CALIBRATION OF THE PERTH SAND PENETROMETER (PSP) FOR SILICA SANDS[*]

S. D. MOHAMMADI[1**], S. G. FITYUS[2] AND L. BATES[2]

[1] Dept. of Geology, Bu-Ali Sina University, Hamedan, I. R. of Iran
Email: s_d_mohammadi@yahoo.com
[2]Dept. of Civil, Surveying and Environmental Engineering, The Univiversity of Newcastle, Callaghan, NSW 2308, Australia

Abstract– The blunt tipped "Perth Sand Penetrometer" is used extensively in Australia for characterization of silica sand sites prior to the construction of light weight domestic structures. The hand operated device, which can be readily deployed in fine granular soils at depths up to 5 m, is routinely and successfully used to infer in situ density and internal friction angles in extensive coastal sand deposits. Some calibration charts are presented for a light weight dynamic penetrometer device. The charts presented here are based on the results of 18 calibration chamber tests, performed in a specially constructed chamber, 1m high and 1m in diameter. All tests were performed on silica sand samples were consistently prepared to 3 densities using the sand raining or pluviation technique. The prepared samples were pressurized during testing to simulate overburden effects due to burial at depths up to 5m. Particular account is taken of the effects of rod friction.

1. INTRODUCTION

The in-situ density of sand foundations is commonly assessed by penetrometer testing. Current international practice uses both static (pushed) and dynamic (driven) penetration devices. The most commonly employed dynamic method is the "Standard Penetrometer Test", or SPT, which involves the driving of a split spoon sampler using a 63.5 kg. drop weight [1, 2]. While such devices are useful tools for larger scale site investigations, and to depths of tens of metres, their applicability to scale projects is limited by the scale of the apparatus and its relative insensitivity at shallow depths.

Dynamic probing is a continuous soil investigation technique, which is one of the simplest soil penetration tests. It basically consists of repeatedly driving a metal tipped probe into the ground using a drop weight of fixed mass and travel. Testing is carried out continuously from ground level to the final penetration depth. The continuous sounding profiles enable easy recognition of dissimilar layers and even thin strata by the observed variation in the penetration resistance.

Most of the larger cities in Australia are situated on the coast and many have extensive coastal deposits of clean, aeolian and alluvial sands of Quaternary age. These are commonly exploited for residential developments comprising one and two storey residential structures and light traffic pavements. In many instances, the natural density of these deposits is spatially inconsistent, with relative densities from 30% to 80% commonly encountered within 1.5m of the ground surface. Also, many sand soil areas are low lying or dunal, and require reclamation and/or regrading.

Whether natural or regraded, there is a need to characterize the density of sand sites prior to the construction of roads, dwellings and light weight commercial and industrial structures. As the depth of interest is usually no more than about 3m, the expense of heavy, truck mounted equipment is seldom justified. In order to reliably and efficiently characterize sand sites, Australian geotechnical practice has adopted a light weight, hand operated dynamic penetrometer device, the Perth sand penetrometer (PSP). With this device, sites as small as a single residential block can be thoroughly characterized to a depth of 2 or 3m by an unaided technician, in 1 or 2 hours, and with minimal equipment hire and running costs. Despite its extensive use over the past 40 years, only a few papers to date (e.g. [3]) have attempted to provide a quantitative calibration of blow counts to in-situ density; and to depths of only 0.75m. More commonly the device is employed to assess compliance with empirically developed industry standards.

For example, the Australian residential foundations code requires that a minimum of 7 blows per 300mm be achieved in sandfill up to 0.8m deep, to indicate an adequate foundation density for residential construction [4]. Many of the larger Australian consulting firms have developed their own in-house density calibrations; however these remain closely guarded and unpublished. This paper presents some calibration charts for the Perth Sand Penetrometer in silica sand. It relates the blow count, as a function of depth, to the relative density of shallow, insitu sand layers.

2. THE PERTH SAND PENETROMETER (PSP)

The Perth Sand Penetrometer is described in detail in Australian Standard AS1289.F3.3 [5]. The physical arrangement of PSP is summarized in this part, and illustrated in Fig. 1. It consists of a 9kg sliding weight which delivers a measured quantity of energy by falling through a height of 600mm onto an anvil block. This energy is used to push a 16mm blunt ended steel rod into the ground. The steel rod is usually scribed at increments of 50mm and the results expressed as the number of blows required to drive the rod through a distance of 150mm. The total mass of the device is less than 20kg, making it relatively portable. Raising and releasing of the weight is achieved by hand, with a certain amount of care required to ensure that

- The weight is lifted through the full 600mm height,
- There is negligible impact on the upper stop at the top of the lift, and
- The weight is released cleanly and allowed to fall without interference.

