepared in a large laboratory calibration chamber, as described by Chapman (1974). Sample density was controlled by using screen plates with holes of various sizes to regulate the rate of deposition. For this study densities of 1.75 and 1.64 t/m$^3$ were achieved, as determined by measuring the mass of sand deposited and measuring its total volume in the chamber. Before CPT testing, a triaxial loading was imposed under $K_0$ conditions, after which a constant boundary stress was maintained during penetration.

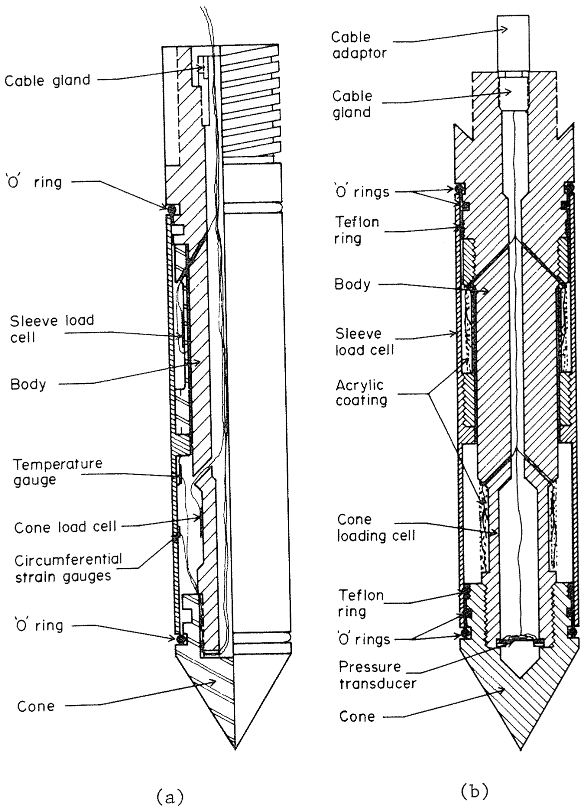


Figure 1(a) CRB penetrometer
(b) Stiffened core penetrometer

In the case of the CRB penetrometer, tests were performed in a homogenous sample and a layered sample as shown in Fig. 2. For the stiffened penetrometer only a homogenous sample was tested.

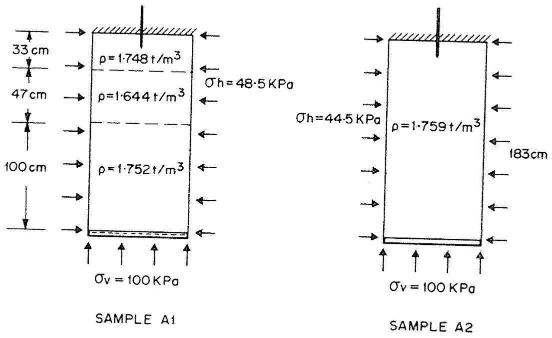


Figure 2 Specimen boundary conditions

## 3. RESULTS

### 3.1 CRB Penetrometer

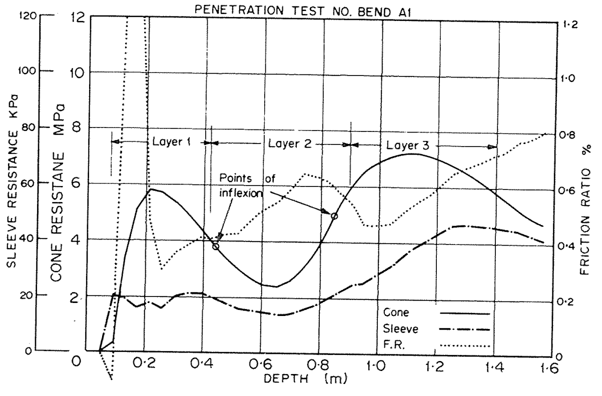


Figure 3(a) Penetration test in layered sand (flexible penetrometer).

