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CORRELATION BETWEEN PENETROMETER TEST VALUE AND BEARING CAPACITY FOR GRANULAR SOIL

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ABSTRACT

In the present study, an attempt to investigate the correlation between hand penetrometer test value and bearing capacity of granular soil especially sand, was under consideration. To achieve this goal artificial sand beds of thirteen samples were prepared in an open test bed above the ground surface, and on these samples, direct shear test and field density test were carried out to find out the friction angle and the field density of each sample. Bearing capacity of sandy soil was predicted from Terzaghi's bearing capacity equation for strip footing. Three hand penetrometers of diameters 18.75 mm, 25 mm and 31.25 mm were especially fabricated and used to find out the penetrometer test values N_h*. The test procedure of these penetrometers is similar to standard penetration test (SPT) by split spoon sampler, but diameter of penetrometers, weight of hammer and height of fall were different.*

To correlate between hand penetrometer test value and bearing capacity of sand bed three constitutive equations have been established for hand penetrometer of three different diameters. From the investigation it has been found that there established better correlations between hand penetrometer test value and bearing capacity for two lower diameters penetrometers than the higher diameter penetrometer for granular soil (sand).

Keywords: *Bearing capacity, Granular soil, Penetrometer test value, Artificial sand bed, Angle of internal friction*

1. INTRODUCTION

For the construction of multi-storied buildings, highway, bridge, tower, overhead water tank, industrial plants, etc., sub-soil investigation is very important to know the soil type, consistency or relative density and ground water table. To design the selection of foundation type and depth of foundation of any super-structure, it is essential to know the bearing capacity, settlement of sub-soil layers. For these cases, field tests and/or laboratory tests are performed. But it takes more than one month for field and laboratory tests. (Terzaghi, 1929; Skempton, 1951; Meyerhof, 1963; Hansen, 1970; Vesic, 1973) proposed bearing capacity equation with some variations of factors. However, it is required to investigate soil of different layers which is costly and also takes more time even for a small project. Now-a-days, N-value from standard penetration test (by split spoon sampler) is widely used for determining bearing capacity of soil but it also takes long time as well as costly.

The site engineer is often faced with the problem of ascertaining the is-situ bearing capacity of soil. To find out in-situ bearing capacity of soil, standard penetration test, plate load test. etc. are performed which are time-consuming and expensive. A soil survey can never cover the entire site. Based on the parameters obtained from the soil investigation safe bearing capacity is predicted. The site engineer has to verify quickly whether the specified value is available or not. But the time involved in the process of laboratory tests would make it rather impractical. To overcome these difficulties a hand penetrometer has been developed which is simple to handle and operate (Sanyal, 1987) developed a correlation between hand penetrometer test value N_h and standard penetration test N- value. It is particularly useful to the field engineer to determine the bearing capacity of the excavated strata. If can also be used for compaction control. For lightly loaded shallow foundation, the instrument can be useful in which case owner is not at all interested to perform costly soil investigation work. To avoid these difficulties present investigation was undertaken hand penetrometer of three different diameters (18.75 mm, 25 mm and 31.25 mm) to find out the bearing capacity of granular soil.

2. EQUIPMENTS AND INSTRUMENTATION

2.1 Fabrication of Hand Penetrometers

For carrying out the tests required in this investigation a number of instruments and equipments have been used. The main instrument is hand penetrometer which was fabricated and made by mild steel rod of three different diameters 18.75mm, 25mm and 31.25mm. The total length of each penetrometer is about 1.5m and total system is shown in Figure 1. A collar is subject to the middle third of the rod. The rod is divided into two parts. Upper

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part is one third and lower part is two third of the total length of the rod. One end of the lower part of the rod is tapered to a cone while the other end is threaded. Both ends of upper part of the rod are threaded. A circular steel disc weighing 10 kg (98 N) is allowed to slide freely through the rod. An adjustable nut is then adjusted so that the distance from the top the disc to the underside of the nut is exactly 375 mm.

2.2 Preparation of Box for Model Sand Bed

A box of length 90 cm, width 90 cm and height 105 cm was constructed above ground surface near the laboratory of Civil Engineering Department, KUET as shown in Figure 2. This box was used to prepare model sand bed. The bottom of the box was constructed by cement concrete and the wall was constructed by brick work of 12.5 cm thick on four sides.