The sounding rods are configured so that once driven, the hammer can be removed and additional rods added to enable testing to continue to depths of several metres. In the author's experience, maximum practical depths are in the order of 5 or 6m in exceptionally loose conditions. Beyond these depths, difficulties in the retrieval of rods and the risk of lost rods through damage become too great. Australian practice also employs a variation of the PSP in the characterization of pavement subgrades and mixed soils. The variation is known as the Dynamic Cone or Scala Penetrometer [6-8]. Its principal differences are a falling weight distance of 510 mm and a conical point with a maximum diameter of 20mm. The enlarged point is intended to reduce shaft adhesion in more cohesive soils. Whilst sometimes deployed in sands, it will not be considered further in this discussion.

The repeatability of the PSP test results is an important consideration. To evaluate the repeatability, several tests were carried out. Each testing series included three PSP tests. Figure 2 shows the results of three series of tests undertaken for different relative densities (Loose, Medium and Dense). In this figure N_{PSP} is the number of blow for 150 mm penetration.

In order to study the repeatability of the results, it was important to choose a suitable parameter that represents the repeatability. The use of the standard deviation value, s, is not appropriate for this purpose because it is large for large values of N_{PSP} [9]. However, the coefficient of variation (Cv) can be considered as an indicative parameter because it represents a normalized standard deviation.
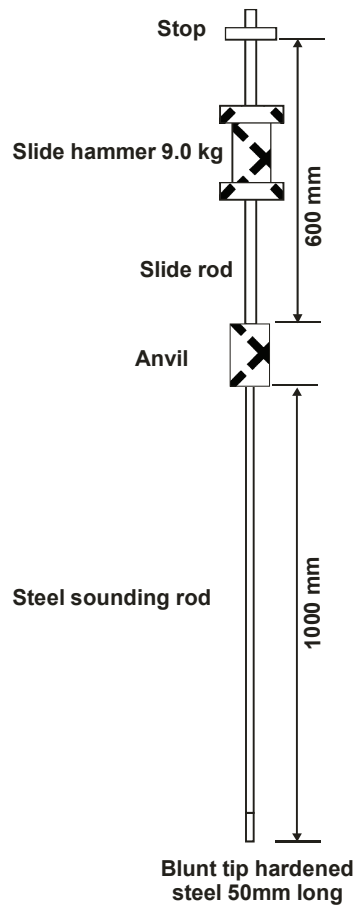
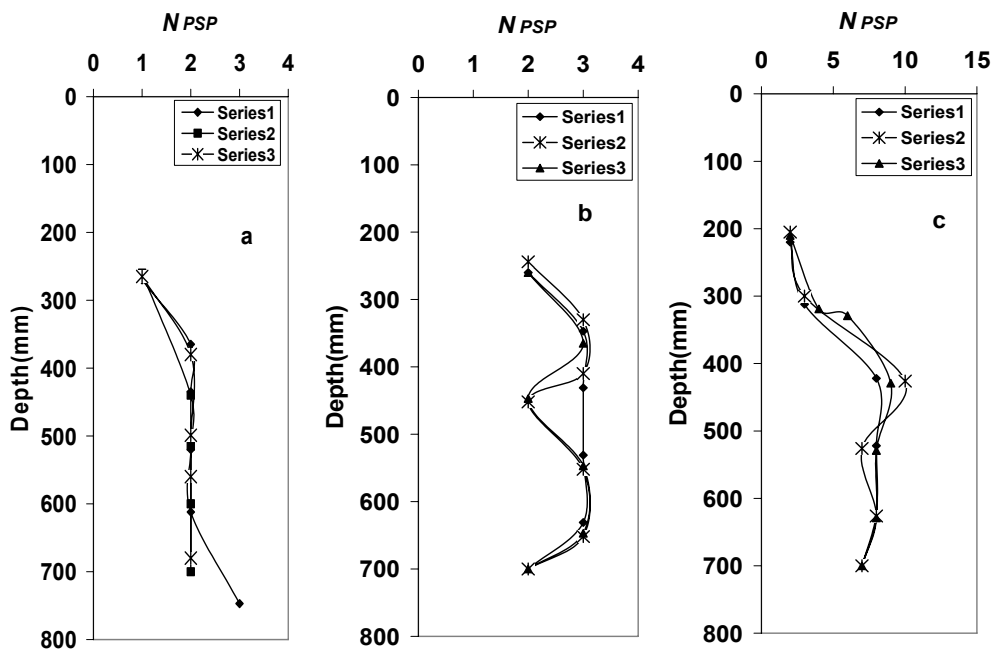Fig. 1. The Perth sand Penetrometer [5]

