

PENETROMETER APPLICATION, SANDS, PERTH

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SUMMARY This paper reviews the introduction and application of penetrometers to site investigation and compaction control in sands of Perth area. It deals principally with the 9 kg, 600 mm drop, 16 mm dia. rod penetrometer. A survey has shown extensive use of this device as an alternative to field density testing. Influence of sand type, depth and moisture content on penetration resistance are discussed. Comparison is made with other penetrometers. Recent field and laboratory observations indicate its possible application to settlement analysis by correlation with moduli from screw plate bearing and bore hole pressure meter tests.

1 INTRODUCTION

The expansion of the Perth Metropolitan Area has led to extensive use of the light (9kg) penetrometer as presented by the author together with Mr. Graham Glick just 14 years ago at the I.E.Aust. Conference in Perth. (Glick and Clegg 1965).

A large proportion of the light structures, principally houses, are founded on sand and also, where clay and other soils are encountered near the Darling escarpment and in the ranges, it is now common practice to excavate and replace with a "sand pad". The compaction requirements in these situations are now almost invariably expressed directly in terms of driving resistance of this penetrometer. At times the density is inferred by a calibration of density with driving resistance but this is generally confined to major projects for a specific purpose. At the same time there has been a swing away from what was the traditional limestone block strip footings with suspended timber floors to concrete strip footings and "slab on the ground" construction. This has required uniform compaction over the whole site and as a result rapid compaction with use of vibratory devices has also become common. Rapid assessment of the compaction achieved has been essential, hence the acceptance of the penetrometer. Local authorities now require compaction certificates for house sites and these are generally accepted on the basis of penetrometer tests.

In view of the considerable increase in its application this paper reviews the historical background; assesses its current useage; reports some research and comments on future possibilities, particularly as a means of estimating settlement.

2 HISTORICAL BACKGROUND

Soon after taking up the position as first full time lecturer in Soil Mechanics at the University of Western Australia, Department of Civil Engineering, the author included projects on the use of penetrometers as final year thesis topics. The emphasis was then on their use for site investigations. The first penetrometer consisted of 'E' type 33.3 mm dia. diamond drill rods fitted with a 38.1 mm dia. 90° cone and driven by a 32.3 kg mass dropping 457 mm. This penetrometer was calibrated in a 3 m length of 495 mm diameter pipe with the results as shown in Figure 1 and Table 1 (Yim 1957). This

device was used on a number of small site investigations. One of particular interest is that at St. George's College Chapel (Ferne 1957). Typical penetration resistance with depth profiles at this site are shown in Figure 2. It is of interest to note that the test marked 'g', taken in the vicinity of a badly cracked area of the building, shows approximately constant driving resistance below about 2 m whereas the other tests show a definite increase with depth. About the same time the standard Penetration Test was introduced to Perth for the site investigation for the proposed Chevron Hotel - where the Perth Concert Hall is now located. (Clegg and Smith 1965).

In the early 1960's the Department of Civil Engineering offered the only commercial soil testing in Perth as an extension of its general testing facilities established many years previously. When the demand for field density tests in sand fill became excessive the need for a simple rapid test became evident. About this time the Main Roads Department had acquired from the Country Roads Board Victoria a Scala Penetrometer (Scala 1960). Using only a 9kg mass this device was considerably more portable than the 32kg mass being used and appeared to be more useful since there was only a need for shallow probing. Experiments showed that the conical point was not necessary in the fine sand. The Scala penetrometer was therefore modified slightly to a blunt end, 16 mm diameter rod, driven with a 9kg mass dropping 600 mm. This rod was calibrated by Pihu (1961). In his study he investigated such factors as the effect of conical tip versus blunt ended, height of drop, depth of penetration and moisture content. One of the first projects on which it was used was the 1962 Empire Games Village at City Beach. The growing demand for field density testing of sand prompted the author to persuade a local machinery merchant to have the device manufactured and readily available in his showroom. Its use spread rapidly with "8 blows per foot" becoming the specification for good compaction. This value was determined between the 150 mm and 450 mm depth, since the calibration had shown a linear blows vs depth over this range. The suggestions for compaction control and site investigations put forward by Glick and Clegg (1965) became generally accepted and its use widespread. By 1975 a review of the use of this penetrometer seemed appropriate and a "state of the art" report was undertaken by Hewitt (1975). He followed this with some field and laboratory investigations