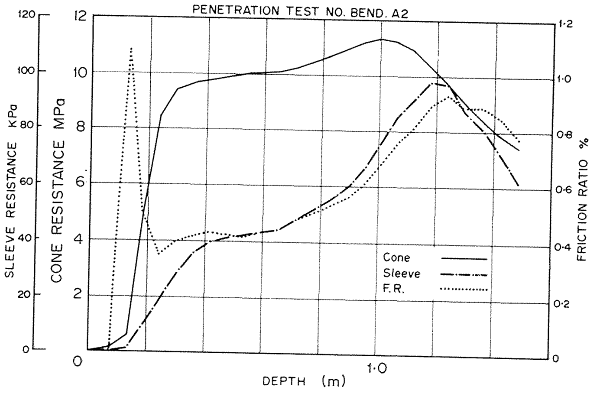


Fig. 3(b) Penetration test in homogenous sand (flexible penetrometer)

Typical results for cone and sleeve resistance in layered and homogenous sand are plotted in Fig. 3. For Test A1 (layered sand) the cone resistance varies widely between layers, with points of inflexion close to the layer interfaces. However, the cone resistance does not achieve a plateau in any of the three layers, so that the peaks cannot be relied upon to give representative parameters for the individual layers. The friction resistance also responds to the layer boundaries, but less clearly, which makes the friction ratio difficult to interpret.

For Test A2 (homogenous sand) the cone resistance attains a reasonable plateau at about 10 MPa. The friction sleeve resistance shows similar initial behaviour but increases rather rapidly below mid-sample height. A Friction Ratio of about 0.43 is indicated at this level, but becomes uncertain beyond this.

The lower 40% of Sample A1 had approximately the same density as all of Specimen A2, and yet the maximum value of cone resistance was only 7.3 MPa. The Friction Ratio for A1 did reach a short plateau with a value of 0.47 at 1.3 m penetration, but this was in the region where end effects are usually becoming significant.

### 3.2 Stiff Penetrometer

A typical result for the stiff penetrometer is given in Fig. 4. Both cone and friction resistances form reasonable plateaus with mid-height values of 9.7 MPa and 0.53 respectively. End effects due to the chamber loading platens are noticeable over the first 0.4 m and the last 0.3 m of penetration, but the values over the central 60% of the specimen may be taken with confidence.

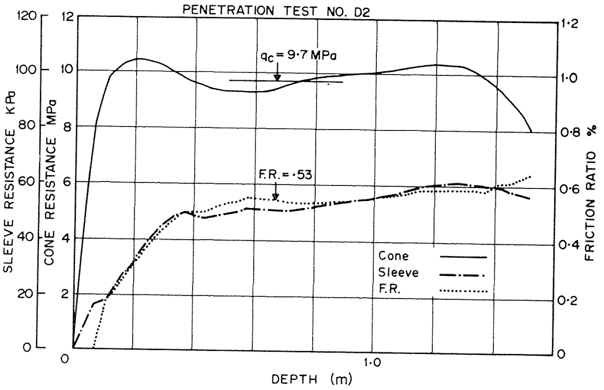


Figure 4 Penetration test in homogenous sand (stiff penetrometer)

### 3.3 Bending Effects in Flexible Penetrometers

Comparison of the performance curves for the two penetrometers shows much greater irregularity of output from the more flexible instrument, particularly with respect to sleeve resistance. The possibility of this being caused by bending was further investigated by individual monitoring of the strain gauges in the modified CRB penetrometer.

The strains in the sleeve load cell for diametrically opposed pairs of gauges are shown in Figs. 5 and 6 for Tests A1 and A2 respectively. The mean output of each gauge pair is represented by a dotted line and bending is then indicated by fluctuations of individual gauges about the mean. It should be noted that for both tests the mean curves for gauge 1, 3, and 2, 4 are similar, so that the average result does not seem greatly influenced by the bending. However, when bending becomes appreciable in the later stages of penetration for Test A1 the sleeve resistance readings behave erratically when compared with the output from the stiff penetrometer. The layered sand was not tested with the stiff penetrometer but inconsistent results were obtained with the modified CRB penetrometer, the resistances being very different in layers 1 and 3, despite their similar densities.