Fig. 2. Examples of the results of tests repeated at chamber test
(a) for loose (b) for medium (c) for dense

The (C_v) parameter is calculated using Eq. (1):

$$C_V = s / \overline{X} \tag{1}$$

Where:

$\overline{X}$ = the average of N_{PSP} at each depth

s= the standard deviation of NPSP at each depth

Table 1 shows some soil properties, determined by various standard tests, together with their coefficient of variation reported by various researchers [10]. The sources of variability in soil properties differ, and accordingly the coefficients of variation differ for different properties [9]. It can be seen that the variation of Cv for the results of the Standard Penetration Test (N), which is basically a super heavy dynamic probe test, is reported to be between 27% and 85% with a recommended value of 30%, [10]. The repeatability of SPT test results could be used as a measure of the repeatability of PSP results by comparing the Cv values of the two methods. In the present research, the values of Cv have been determined for each depth in each series of the tests.

Table 1. Coefficient variation for soil engineering tests [10]

Test	Reported Cv (%)	Recommended standard
Angle of friction (sands)	5–15	10
CBR	17–58	25
Undrained cohesion (clays)	20–50	30
Standard penetration test (SPT)	27–85	30
Unconfined compressive strength (clays)	6–100	40

The average value of Cv is about 5.60% and its standard deviation is 9.51. In more than 68.7% of the tests, the value of Cv is 0% and in 12.5% of the tests, this value is 20.28%. In the tests undertaken, the values of Cv varied between 0 and 28.3% and for all cases it was less than 30%. Therefore, the results of PSP tests for the three relative densities (Loose, Medium and Dense) can be considered as repeatable when compared with the values presented in Table 1.

3. CALIBRATION PROCEDURE

Calibration of the PSP was achieved using a purpose built calibration chamber at the University of Newcastle. The chamber was originally constructed to facilitate research into pressuremeter calibration [11, 12]. A full description of its arrangement and sample preparation techniques are presented in [11]. Only a brief summary of these details is presented here.

a) Calibration soil

Because of the abundance of clean, poorly graded (well sorted) silica sands around the Australian coastline, a representative sand of this type was employed in the calibration. A Holocene dune sand was selected from the Stockton beach. Based on a mineralogical analysis of the number of grains, the mineralogy of Stockton Beach sand is composed of:

Quartz   98.82%
Rock fragments   0.8%
Zircon   0.21%
Ilmenite   0.11%
Rutile   0.06%

The particle size distribution of Stockton beach sand is presented in Fig. 3. Ajalloeian et al. [12] reported that the sand has a roundness of 0.41, a sphericity of 0.72 and maximum and minimum dry densities of 1.77 and 1.49 t/m^3, respectively.
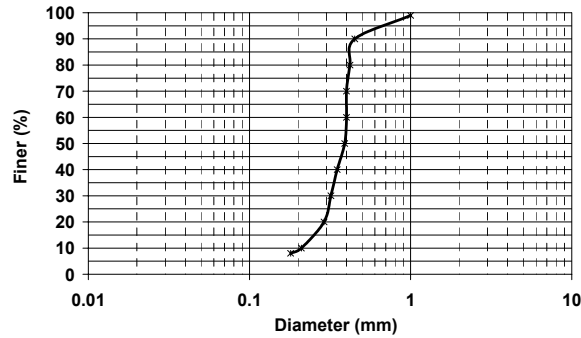
Fig. 3. Particle size distribution for Stockton beach sand

b) Calibration chamber and sample preparation

The calibration procedure was conducted using a cylindrical calibration chamber which was designed and constructed at the University of Newcastle. It has a height and diameter, both of 1m. The chamber was lined with 2 inflatable rubber membranes: one in the base of the chamber; the other around its internal circumference. Each of the membranes was connected to a separate, passive inflation/pressurization system. Water was used as the pressurization fluid. Vertical pressurization was achieved by inflation of the base membrane to bring the sample into contact with the lid. Before the water pressure reaches the chamber, it is checked by the gauge and digital controllers. The digital controller is a microprocessor controlled hydraulic actuator for precise regulation and measurement of liquid pressure and liquid volume change. Testing was conducted through a 20mm diameter hole in the centre of the lid.