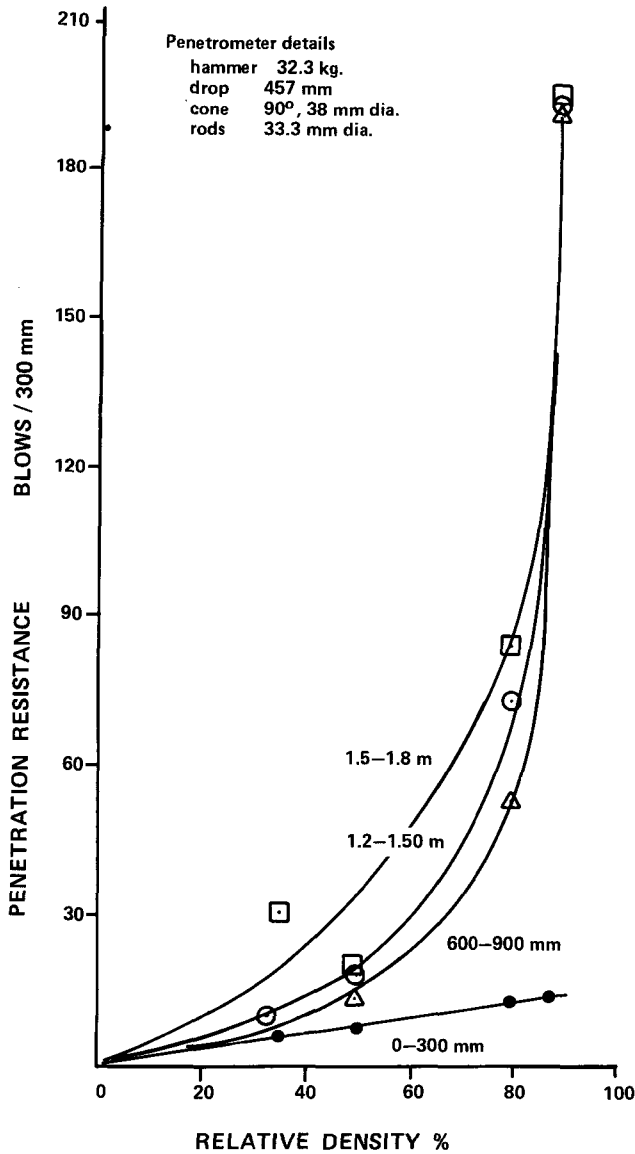


Figure 1. Calibration, 32.3 kg penetrometer showing influence of depth (Yim 1957)

TABLE 1

Data for calibration 32.3 kg penetrometer showing influence of submergence (Yim 1957)

Depth m	Relative Density, Moisture,					
	0 dry	37 dry	56 dry	80 dry	85 4.5%	85 sub-merged
0 - 0.3	4	8	9	14	7	8
0.6- 0.9	4	8	14	53	190+	38
1.2- 1.5	4	12	18	74	190+	50
1.5- 1.8	4	32	18	85	190+	56

Figures indicate number of blows per 300 mm.

Note effect of submergence and rapid increase in blows at higher relative densities. For details of penetrometer see Figure 1 (Yim 1957)

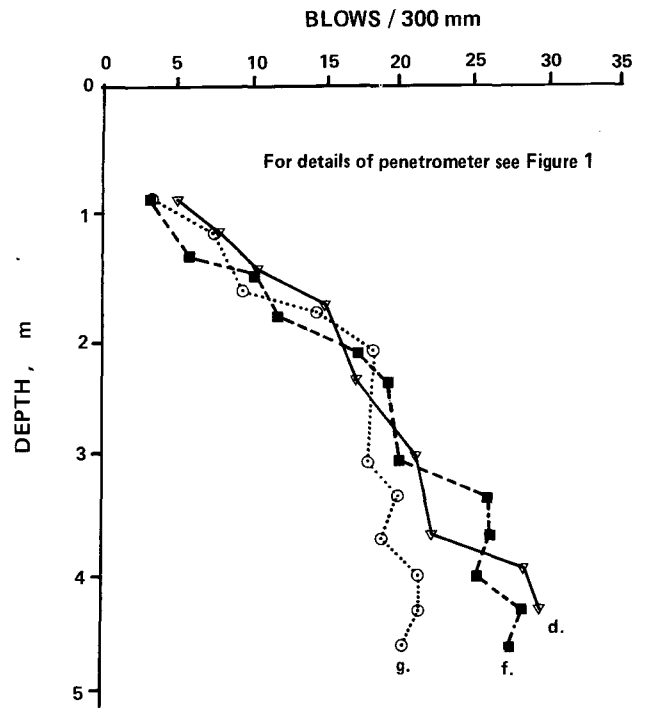


Figure 2. Application, 32.3 kg penetrometer, St. George's College Chapel (Ferne 1957)

as described in later sections of this paper.