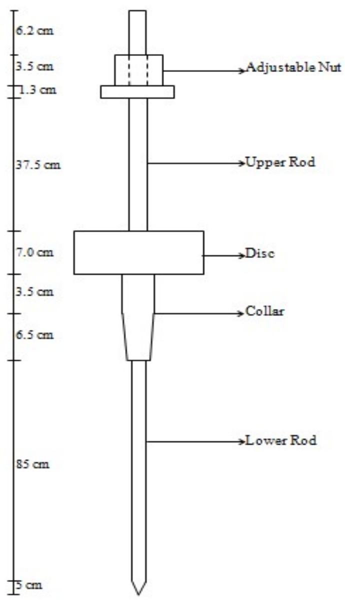

Figure 1: Hand penetrometer

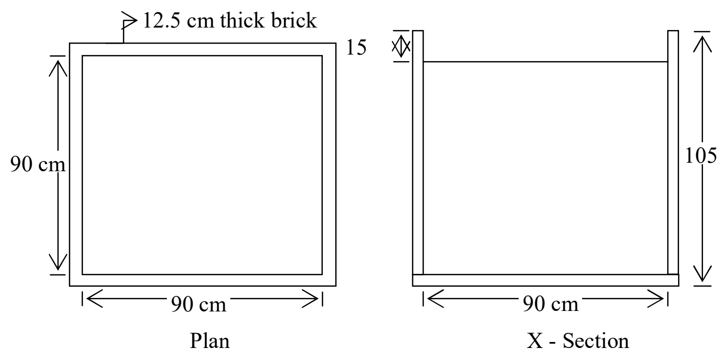

Figure 2: Box to prepare artificial sand bed above ground surface

3. LABORATORY INVESTIGATIONS

The use of disturbed samples of soils for testing would be very desirable in the investigation of their behavior. Such samples are seldom uniform due to the complex geological conditions acted upon them and as such, from the test results on such samples, it is rather difficult to generalize the behavior of soils. Therefore, to study any specific effect on the behavior of soils, it is considered essential to use uniform reconstituted samples prepared under controlled conditions in the laboratory (Hvorslev, 1960). The laboratory investigations made on selected samples have been described in the following articles.

3.1 Soil Samples Used for the Test

In this study sand samples were used as granular soil. Three sizes of sand namely, Sylhet sand, Kushtia sand and local sand were selected for this purpose. Disturbed samples of these sands were collected from local business center at Fultala. Among thirteen sand samples ten samples were prepared artificially by mixing the original sand samples of Sylhet, Kushtia and local (Khulna) in different proportions to obtain different fineness modulas.

3.2 Preparation of Sand Beds

For each sample a sand bed was prepared in the box by filling each type of sand with proper compaction of each 15 cm layer. The original and artificially mixing 13 sand beds are designated by sample S1, S2, S3, up to Sample S13. Samples designation and different mixing proportions of thirteen beds are shown in Table 1.

3.3 Tests Performed in the Laboratory

The samples were collected from thirteen sand beds. In the laboratory grain size analysis and direct shear tests were performed according standard test procedures on all samples collected from all the sand beds. The grain size analysis on these samples was performed by using ASTM sieve numbers 4, 8, 16, 30, 50 and 100. Figure 3 shows the grain size distribution (GSD) curves of all the samples of thirteen sand beds. From this grain size analysis, fineness modulus (F.M.) of each sand sample was determined. Direct shear tests were performed to determine the angle of internal frictions (ϕ) of all the samples. This test was repeated on three samples collected from different depths of each sand bed. The difference in ϕ in three tests of a sand bed was so small that it could be neglected. However, average value of ϕ was under consideration. In direct shear test normal loads were 10kg (98 N), 20kg (196 N) and 30kg (294 N). F.M. and ϕ of all the sand beds are shown in Table 2.

Table 1: Samples designation and mixing proportions of sand bed

Sample designation for each sand bed	Mixer of granular soils	Mixing ratio of sand bed
S1	Sylhet sand	-
S2	Sylhet sand: Kushtia sand	3:1
S3	Sylhet sand: Local sand	3:1
S4	Sylhet sand: Kushtia sand	1:1
S5	Sylhet sand: Kushtia sand	1:3
S6	Sylhet sand: Kushtia sand: Local sand	1:1:1
S7	Sylhet sand: Local sand	1:3
S8	Sylhet sand: Local sand	1:1
S9	Kushtia sand	-
S10	Kushtia sand: Local sand	3:1
S11	Kushtia sand: Local sand	1:3
S12	Kushtia sand: Local sand	1:3
S13	Local sand	-