The experimental arrangement used to generate a suitable sample for this study is schematically shown in Fig. 4. Sand was rained from the hopper, through holes ranging in size from 6mm to 15mm diameter, at spacing (S) ranging from 20 to 100mm, with holes arranged in a triangular pattern (see inset, Fig. 4).
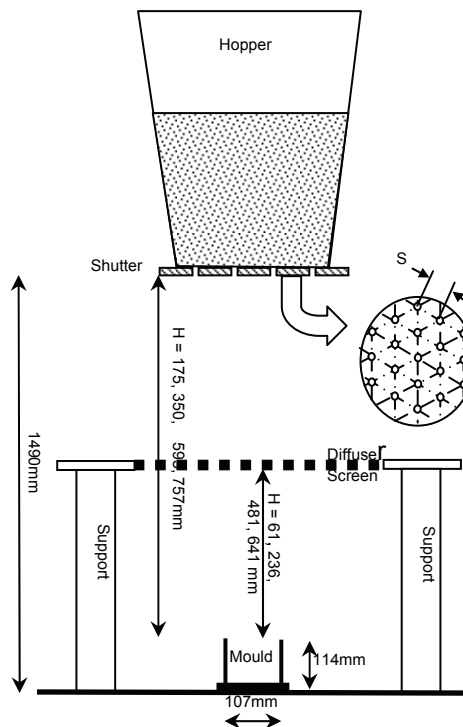

Fig. 4. Experimental arrangement used in this study

In all cases, a single diffuser screen, with an aperture size of 2.36mm was employed (except where the pluviation rate was so great that sand accumulated on the screen, at which point the diffuser was removed). The fall heights (free fall distance traveled by the sand from the diffuser to the top of the mould) considered were 61mm, 236mm, 481mm, 641mm. A 1 litre mould (107mm in diameter and 114mm in height) was used to catch the sand for densities control. Table 2 shows the typical density statistics of the prepared samples.

Table 2. Typical density statistics of prepared samples

	Loose	Medium	Dense
Number of tests	10	21	28
Bulk Densities (kg/m^3)			
Max	1.555	1.657	1.731
Min	1.579	1.690	1.759
Average	1.570	1.678	1.739
Standard deviation	0.0076	0.0092	0.0068
Relative Densities (%)			
Average	31	63	87

c) Testing

Because of the dynamic nature of the PSP test, it was expected that some amount of sample densification might occur during the course of each test. It was thus decided that only one sounding profile could be reliably measured in each prepared sample. Testing was carried out in the centre of the chamber, to a depth of 0.85m.

For each of the 3 sand densities described above, tests were carried out under applied pressures to simulate depths up to 5m. The density data and the friction angle data of Ajalloeian [11] were used to estimate the appropriate vertical pressures and to calculate at-rest earth pressure coefficients respectively. The earth pressure coefficient at-rest state was calculated by Eq.2 [13]:

$$K_0' = 1 - \sin \phi' \tag{2}$$

where K' = coefficient of earth pressure and ϕ' = effective friction angle. The values employed are given in Table 3.

Table 3. Schedule of test pressures

	Loose		Medium		Dense	
Unit wt. (KN/m^3)	15.4		16.4		17.1	
Friction angle (°)	32.0		36.5		42.5	
Ḱo	0.47		0.41		0.32	
Simulated depth (m)	S̀v (kPa)	S̀$_H$ (kPa)	S̀v (kPa)	S̀$_H$ (kPa)	S̀v (kPa)	S̀$_H$ (kPa)
1	0	0	0	0	0	0
2	15	7	16	7	17	6
3	31	15	33	13	34	11
4	46	22	49	20	51	16
5	62	29	66	27	68	22

d) Measurement of pullout resistance

The pullout tests to estimate rod and anchor friction in sand were used by some researchers (i.g. 11, 14). Whilst able to simulate deep insitu conditions at the tip of the penetrometer rod, the chamber fails to account for the increasing amount of resistance due to rod friction which would occur in deep test situations. That is, in a simulated 5m test, only 1m of rod was actually embedded, so that 4m of side