In 1970 the CSIRO Symposium on Foundations on Interbedded Sands held in Perth included several papers that should be referred to. Clegg (1970) reviewed the question of "Coastal Plain Dune Sand as a Foundation Material". Others discussed more specifically the use of SPT and Static Cone penetrometers for estimating bearing capacity and settlement. (D'Appolonia and D'Appolonia 1970), (Hollingsworth and Wood 1970), (Greenwood and Tait 1970). This interest in penetrometers for settlement estimates led the author to investigate a project using the penetrometer for determination of an in-situ modulus of deformation. (Dumas 1978).

3 EXTENT OF USE

In order to obtain an overall picture of the penetrometer's use in Perth, Hewitt (1975) carried out a survey by questionnaire.

Of the 419 forms sent out 117 were returned with 90 organisations indicating either possessing or having access to one of the devices. The distribution among the various categories of users was found to be as follows :

Architects	33
Consulting Engineers	28
Local Authorities	12
Contractors	10
Government	7
	<u>90</u>

Informal enquiries around the firms manufacturing the penetrometer suggest that some two thousand have been produced. Even allowing for its consumable nature it appears that many small contractors and builders make use of it.

The questionnaire also showed that the expectancy varies from simply an assessment of uniformity of a site to predicting per cent compaction. The recogni-

tion that for most domestic construction purposes broad categories of density i.e. "loose", "medium" and "dense" are all that is required, has led to the achievement of a specific blow count, generally 7 or 8 for 300 mm as indicating good compaction. However the returns indicated some concern about the influence of the following factors :

- variation with sand type
- influence of depth
- influence of moisture content

In view of this concern Hewitt (1975) carried out a limited programme of laboratory and field testing concentrating on the first two of these. The third aspect, the moisture content, was found to be too difficult for the kind of study being undertaken and this awaits possible future investigation.

4 INFLUENCE OF SAND TYPE, DEPTH, MOISTURE CONTENT

The variation in sand types in the Perth area may best be seen in relation to the Soil Association of the Swan Coastal Plan (Bettenay, McArthur, Hingston 1960). The associations of particular interest are as follows. They roughly parallel the coastline.

- Quindalup - calcareous dunes, along the coast.
- Cottesloe - yellow and brown over limestone, Spearwood dune system.
- Karrakatta - leached yellow and brown over limestone Spearwood dune system.
- Bassendean - grey highly leached, dunes.

While this pedological classification may not be considered the most desirable from the point of view of penetrometer calibration it is considered a reasonably sound basis from which to proceed. Information about the gradings of these sands is given by Clegg (1962), Beattie (1964).

For his studies Hewitt chose two test areas in each of the above Associations, one north and one south of the Swan River. At his test sites, in terms of grading, the Quindalup sand was found to be much finer than the other three having D_{50} of 0.2 mm compared to D_{50} of 0.35mm to 0.45 mm for the others. This difference was also evident in the range of densities from minimum to maximum, 1.1 to 1.3 Mg/m^3 for Quindalup and 1.4 to 1.8 Mg/m^3 for the others. He did however encounter the well recognised problem with respect to the laboratory test methods for determining the maximum and minimum densities on which the relative density is based. He obtained a much better correlation between blows and minimum density and therefore doubted the reproducibility of the maximum density test procedure of vibrating wet under a surcharge. This aspect needs careful consideration since the original correlation of Pihu (1961) appears to have produced higher maximum densities and consequently lower relative densities for the same blow count. He therefore adjusted his data to the earlier study with results as shown in Figures 3 and 4. From this study it was concluded that there was essentially no difference between the Cottesloe, Karrakatta and Bassendean Associations and that Quindalup Association appeared to give lower density for a given number of blows, but this needed further substantiation.

