Measurement of Soil Parameters by Using Penetrometer Needle Apparatus

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ABSTRACT : *In this research a simple practical was applied to determine soil parameters using penetrometer needle apparatus. Penetration tests were performed on both coarse and fine sands. Different sands densities and penetration disk diameter were applied in the tests. Correlations between applied normal stresses and resulting penetration distances were obtained. Correlations between soil densities and applied stresses were then determined. These correlations were used to estimate different soil parameters.*

Keywords: *Penetration, sand, friction angle, normal stress, density, Young's modulus.*

I. INTRODUCTION

The history of the penetrometers dates back to 1846 when a French engineer Collin developed a 1 mm diameter needle shaped penetrometer to estimate the cohesion of different clay types (Sanglerat, 1972). Several types were used thereafter to cope with different types of soil and guarantee reproducibility of results. There are two general types of hand-held penetrometers: Static and Dynamic penetrometers. Both measure soil resistance to vertical penetration of a probe or disk, the distinction between the two types lies in how force is applied to the disk. The static penetrometer measures the force required to push a metal disk through the soil at a constant velocity. The force is usually measured by a load cell or strain gauge (e.g. proving ring) coupled with an analog dial or pressure transducer for readout (Herrick and Jones, 2002). As the operator pushes down the penetrometer, the note keeper records cone index values for each depth increment to evaluate the depth and thickness of compacted layers. disk indices depend on disk properties (high and size) and soil properties, e.g. bulk density, texture, and soil moisture (ASAE b, 1999; Herrick and Jones, 2002). Soil behavior under disk penetration involves a combination of cutting, compression, shear or plastic failures, or any combination of these (Gill, 1968). Various approaches (Farrell and Greacen, 1965; Rohani and Baladi, 1981; Tollner and Verma, 1984; Tollner et al, 1987; Yu and Mitchel, 1998) studied the soil responses in cone penetration including: (i) bearing capacity theory, (ii) cavity expansion theory, (iii) steady state deformation, (iv) finite element (FE) analysis, and (v) laboratory experimental methods. The main objective of this research is to develop a practical method to estimate soil parameter using penetration method. To assess this objective laboratory tests were applied. In the laboratory testing stage, laboratory tests on sandy soil and imposing densities different comparative and get them on the dry densities the sand user and conduct laboratory tests of various such as, , Grain Size Analysis, Specific Gravity Test, Direct Shear Test and Stress – Strain modulus, two types of sandy soil (fine and coarse sand) were used in this laboratory work in which relationships between normal stress and penetrating distance at different dry densities using the following procedure. Samples of each kind from sand were prepared for the purpose of performing the handled penetrometer needle tests. These samples were prepared in relative density molds.

II. EXPERIMENTAL WORK

2.1. Sample Preparation

Two types of air dry fine and coarse sand were used in this laboratory work. Samples were compacted to different densities in a circular mould 15 cm diameter and 15 cm high. Fine sand samples were prepared at seven different dry densities and five dry densities for coarse sand is shown in Fig. (1).

2.2 Penetrometer Needle Apparatus

The apparatus basically consists of a needle attached to a spring - loaded plunger through a shank. An array of interchangeable needle tips is available, to facilitate the measurement of a wide range of penetration resistance values. A calibration of penetration against dry unit weight and water content was obtained by pushing the needle in to specially prepared samples for which these values are known and noting the penetration. The penetration of needle and the penetration resistance may be shown on a graduated scale on the shank and the stem of handle respectively. Against the penetration resistance, the corresponding values of water content and dry unit weight are obtained from the calibration curve. Proctor-type penetrometer is a device that is used to determine the strength of the soil in terms of its distance to penetration. It is commonly used in characterization of the soil by off-road mobility experts and scientists it consists of a different types of rings, cone and spherical shapes in measuring penetration distance with different dry density for cohesion lees soils and for use with needles of larger areas. Small stem graduated at 12.5 mm intervals, to indicate the depth of penetration and for use with needless of smaller areas. The stem is calibrated 150 Ibf * 2Ibf division, one needle point set comprising one each of