friction on the rods was unaccounted for, rendering the results potentially unconservative. Three approaches were adopted to account for this. Firstly, the relative side friction on embedded rods in loose, medium and dense samples, and simulated depths up to 5m, were assessed by measuring the quasistatic pullout resistance of the rods after driving. This was achieved simply by incorporating a spring balance between the embedded rod and a pullout cable. The load on the balance was recorded as the rod was extracted at a steady rate of about 100mm per second. The arrangement of this method is illustrated in Fig. 5.
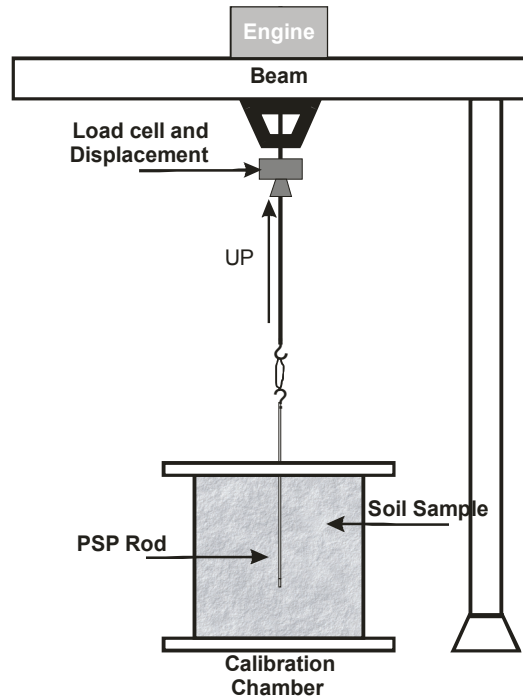

Fig. 5. Arrangement for pullout resistance measurement by pullout quasistatic method

The second approach involved attaching the PSP slide hammer to the end of the embedded rod, via a rope over a large, free running pulley. This effectively facilitated driving of the rod in the reverse direction, allowing the number of blows to overcome side friction to be estimated directly. The arrangement is illustrated in Fig. 6.
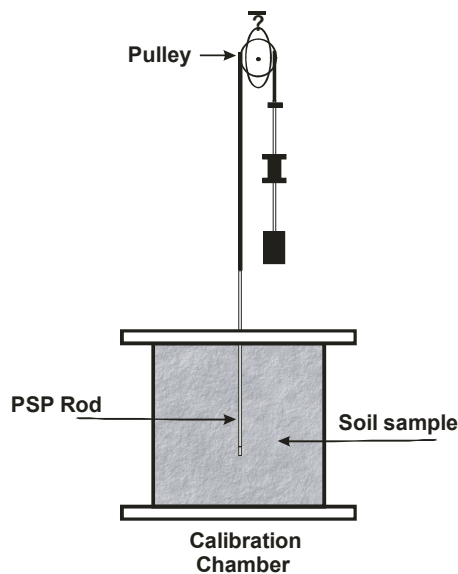

Fig. 6. Arrangement for pullout resistance measurement by slide hammer method

Finally, in the third method the relative side friction on embedded rods in prepared samples and simulated depths were assessed by measuring the torque resistance of the rods after driving. This was achieved by incorporating a torquemeter wrench. In this research a torquemeter, precisely 0.1 N.m, is used to determine the relative side friction. The arrangement of this method is shown in Fig. 7. The trends of torque values versus vertical stresses are shown in Fig. 8 as well. After that, the equivalent blows of side friction were calculated by Eq. (3) [15]:

$$N_{eque} = \frac{2}{d} \frac{e\tau}{WgH}$$

(3)

where Neque= equivalent blow, d= diameter of tip (m), e = value of penetration (m) for each step, τ = value of torque (N.m), W= Weight of hammer, H=height of hammer fall (m) and g= acceleration due to gravity.
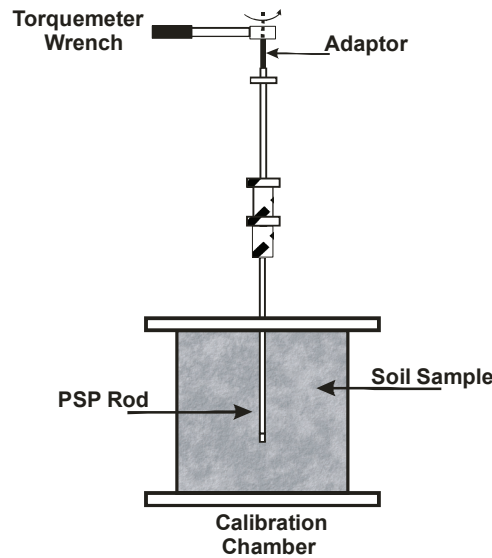