With respect to a depth, the Hewitt study confirmed the general observations that there is frequently an increase in driving resistance with depth, at least down to 90 mm and that, (as illustrated in Figure 4) this need not correspond to an increase in density. He suggested that the influence of depth may become complicated near the surface

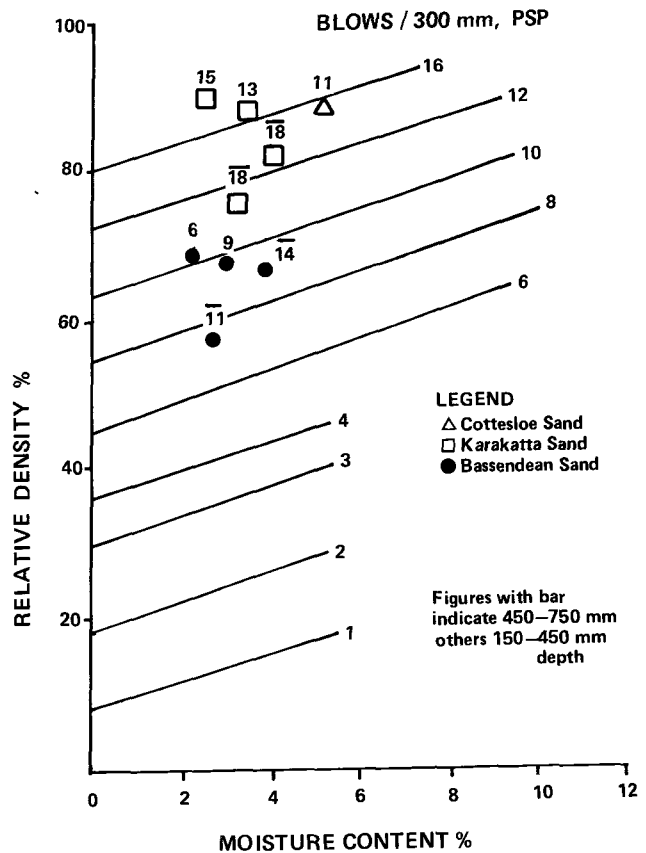


Figure 3. Field data on laboratory calibration (Hewitt 1975)

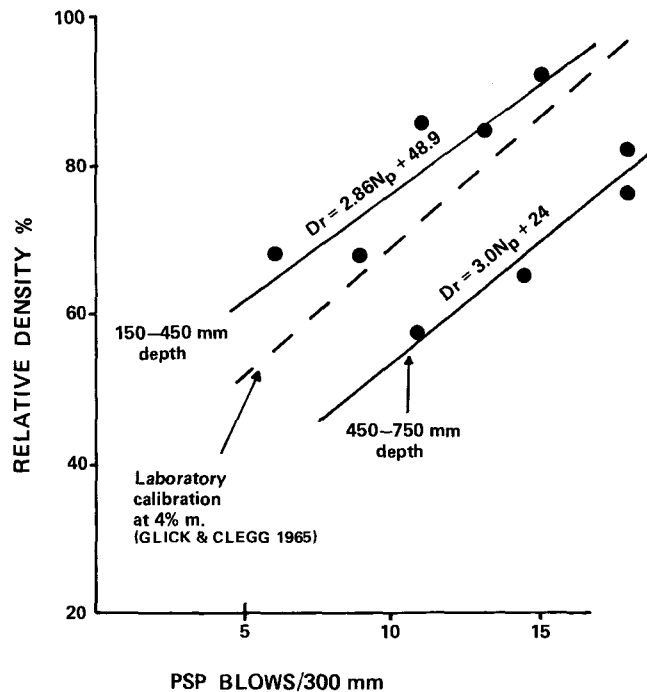


Figure 4. Comparison field and laboratory, relative density vs. penetration resistance.

because of the compaction modifying the stress history so that the driving resistance may not be influenced by the overburden stress alone. Experiments with friction on the rod suggested that it was not a factor to be concerned with at least down to the depth used when testing for compaction control.

The original calibration (Pihu 1961) indicated a decrease in driving resistance for an increase in moisture content. Attempts to verify this in the field were not successful. The free draining characteristics of these sands is such that they very quickly adjust after wetting to their field capacity. Also, excessively low moisture contents do not occur until after prolonged dry periods.