2.5 , 2.0 , 1.5 and1.3 cm diameter and 1 cm height for all rings In addition to the cone diameter of 2 cm and a height of 2 cm. Complete as above in a wooden carrying case. mounted on a 22 mm long 12.6 mm penetrating shaft, connected to a 32 mm diameter and 278 mm long pipe (pressure shaft), enclosing a 25 3 mm mean diameter, 3.3 mm diameter of the wire and 243 mm long compression spring, with a connecting nut. This nut equally connects a 210 mm long and 12.6 mm diameter pressure shaft. The handle is a 305 mm long and 21.5 mm diameter pipe which is connected to the pressure shaft. This tool is designed to allow at least a maximum force of 2000 kPa and can be operated in a vertical position. The design is limited by the fact that resistance increases with increasing depth due to the increase contact area with the ring, Description of component parts and shape of the apparatus is shown in Fig. (2).

Fig (1): Model Used in Laboratory penetration Test

Fig (2): Shape of penetrometer needle apparatus

III. RESULTS AND ANALYSIS

Common handle penetrometer was used to perform penetration tests on coarse and fine sand. Five densities were used for coarse sand samples, whereas seven densities were used for fine sand samples as explained above.

3.1 Tests performed on coarse sand

Table (1) shows penetration distance and normal stress regarding a density of 1.76 g/cm^3 for different disk diameters.

Table (1): Results of Penetrating Distance and Normal Stress at Dry Density 1.76 g\cm^3

Disk diameters	Penetrating distance (cm)	Normal stress (kg/cm^2)				
		Trial 1	Trial 2	Trial 3	Trial 4	average
2.5 cm	9	13.27	13.37	13.06	13.47	13.29
	8	9.19	9.50	9.39	8.98	9.26
	7	7.15	7.25	7.45	7.04	7.22
	6	6.84	6.94	6.94	6.84	6.89
	5	4.39	4.49	4.59	4.39	4.47
	4	2.66	2.55	2.76	2.55	1.13
2.0 cm	9	16.56	16.4	16.56	16.09	16.4
	8	11.47	11.15	11.31	11.47	11.35
	7	8.315	8.76	9.08	8.92	8.92
	6	8.59	8.44	8.44	8.59	8.52
	5	5.57	5.42	5.26	5.73	5.50
	4	3.35	3.19	3.19	3.5	3.31
1.5 cm	9	22.05	21.75	21.75	22.32	21.97
	8	15.26	15.26	15.54	14.69	15.19
	7	11.87	11.30	11.08	12.15	11.60
	6	11.30	11.30	11.00	10.75	11.09
	5	7.35	7.35	7.06	7.63	7.35

	4	4.52	4.52	4.24	3.96	4.31
1.3 cm	9	25.94	26.32	25.94	26.69	26.22
	8	18.05	18.42	17.67	18.42	18.14
	7	13.91	13.91	13.54	14.29	13.91
	6	13.16	13.16	9.61	9.61	11.39
	5	8.65	8.27	8.65	7.90	8.37
	4	5.27	4.89	5.27	5.64	5.27
cone	9	15.75	15.85	15.56	15.97	15.63
	8	10.91	11.25	11.14	10.73	11.01
	7	8.49	8.60	8.80	8.39	8.57
	6	8.11	5.74	8.24	8.14	8.18
	5	5.21	5.31	5.41	5.21	5.29
	4	3.16	3.05	3.26	3.05	3.13