Fig. 7. Arrangement for pullout resistance measurement using torquemeter wrench
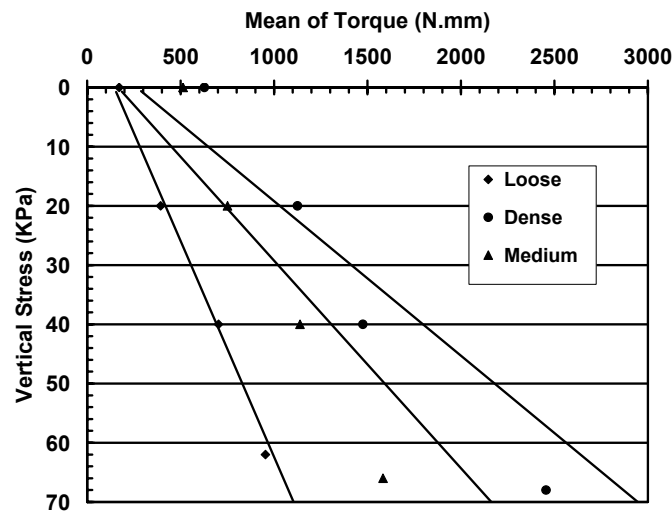

Fig. 8. The trends of torque values versus vertical stresses

4. RESULTS AND DISCUSSION

a) Preliminary results

As expected, the number of hammer blows to achieve a nominal rate of penetration generally increased with the density of the sample and increases in sample confining pressure. During the test procedure, results were recorded as the number of blows per 50mm. In analyzing the data, blow counts per 150mm were obtained by summing any 3 consecutive 50mm values. The results are presented in Fig. 9. It is apparent from this figure that only the results between 0.4 and 0.85m within the chamber have been plotted; those outside this range are omitted because of possible boundary effects. The results show a significant amount of scatter, possibly resulting from several effects. These include:

- The effect of vibrations on the sample due to dynamic testing. The principal effect is that of sample settlement, causing the sample volume to decrease. This results in the upper surface of the sample falling away from the lid of the chamber. As the pressurization is passive (not self maintaining) it results in a drop in the vertical confining pressure. While this behaviour was anticipated and efforts were made to account for it by continual adjustment of the pressures, it is likely to have had some effect on the consistency of the results.
- The effect of slight differences in the prepared densities of the samples. Despite reports of only small statistical differences in measured densities between and within prepared samples [11], the results here suggest that there may be some variations between successive sample variations.
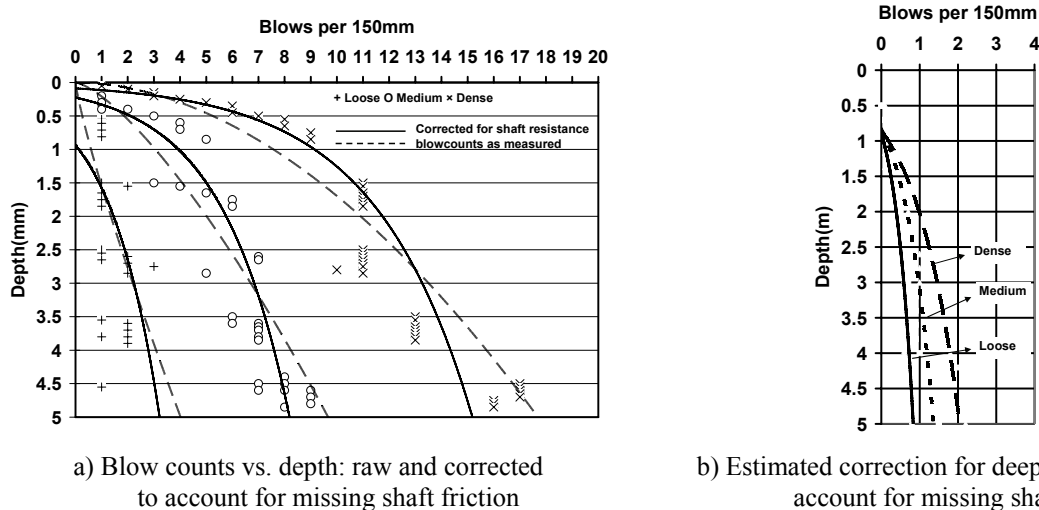
a) Blow counts vs. depth: raw and corrected to account for missing shaft friction

b) Estimated correction for deep (>1m) tests to account for missing shaft friction