5 COMPARISON WITH OTHER PENETROMETERS

In view of the possible extension of the application of the penetrometer to site investigation and settlement estimates it is appropriate to consider it in relation to other similar devices.

The penetrometer closely resembles the Scala Penetrometer with the two important differences. As previously mentioned it uses a blunt ended rod instead of a cone and the second is that the height of drop is 600 mm instead of 500 mm. The difference in driving resistance between these two penetrometers appears to be related mainly to the height of drop with 20% more blows being required for the Scala Penetrometer. The blunt ended rod is much easier to manufacture and is in fact easier to remove and this has become virtually the "standard model". It is possible that the sand trapped below the blunt end provides a "natural" cone with some clearance.

The status of penetration testing in Australia was reported by Holden (1974). The shallow probing devices for depths down to about one metre were said to be not relevant to his study. However, the penetrometer was included, presumably because of

the possible use of extension rods and its adaptation to site investigations. He made an interesting comment to the effect that the use of the penetrometer should be discouraged because of the unknown effect of the skin friction on the rods.

Similar penetrometers are in use elsewhere, particularly in Europe. Details of some of these are given in Table II. It should be noted that all of these devices have conical ends with larger diameters than the rods while hammer masses of 10kg and drop heights of 500 mm are common. Thus again, the blunt end is the unique feature of the penetrometer under discussion. A more comprehensive review is given by Sanglerat (1972).

Of particular interest in relation to the present discussion is the relationship between the SPT and the penetrometer. The SPT while not used for shallow density control probing is used extensively for site investigations and if the penetrometer is to be used for this purpose it would be helpful to have a correlation between them. Assuming that the SPT "cone" is the full cross sectional area of the sampler, it is of interest to note that the "driving energy" would be 24 kg.mm/mm² compared with the penetrometer at 27 of these units. Gibbs and Holz (1957) reported the effect of surcharge on SPT as obtained from comprehensive laboratory studies. Their suggested relationship between SPT and relative density for "zero" overburden stress is very close to the penetrometer for damp sand with the SPT requiring slightly more blows for the same relative density. From some shallow SPT tests Chodorowski (1964) undisturbed "typical Perth sand" at a relative density of about 45% has an SPT blow count N of about 4 - the same as the penetrometer for this relative density. It is worth noting here that Chodorowski also reported the use of the penetrometer consisting of a 60° solid cone on the end of the SPT sampler. This device has since been used extensively around Perth for site investigations. It appears to give slightly higher N values than the SPT.

TABLE II

Details of various light penetrometers (Hewitt 1975)

Name and (country)	Penetrometer tip		Rod Diameter (mm)	Mass		"Driving Energy kgmm/mm ²	Main use and comments
	Diameter (mm)	Angle		Weight (kg)	Height of fall (mm)		
- (Bulgaria)	25	90°	22	20	250	10	Site investigations (eccentric lifter to lift mass)
- (Czechoslovakia)	12.6 or 17.8	90°	-	10	500	40 or 20	Site investigation of low earth dams, probing.
Veritas (France)	50	Cone	34	15	1000	8) Checking shallow soil depth) below footing levels.
Socotec (France)	35	Cone	25	8	800	7)
Nordemeyer (Germany)	25.2	Cone	22	10	500	10	Electro-automatic
- (Poland)	35.6	60°	22	10.2	500	5	Site investigation
- (Portugal)	30	90°	25	10	500	7	Sounding to bedrock
- (Switzerland)	35.6	90°	22	10	500	5	Mechanised, electrical) Site
	36	90°	24	20	500	10) investi-) gation.

The "driving energy" is introduced as a measure of comparison of the different penetrometers.

$$\text{"driving energy"} = \frac{\text{mass} \times \text{height of fall}}{\text{area of tip of penetrometer}} \quad \frac{\text{kg mm}}{\text{mm}^2}$$

6 CORRELATION WITH SOIL MODULUS

There has developed in recent years an interest in predicting settlement on sand based on in-situ modulus determinations from bearing tests or inference from penetration tests such as the Static Cone or SPT.