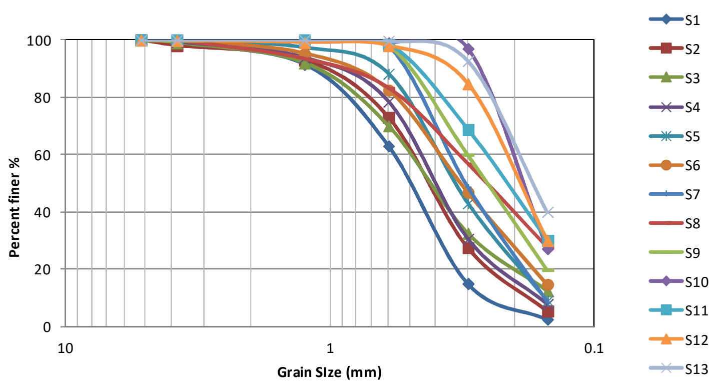

Figure 3: Grain size distribution curves of thirteen samples

Table 2: Fineness modulas and friction angles of different samples for thirteen sand beds

Samples designation	F.M. of the sample	ϕ (degree)	Samples designation	F.M. of the sample	ϕ (degree)
S1	2.28	42.4	S8	1.42	37.8
S2	2.05	41.0	S9	1.24	37.3
S3	1.95	40.2	S10	1.09	36.7
S4	1.90	39.7	S11	1.04	36.2
S5	1.64	38.6	S12	0.89	35.4
S6	1.63	38.5	S13	0.68	35.2
S7	1.46	38.0			

3.4 Determination of Field Density and Hand Penetrometer Value for Each Model Sand Bed

Field density test by sand replacement method was performed on each prepared sand bed in the test box to evaluate the bearing capacity of the sand bed. Table 3 exhibits the field densities of sand samples compacted in the test bed.

To determine the hand penetrometer test value N_h, the upper rod, lower rod and collar of the hand penetrometer were set on the top of the compacted sand bed. The circular disc of weight 10kg was slided through the upper rod to rest on the collar. The nut was then adjusted so that the height from the top of the disc to the bottom level of the nut of 37.5cm. A check nut on the top of the adjustable nut is preferable. This prevents the movement of the original nut. The instrument thus set was then held vertically by one person. Another person is then required to lift the disc slowly up the bottom of the nut and allow it to fall freely from that height to the top of the collar. This procedure was repeated until the rod penetrated 45 cm into the soil. The number of blows required for first 15 cm penetration was ignored to allow for any soil disturbance. The number of blows required for the penetration of the last 30 cm of the rod was taken as the N_h value (hand penetrometer test value) of the particular penetrometer. Three tests were performed by three different hand penetrometers at different locations in each artificial sand bed. For each sand bed three tests were repeated by a particular hand penetrometer. The values of N_h are shown in Table 4.

Table 3: Determination of field densities of compacted sand beds

Samples designation	Wet density in field, γ (gm/cc)	Dry density in field, γ_d (gm/cc)
S1	1.93	1.76
S2	1.80	1.68
S3	1.91	1.52
S4	1.87	1.69
S5	1.76	1.62
S6	1.83	1.66
S7	1.87	1.63
S8	1.96	1.70
S9	1.78	1.62
S10	1.94	1.67
S11	1.64	1.51
S12	1.79	1.57
S13	1.64	1.40

Table 4: Hand penetrometer test values for 13 sand beds

Sample	Dia. of hand penetrometer (mm)	N_h-value	Sample	Dia. of hand penetrometer (mm)	N_h-value
	18.75	22		18.75	14
S1	25.00	33	S8	25.00	22
	31.25	54		31.25	38
	18.75	16		18.75	15
S2	25.00	25	S9	25.00	21
	31.25	45		31.25	36
	18.75	16		18.75	13
S3	25.00	25	S10	25.00	19
	31.25	45		31.25	31
	18.75	21		18.75	11
S4	25.00	27	S11	25.00	20
	31.25	44		31.25	31
	18.75	17		18.75	10
S5	25.00	23	S12	25.00	18
	31.25	41		31.25	27
	18.75	16		18.75	09
S6	25.00	23	S13	25.00	14
	31.25	40		31.25	20
	18.75	14		--	--
S7	25.00	26	--	--	--
	31.25	40		--	--

4. RESULTS AND DISCUSSION

4.1 Evaluation of Bearing Capacity of Sand Bed

Terzaghi's formula (1929) was under consideration. From direct shear tests and field density tests by sand replacement method on sand beds, friction angles and field densities were used for the determination of ultimate bearing capacity, q_{ult} from Terzaghi's formula. The ultimate bearing capacities of different sand beds were presented in Table 5.