Fig. 9. Test results

Whilst the extent of scatter appears to be of considerable significance, it is not inconsistent with the results which are routinely obtained from natural sand deposits. In this study, it is addressed by maintaining conservatism in the adoption of interpretative trend lines. In Fig. 9a, the trend lines (dotted) are drawn to link the isolated raw data groups, and are positioned to serve more as upper bounds than as averages.

b) Correction for missing shaft friction.

As discussed in section 3.e, tests performed in a 1m. deep chamber to simulate deep conditions (>1m) are potentially unconservative, because they do not account for frictional losses along the length of the rod which would be embedded in the ground (above test level) under actual field conditions. An attempt to account for this has been made by conducting pullout tests on the driven rods at the end of each test. In the case of both quasi-static and dynamic pullout tests, it was observed that the pullout resistance was

relatively steady after a peak pullout load had initially been applied to reverse the driven rod through a short distance of about 50mm. By comparing both the peak and steady resistances of the quasistatic tests, the following trends were established.

- For tests at any particular depth, the resistances in loose and medium sands were in the order of 25% and 60%, respectively, of values in dense sand.
- For tests at any particular density, the resistances increased steadily, in proportion to the increasing confinement, with the values for 0-1m of confinement being about 35% of those for 4-5 m of confinement.

Based on the results of 5 dynamic pullout tests from dense samples under 4-5m. of confinement, the following values were established:
- The pullout distance for a single upward blow varied from 150 to 300mm.
- The average pullout distance for a single upward blow was 200mm, corresponding to a maximum correction of 0.75 blows per 150mm, in dense sand at 5m.

On the basis of this information, it is possible to estimate the number of blows which would be required to advance the rod through overlying depths of soil, if it were present. The estimated correction is shown in Fig. 9b. Note that there is no correction for unconfined samples representing the upper 0-1m of a soil profile. When added to the interpreted trends in the raw data, the solid lines in Fig. 9a. are obtained.

c) Calibration chart for the PSP.

By interpolating the corrected blow count data in Fig. 9a, a calibration chart relating the density of sand to testing depth and blow counts/150mm has been developed. It is presented in Fig. 10. The plotted points in Fig. 10 have been taken from the corrected results in Fig. 9a. Comparisons of the chart with the results of Glick and Clegg [3] are difficult because of the limited depths considered in that study. However, it is interesting to note that the quoted blow counts for depths of sand between 200 and 750mm, at 80% relative density, are a constant value of 8/150mm (Fig. 11). By comparison, this study determined blow counts ranging from 3/150mm at 200mm to 8/150mm at 750mm in sand at the same density. The constant blow count value for shallow depths in the 1965 study is inconsistent with the results of this study, and the extensive field experience of the authors.
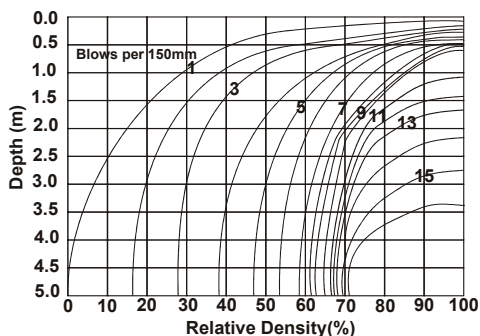

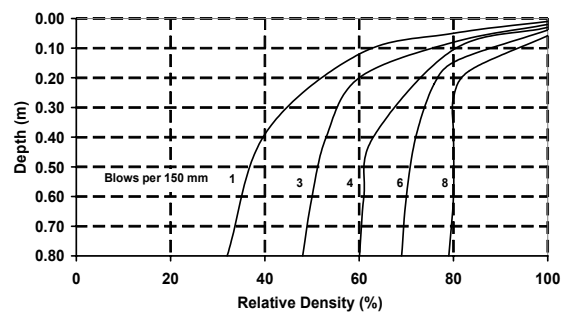Fig. 10. Calibration chart for the blunt tipped, Perth sand Penetrometer, in silica sands