Schmertman (1970) presented a study of the use of the static cone for settlement estimates by correlating with a modulus derived from a 230 mm dia. screw plate bearing test. From his observations he considered that the static cone was more desirable than the SPT although the latter could be used if the only field data available. In view of the apparent correlation between SPT and the penetrometer the project of Dumas (1978) was undertaken. This consisted of some preliminary experiments aimed at establishing a correlation with the screw plate as used previously by Simpson (1972). The results are shown in Figure 5. The modulus, E_s , was derived from the load settlement data by first calculating a secant modulus E' and converting this to a representative modulus for the zone down to a depth of twice the diameter, B , of the plate using Schmertman's equation, that incorporates a vertical strain influence factor I_z and correction factors viz.:

$$s = c_1 c_2 \Delta p \sum_0^{2B} \frac{I_z}{E_s} \Delta z$$

The constant c_1 , used to account for the reduced settlement to be expected at high ratios of overburden stress to net foundation pressure increase was taken as unity in accordance with Shultze and Sherif (1973). The constant c_2 , to allow for creep was also taken as unity so that the relationship used became

$$E_s = 0.6 E' B$$

$$\text{or } E_s \approx 0.14 E' \text{ (MPa)}$$

It should be noted that the field screw plate tests were over a depth from about 1.0 m to 2.5 m, the laboratory tests from 150 mm to 600 mm and the pressuremeter tests were all at about 1 m depth. While these tests may be seen as preliminary only the possibility of using the penetrometer for settlement analysis is evident.

Correlation with the modulus as obtained from bore hole pressure meter tests is also indicated. Schultz and Bierdam (1977) presented the results of comprehensive study of the pressuremeter-penetrometer relationships. Three types of sounding apparatus were considered, heavy, light and SPT. The light penetrometer used had two variations but would be basically similar to that of Nordmeyer of Germany as indicated in Table 2. The pressuremeter used was of the Menard type. Excellent correlations were established between the penetration resistance and lateral modulus of deformation. In view of this it is of interest to note the results of Van der Meer (1973). While not seeking a correlation he performed bore hole pressuremeter tests and used the penetrometer at the same sites. Data from his work is also plotted on Figure 5.

7 DISCUSSION

From the foregoing it can be seen that the penetrometer was introduced and developed out of necessity. Its usefulness is amply demonstrated by its almost universal acceptance in the Perth area as the basis for compaction assessment. Its simplicity has resulted in it being used extensively by the "man on the job". Its reliability has resulted in it

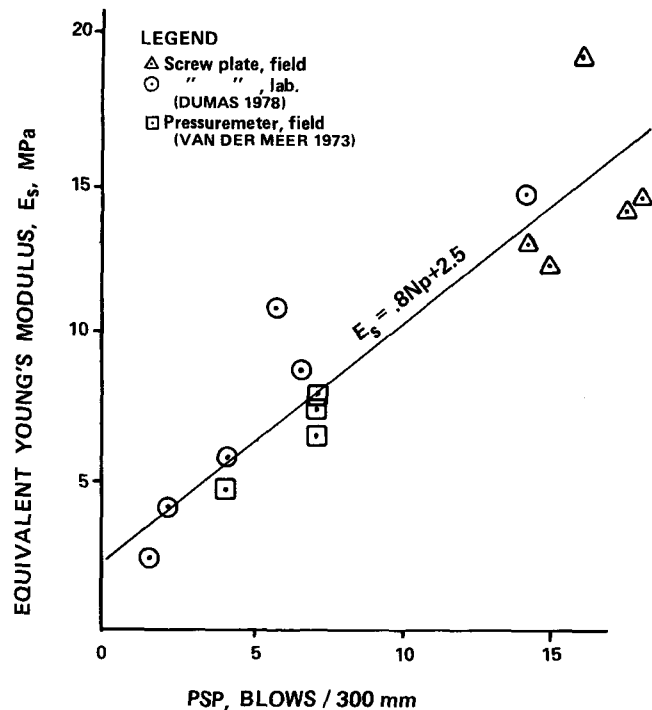


Figure 5. Penetration resistance vs. equivalent Young's Modulus E_s , from screw plate bearing and bore hole pressure meter tests.

being specified by "those in control". Basically it is little different from other penetrometers and may in fact be seen as merely another variety adapted to a particular local environment. It is suffering a little at the moment from lack of a standard name. It seems logical that this should embrace both "penetrometer" and "sand" or even "fine sand". While those associated with its introduction may well deserve recognition it has been the ready acceptance by the "technologists" of Perth that has led to its adaption to this particular soil environment. Thus "Perth Sand Penetrometer" or "PSP" is perhaps the most appropriate title together with possibly the use of symbol N_p to denote the driving resistance.