By plotting the results of normal stress values against that of different penetration distance from 4 cm to 9 cm, a reliable correlation were obtained as shown in Fig (3). The values of coefficient of determination associated with the following best – fitted equation for 2.5 cm diameter disk are

$$y = 2.157(x) - 6.978$$
$$R^2 = 0.951$$

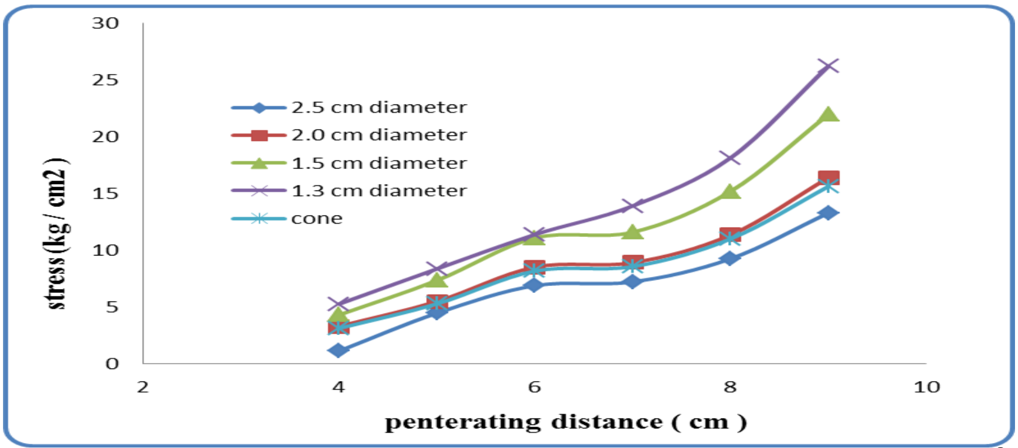

Fig (3): Correlation between normal stress and penetration distance at dry density 1.76 g/cm^3

Figure (3) indicates that normal stress increases with increases of penetration distance. The results showed linear correlation with acceptable coefficient of determination.

Similar correlations were determined for disk diameters of 2.0, 1.5, 1.2, and cone. The linear correlations for theses disk diameters are:

2.0 cm diameter disk

$$y = 2.382(x) - 6.488$$
$$R2 = 0.945$$

1.5 cm diameter disk

$$y = 3.209(x) - 8.943$$
$$R2 = 0.942$$

1.3 cm diameter disk

$$y = 2.382(x) - 6.488$$
$$R2 = 0.945$$

Cone

$$y = 2.287(x) - 6.231$$
$$R2 = 0.95$$

Similar correlations were obtained for samples of other used densities. All Correlations above indicates that normal stress increases with increases of penetration distance.

The previously explained penetration/stress correlations were used to obtain a correlation between soil density and normal stress. Fig (4) Shows correlations between dry density and normal stress for different disk diameters for each penetration distance. These correlations may be used to estimate soil density directly by knowing penetration distance corresponding to used disk diameter and resulting normal stress.

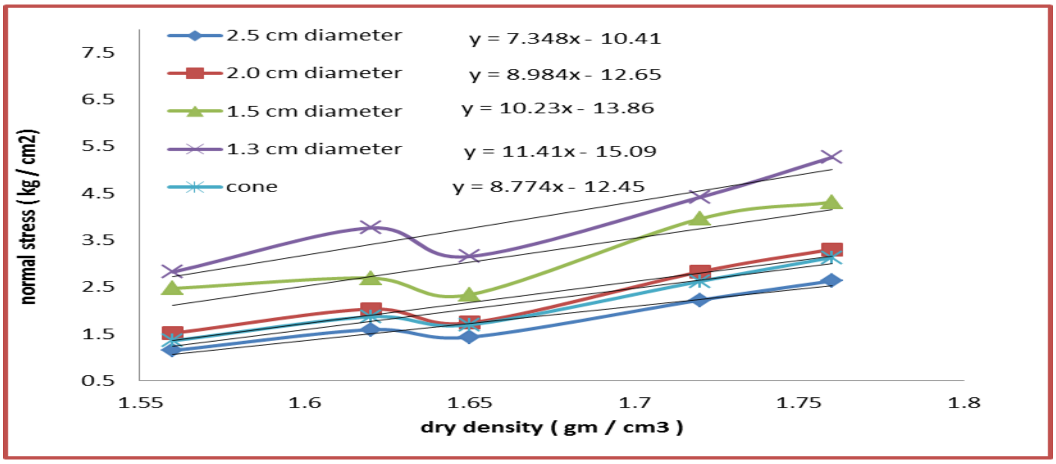

Fig (4) Correlation between normal stress and dry density at 4 cm penetration distance with different diameters of disk