Table 5: Ultimate bearing capacity of sand beds

Sand bed No.	S1	S2	S3	S4	S5	S6	S7
q_{ult} (kPa)	3140	2300	2488	2832	2349	2353	2258
Sand bed No.	S8	S9	S10	S11	S12	S13	--
q_{ult} (kPa)	2354	2139	2205	1944	1971	1642	--

4.2 Development of Constitutive Equations

Number of blows from hand penetrometer test, N_h and ultimate bearing capacities, q_{ult} from Terzaghi's equation were used to correlate among them. Figures 4, 5 and 6 show the variation of bearing capacity with number of blows (penetrometer test value) for three types of penetrometers. From Figures 4, 5 and 6 it is observed that bearing capacity of sand increases with the increase of penetrometer test value in all penetration tests. The curves in Figures 4, 5 and 6 might also be presented the correlations between N_h and q_{ult} as constitutive equations. These constitutive equations are shown in Table 6.

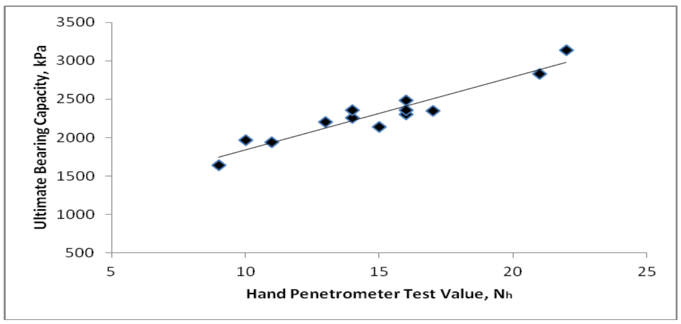

Figure 4: Variation of bearing capacity with hand penetrometer test value for strip footing (for 18.75 mm dia. penetrometer, D = 120 cm, B = D)

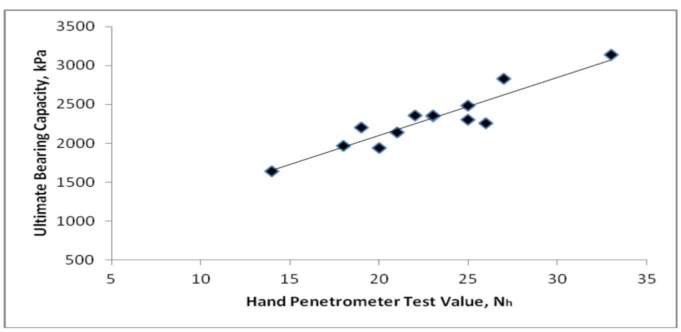

Figure 5: Variation of bearing capacity with hand penetrometer test value for strip footing (for 25 mm dia. penetrometer, D = 120 cm, B = D)

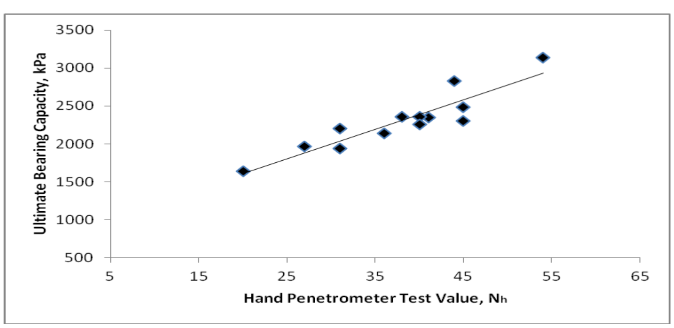

Figure 6: Variation of bearing capacity with hand penetrometer test value for strip footing (for 31.25 mm dia. penetrometer, D = 120 cm, B = D)

Table 6: Constitutive equations for three hand penetrometers

Diameter of penetrometer (mm)	Constitutive equations	Coefficient of correlations, R^2
18.75	$y = 94.966x + 888.58$	0.91
25.00	$y = 74.833x + 601.88$	0.88
31.25	$y = 38.871x + 834.67$	0.83

where, y = ultimate bearing capacity, q_{ult} (kPa) and x = hand pernetrometer test value, N_h

5. CONCLUSION

Based on this study, the following conclusions can be drawn:

(i) Penetrometer of all the diameters showed good correlation between hand penetrometer test value and bearing capacity of granular soil (sand). Among the three diameters, lower two provided better correlations than the higher one.

(ii) From the finding of the present investigation, it was established that irrespective of any diameter, ultimate bearing capacity of granular soil can be found out directly from the known value of hand penetrometer test by using following constitutive equations.

$$y = 94.966x + 888.58 \quad (a)$$
$$y = 74.833x + 601.88 \quad (b)$$
$$y = 38.871x + 834.67 \quad (c)$$

where, y = ultimate bearing capacity, q_{ult} (kPa)
x = hand pernetrometer test value, N_h

(iii) The constitutive equations might be used only for small project.

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