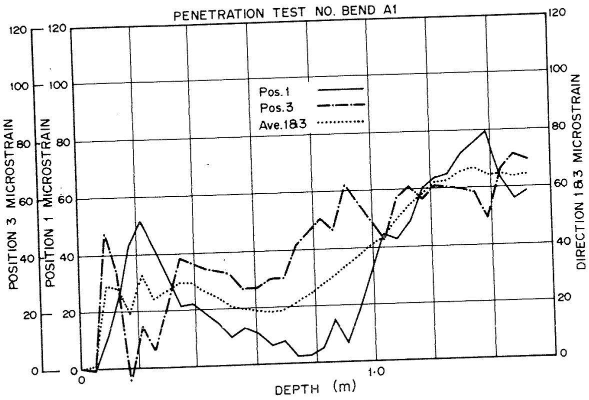


Figure 5(a) Bending behaviour of sleeve load cell in layered sand

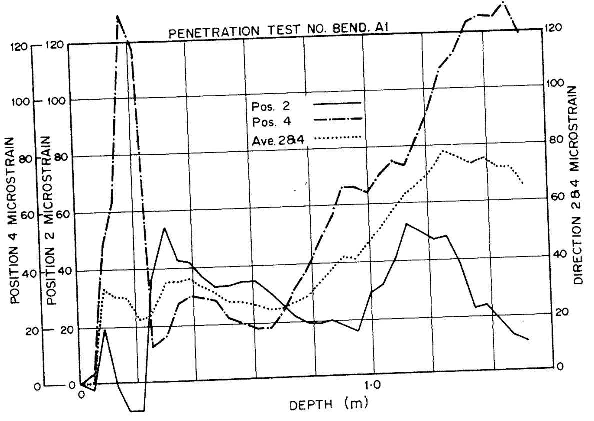


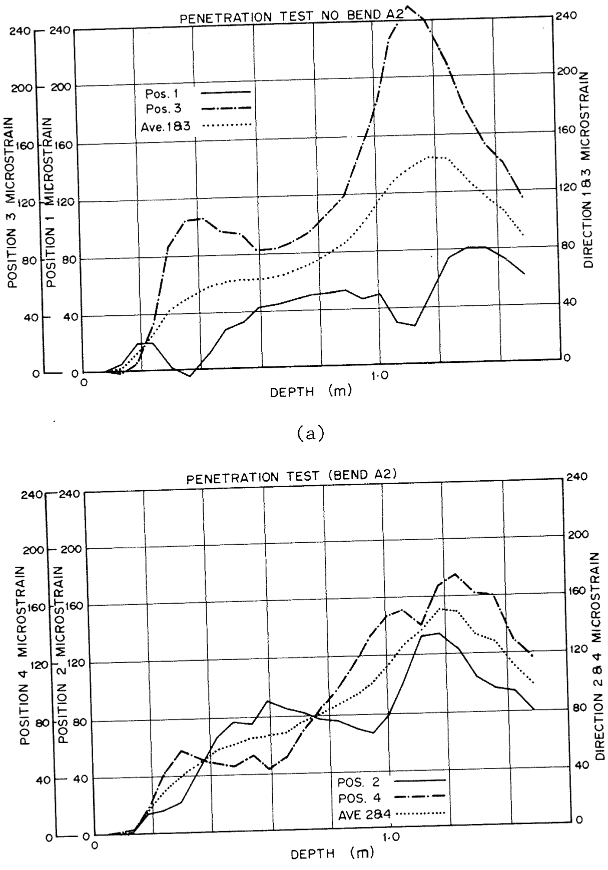
Figure 5(b) Bending behaviour of sleeve load cell in layered sand

The several reversals of the outputs indicate that the penetrometer takes an oscillating path into the sand and that it is therefore subjected to lateral forces which may change direction as the pattern of failure around the cone changes. In extreme cases this effect may throw the penetrometer well off line and cause errors in the operation of the sleeve load cell.