3.2 Tests performed on fine sand

Table (2) shows penetration distance and normal stress regarding a density of 1.63 g/cm^3 for different disk diameters.

Table (2) Results of Penetrating Distance and Normal Stress at Dry Density 1.63 g\cm^3

Disk diameters	Penetrating distance (cm)	Normal stress (kg/cm^2)				
		Trial 1	Trial 2	Trial 3	Trial 4	average
2.5 cm	9	4.895	4.895	4.895	4.695	4.845
	8	3.47	3.57	3.47	3.265	3.82
	7	3.165	3.165	3.06	3.06	3.115
	6	2.855	2.96	2.855	2.55	2.805
	5	1.735	1.835	1.735	1.635	1.735
	4	0.92	1.02	1.02	0.92	0.97
2.0 cm	9	6.21	6.21	5.89	5.89	6.05
	8	4.295	4.295	3.98	4.14	4.18
	7	3.98	3.98	3.505	3.505	3.745
	6	3.66	3.345	3.345	3.66	3.505
	5	2.23	2.39	2.23	1.91	2.19
	4	1.115	1.115	1.115	1.115	1.115
1.5 cm	9	8.19	8.19	7.625	7.625	7.91
	8	5.93	5.645	5.645	5.365	5.645
	7	5.365	5.085	4.8	5.365	5.155
	6	4.8	4.8	4.235	4.235	4.52
	5	2.825	3.105	3.39	2.825	3.035
	4	1.975	1.975	2.54	1.975	2.115
1.3 cm	9	9.775	9.775	9.025	9.025	9.4
	8	6.765	6.765	7.145	7.145	6.955
	7	6.39	6.39	6.015	6.015	6.205
	6	5.64	5.64	4.885	5.265	5.36
	5	3.385	3.76	3.76	4.135	3.76
	4	2.63	2.63	2.63	2.63	2.63
cone	9	5.81	5.795	5.685	5.485	5.69375
	8	4.12	4.22	4.12	3.915	4.09375
	7	3.76	3.765	3.66	3.66	3.71125
	6	3.39	3.51	3.405	3.1	3.35125
	5	2.06	2.135	2.035	1.935	2.04125
	4	1.09	1.17	1.17	1.07	1.125

By plotting the results of normal stress values with that of different penetration distance from 4 cm to 9 cm, a reliable correlation were obtained as shown in Fig (5). The values of coefficient of determination associated with the following best – fitted equation are:

$$\mathbf{y} = 0.741(x) - 1.935$$
$$R^2 = 0.984$$

Fig (5) indicates that normal stress increases with increases of penetration distance. The result is linear correlation with acceptable coefficient of determination.
Similar correlations were determined for disk diameters of 2.0, 1.5, 1.2, and cone, as shown in Fig (5).the linear correlations for theses disk diameters are:

2.0 cm diameter disk

$$y = 0.882(x) - 2.271$$
$$R2 = 0.944$$

1.5 cm diameter disk

$$y = 1.069(x) - 2.223$$
$$R2 = 0.958$$

1.3 cm diameter disk

$$y = 1.265(x) - 2.505$$
$$R2 = 0.971$$

Cone

$$y = 0.838(x) - 2.116$$
$$R2 = 0.959$$

All Correlations above indicates that normal stress increases with increases of penetration distance.
The previously explained penetration/stress correlations were also used to obtain a correlation between soil density and normal stress. Fig (4) Shows correlations between dry density and normal stress for different disk diameters for each penetration distance. These correlations may be used to estimate soil density directly by knowing penetration distance corresponding to used disk diameter and resulting normal stress.