Among the problems that have arisen with its application, the influence of sand type seems to have been the most prominent but, readily accounted for by recognition of departures from the "typical Perth sand", such as in the case of the finer Quindalup sand near the coast. It seems desirable to report a description of the sand type or at least an indication of the precise location of the site or origin of any imported sand.

The influence of depth should only arise when using extension rods. Provided the 150 to 450 mm interval is used consistently there should be no problem in this regard for compaction control. However evidence is that the penetration resistance increases with depth, principally due to the increase in overburden stress. There is also the possibility that "compaction history" may be a factor due to its effect on the lateral earth pressure conditions. It seems safe to assume that a constant or

lowering of driving resistance with depth means lower relative density or alternatively that the water table has been reached.

With respect to the effect of moisture content, apart from the saturated, submerged and completely dry conditions, this appears to be minimal in a practical sense and is largely ignored. It may make a slight difference but the usual requirement for about 8 blows/300 mm probably has within it sufficient margin of safety to allow for this.

In relation to other penetrometers the fact that the penetrometer is blunt ended instead of conical and that the height of drop is 600 mm instead of 500 mm must be recognised. The lower drop height instruments are manufactured in Australia and while they may be used the results will certainly be different. In case of the comparison with SPT there is some evidence of a similarity between the penetrometer and SPT 'N' values for nominally zero overburden stress. The need to confirm this may become more important as the use of the penetrometer for site investigation becomes more widespread.

The prediction of settlement on sand is not usually considered as important as with clay soils but there seems to be a growing need to properly assess level of compaction that is in fact necessary. Is for instance 8 blows/300 mm too high for most situations? The suggested correlations with the moduli obtained from bore hole pressure meter tests and the screw plate bearing tests look very promising and well worth pursuing. A possible approach in applying this correlation would be to use the relationship of Schultz and Sherif (1973) viz that settlement, $s = \frac{0.6 p\sqrt{B}}{E_s}$ and to estimate a

suitable value for E_s from the penetrometer so that $s = \frac{0.6 p\sqrt{B}}{.8 N_p + 2.5}$. A very interesting result is

obtained when applying this to the settlement data for the Department of Main Roads building as given by Glick (1970). The sand beneath the 12 footings was reported as having been compacted to between 12 and 16 blows/300 mm. Using 14 blows/300 mm and the above equation an E_s of 13.7 MPa is obtained. With an average footing width of 4.3 m and an average pressure of 132 MPa the settlement is estimated as 12 mm which is the same as the average of the observed settlements for the 12 footings at 20 months after construction. Dumas (1978), using the relationship that $N_p = 1.2 N_{SPT}$ (Clegg 1970), obtained good agreement between predicted and observed settlements for the 22 sites considered by Schultz and Sherif (1973), further supporting this suggested procedure.

One of the difficulties that has arisen but not yet been considered is the rather more philosophical question of who should conduct the tests and make the judgement. Should this always be a qualified Engineer? The device is so simple that very little skill is required to obtain values. "Why pay for someone else to perform such a test when the device can be purchased for under \$100 and you can do it yourself?" appears to be a common attitude. There appears to be a definite need to have some form of "code of practice" particularly to indicate the required minimum number of tests and whether deeper probing is required.

8 CONCLUSION

The penetrometer (or PSP?) is now so well established in the Perth area that one has to conclude that it is here to stay. It may become modified

in time to meet a changing "environment" but as a basic tool for compaction in sand it should remain for some time.

It is used so widely by so many different people and at so many different levels of technical knowledge that some form of code of practice now seems desirable.

There is a need to be aware of the differences that can occur through variations in sand type, with depth of penetration and also of changing moisture and groundwater conditions. These appear to be important but nevertheless ignoring them doesn't appear to have created any unsurmountable problems.

The possible application of the penetrometer to settlement estimates along the lines being considered elsewhere suggests that there is scope for the extension of its use in these more technically sophisticated areas.

9 ACKNOWLEDGEMENT

The author wishes to acknowledge the invaluable contribution made by those Engineers who, as undergraduates, attacked with enthusiasm the various projects reported in this paper and as listed in the references.

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