Fig. 11. Calibration chart with the results of Glick and Clegg [3]

5. CONCLUSION

The blunt tipped, dynamic PSP is an extremely useful and efficient tool for the characterization of sand sites. Prior to this study, the limited results of Glick and Clegg [3] were the only generally available data for the interpretation of the results of this test. In this study, a calibration chart has been developed for use

in the density characterization of clean, dry silica sands up to 5m deep. Whilst the trends in the raw data showed an amount of inconsistency, it is expected that the conservative approach adopted in the analysis of this data has preserved a satisfactory degree of conservatism in the resultant calibration chart. Nevertheless, the inference of insitu density using the PSP and the chart developed here, must, in all cases, be tempered by engineering judgment and experience. Those seeking to characterize sand sites with the PSP must appreciate that the chart is the product of interpolation of a limited data set, and can thus give only a guide to the likely magnitude of insitu densities. In particular, one must be aware that only a small amount of data for loose sands at shallow levels has been used in the formulation of the chart. Thus, any interpretations made in this regard must be assumed to have a significant degree of uncertainty.

REFERENCES

1. Palmer, D. J. & Stewart, J. G. (1957). Some observations on the Standard Penetration Test and a Correlation of the Test with a new Penetrometer. *Proc.4th Int. Conf. on SoilMech. and Found. Eng.,* London, Butterworths. p 231.

2. Shariatmadari, N., Eslami, A. & Karimpour-fard, M. (2008). Bearing capacity of driven piles in sands from SPT–applied to 60 case histories. *Iranian Journal of Sciences & Technology, B: Engineering*, Vol. 32, No. B2, pp. 125-140.

3. Glick, G. L. & Clegg, B. (1965). Use of a penetrometer for site investigation and compaction control in Perth, WA. *Annual Eng. Conf. Papers,* The Institution of Engineers, Australia, pp. 84-89.

4. AS2870 (1995). Residential slabs and footings. Standards Association of Australia.

5. AS1289.F3.3 (1984). Determination of the penetration resistance of a soil with a perth sand penetrometer. Standards Association of Australia.

6. Scala, A. J. (1959). Simple methods of flexible pavement design using cone penetrometers. *Proc. 2nd Australia New Zealand Conf. on Soil Mech. and Found. Eng.,* Christchurch, New Zealand. The Institution of Engineers, New Zealand. pp.73.

7. Chua, K. M. (1988). Determination of CBR and elastic moduli of soils using a portable dynamic cone penetrometer. *Proc. 1st Int. Symp. on Penetration Testing,* Orlando, Florida.

8. AS1289.F3.2 (1984). Determination of the penetration resistance of a soil using the 9kg dynamic cone penetrometer. Standards Association of Australia.

9. Fakher, A., Khodaparast, M. & Jones, C.J.F.P. (2006). The use of the Mackintosh Probe for site investigation in soft soils. *Quarterly Journal of Engineering Geology and Hydrogeology*, Vol. 39, pp. 189-196.

10. Lee, I. K., White W. & Ingles, O.G. (1983). *Geotechnical engineering*. Copp Clark Pitman; Inc., pp. 57-89.

11. Ajalloeian, R. (1996). An experimental study of the finite pressuremeter length effects in sand. Ph.D Thesis, Department of Civil, Surveying and Environmental Engineering, University of Newcastle, Australia.

12. Ajalloeian, R., Yu, H. S. & Allman, M. A. (1996). Physical and mechanical properties of stockton beach sand. *Proc. 7th Australia New Zealand Conf. on Geomech.*, Adelaide, Australia. The Institution of Engineers, Australia. pp. 60-65

13. Coduto, P. D. (2004). *Foundation design, principal and practices*. Second Edition, Prentice Hall, New Jersey.

14. Kumar, J. (2006). Uplift response of strip anchors in sand using FEM. *Iranian Journal of Science & Technology, Transaction B: Engineering*, Vol. 30, No. B4, 475-486.

15. Card, G. B., Roche, D. P. & Herbert, S. M. (1990) Application of continuous dynamic probing in ground investigation. *Field Testing in Engineering Geology*, Geological Society Engineering Geology Special Publication No. 6, pp. 129-135.