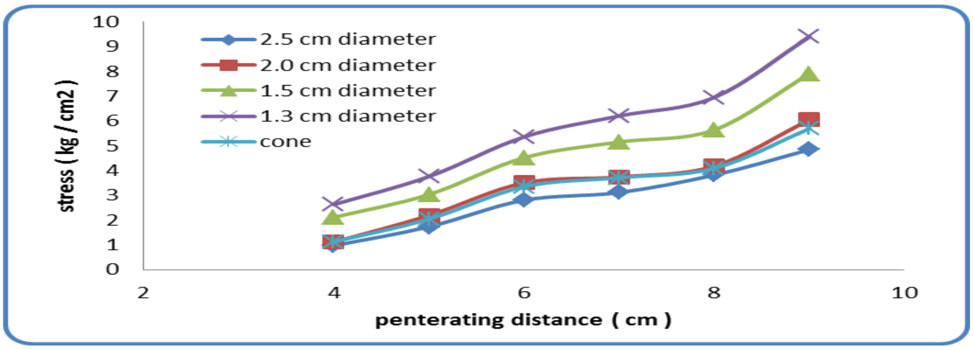

Fig (5): Correlation between normal stress and penetration distance with cone at dry density 1.63 g /cm^3

3.3 Correlation between soil density and normal stresses

The previously explained penetration/stress correlations were used to obtain a correlation between soil density and normal stress. Fig (6) show correlations between dry density and normal stress for different disk diameters for each penetration distance. These correlations may be used to estimate soil density directly by knowing penetration distance corresponding to used disk diameter and resulting normal stress, but we'll show one penetration distance.

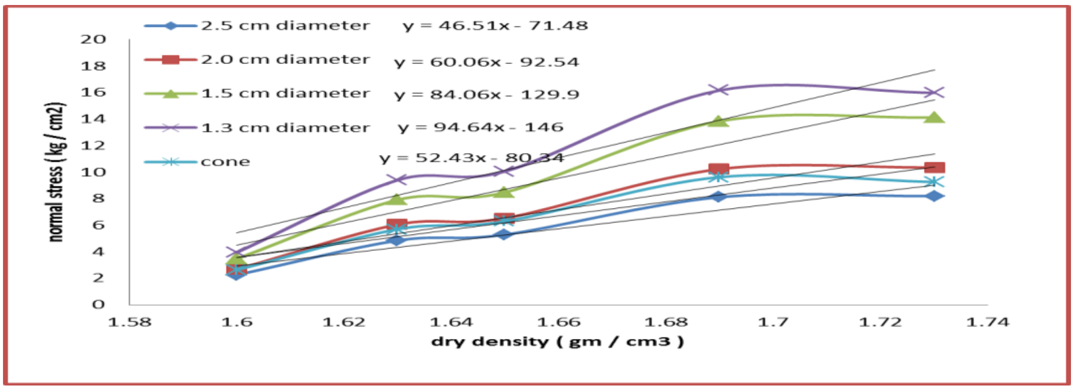

Fig (6): Correlation between normal stress and dry density at 9 cm penetration distance with different disk diameters

3.4 Estimation of soil parameters

Table (3) shows the result of laboratory tests which ware alleged to all densities used in research so as to estimate the internal friction angle and young's modulus. Been drawing a relationship between density and internal friction angle and it is to know the angle of friction of any density within existing densities in Figures (7) and (8) respectively.