It is probable that the failure stress field surrounding the penetrometer is not completely axi-symmetric, causing the instrument to follow an irregular path and forcing the sleeve to bend. Unstable conditions at the cone tip could also be influenced by local variations in density, as was reported by Robinsky and Morrison (1964).

## 4. INTERPRETATION OF RESULTS

Although the number of test results pertaining to this problem are limited, they indicate some significant problems for interpretation. Test 1A, in a layered sand, shows that correlations developed for homogenous sands cannot necessarily be used for more complex deposits. Just as the end effects due to the proximity of the loading platens affect the cone and sleeve resistances for considerable distances at the ends of the specimens, so the presence of a layer of different density and properties will affect the measured cone resistances of an adjacent layer. As stated earlier, this reduced the point resistance from 10 MPa to 7.3 MPa for dense sand and gave continously varying point resistance across homogenous layers. In addition, the friction reading did not reflect the layering well, which can be attributed, to some degree, to the effects of bending.



(a)

(b)

Figure 6 Bending behaviour of sleeve load cell in homogenous sand
(a) Gauges 1 & 3 (b) Gauges 2 & 4

Holden (1971) also carried out some preliminary investigations into the effects of layering, but the use of a penetrometer of reduced size (such as used by Baldi et al., 1986) may be appropriate for further studies.

For the homogenous sand, Test A2, the stiff penetrometer gave excellent results with both resistances varying smoothly over the sample depth. The more flexible penetrometer did in fact yield a comparable value of cone point resistance before the behaviour became erratic, but the poorly defined friction ratio was somewhat lower at 0.43 (cf. 0.53). Again there is evidence of significant errors in sleeve resistance when bending becomes excessive, but these are probably not so important as they may seem, as various investigations (eg. Baldi et al., 1987; Chapman and Donald, 1981) have shown that friction ratio is rather insensitive to changes in density and stress history. Hence the sleeve resistance does not play a significant part in the interpretation of sand mechanical properties.

## 5. CONCLUSIONS

Significant bending of penetrometers designed for maximum load cell output may contribute to irregularities in results, particularly for friction sleeve resistance. Penetrometers designed for maximum stiffness consistent with sufficient accuracy should produce more reliable results, at least for sand with reasonably thick layers of homogenous properties. Problems of interpretation remain with layered sand deposits and further research is needed.

## 6. ACKNOWLEDGEMENTS

The work reported here forms part of research undertaken for the M.Eng.Sc. degree by the principal author, T.B. Vuong. The authors are grateful to Mr. C.D. Powell for the design and manufacture of the penetrometers, and appreciate various discussions with Dr. J.C. Holden

## 7. REFERENCES

BALDI, G., BELLOTTI, R. GHIONNA, V., JAMIOLKOWSKI, M. and PASQUALINI, E. (1981). Cone resistance in dry NC and OC Sands. Cone penetration testing and experience: Proceedings ASCE National Convention, St. Louis, Mo., pp. 145-177.

BALDI, G., BELLOTTI, R., GHIONNA, V., JAMIOLKOWSKI, M. and PASQUALINI, E. (1986). Interpretation of CPT's and CPTU's. Part 2: Drained penetration of sands. 4th Int. Geotech. Seminar, Singapore.

CHAPMAN, G.A. (1974). A calibration chamber for field test equipment. Proceedings, European Symp. Penetration Testing, Stockholm, 2.2 pp. 59-66.

CHAPMAN, G.A. and DONALD, I.B. (1981). Interpretation of static penetration tests in sand. Proceedings, 10th Int. Conf. Soil Mech. and Fndn. Engg., Stockholm, 2:455-458.

HOLDEN, J.C. (1971). Laboratory research on static cone penetrometers. Report No. CE-SM-71-1, Dept. of Civil Engg., University of Florida.

ROBINSKY, E.I. and MORRISON, C.F. (1964). Sand displacement and compaction around model friction piles. Canadian Geotechnical Journal. Vol. 1, No. 2 pp. 84-93.