Table (3): Results of Young's Modulus and Friction Angle for Sandy Soil

Dry density (gm/cm^3)	m_v	E_{oed} = (1/m_v)	E(kg/cm^2)	Φ(degrees)
1.79	0.0016	612	510	40
1.75	0.0016	598.8	499	39
1.73	0.0017	574.8	479	38
1.71	0.0019	525.6	438	37
1.69	0.002	489.6	408	36
1.68	0.0021	465.6	388	36
1.67	0.0022	452.4	377	35
1.65	0.0025	404.4	337	34
1.63	0.0028	355.2	296	33
1.62	0.0029	342	285	32
1.6	0.0034	294	245	32
1.56	0.0039	256.8	214	31

$$E_{oed} = (1/m_v)$$

$$E_{oed} = E\,(1-\nu) / (1+\nu)\,(1-2\nu)$$

Where:

m_v = coefficient of volumetric compressibility.
E = young's modulus
ν = poisons ratio in this research assumed 0.25

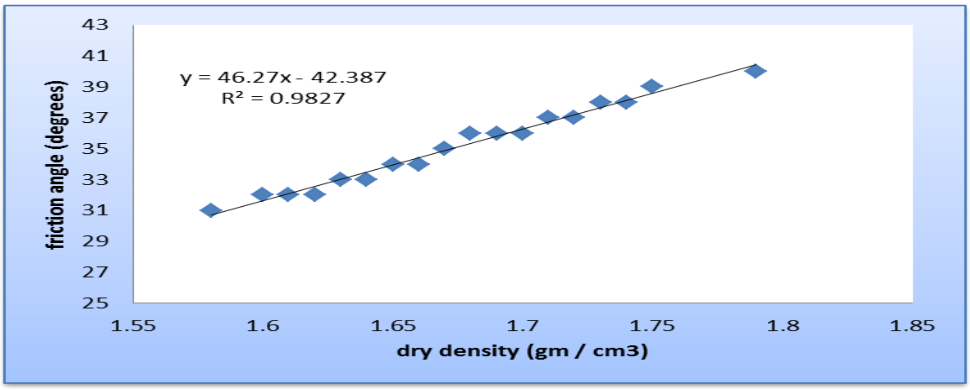

Fig (7): Correlation between friction angle and dry density for sandy soil

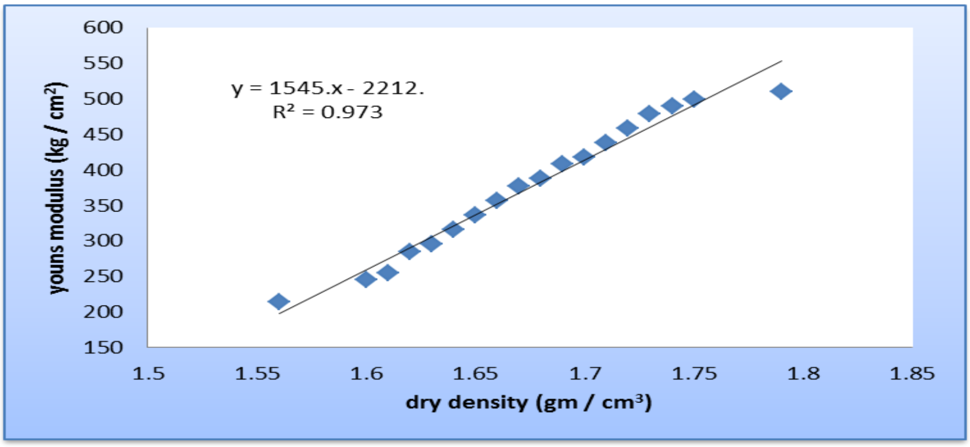

Fig (8): Correlation between dry density and Young's modulus for sandy soil

IV. CONCLUSIONS

Based on laboratory and field tests results, the following conclusions can be drawn, for sandy soil with Correlation between normal stress and penetration distance with different rings (cm) diameter at different dry density (gm / cm^3) for coarse sand , Correlation between Normal Stress and Dry Density at different Penetration Distance with Different Diameters of Rings for coarse sand, Correlation between normal stress and penetration distance with different rings (cm) diameter at different dry density (gm / cm^3) for fine sand and Correlation between Normal Stress and Dry Density at different Penetration Distance with Different Diameters of Rings for fine sand.

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