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Correlation between compressibility of gravely deposits and dynamic cone penetration tests

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ABSTRACT: Footing load tests were carried out in a reclaimed site in Alexandria, Egypt. The site was reclaimed by underwater filling with coarse gravel having diameter sizes in the range from 20 to 60 mm. The thickness of reclamation was in the range of about 2 m to 6 m. The major challenge in the site was to characterize the compressibility of the reclaimed soil and thus design of shallow foundations for the planned structures. Footing load tests were carried out at several locations of the site. Dynamic cone penetration tests were carried out at the same locations of the Footing load tests. Thus a correlation between the results of the footing load tests and those of dynamic cone penetration tests is possible. Such a correlation allowed the use of dynamic load tests results to estimate the compressibility of the gravely material in the site. The correlation is also useful to characterize similar materials in other sites.

1 INTRODUCTION

Estimation of deformation modulus of cohesionless soils from laboratory testing is a challenging process if it is even possible due to disturbance of extracted samples from the ground. Therefore, the estimate of deformation modulus of cohessionless soils relies on availability of correlation between in situ field test parameters and deformation modulus back calculated from field results of pressure versus settlement relationship based on plate load tests, footing load tests, or observed settlement records. There are over dozen of such correlation exist in the literature (e.g. Terzaghi et al. 1996, and Burland and Burbidge 1985). However, such a correlation is rare for gravelly soils. Even if it exists, the correlation is usually constrained with few limitations due to field testing problems associated with presence of gravel size particles in the ground.

The presence of gravel in a deposit may lead to major problems that hinder the possibility of using the in situ test parameter in estimating the compressibility of gravelly deposits and thus presence of correlation between in situ parameter and deformation modulus for gravelly soils. For example, damage could happen to the shoe of the spoon sampler of Standard Penetration Test (SPT) or to the sensitive tip of the Cone Penetration Test (CPT). If large particles were to become stuck in the shoe of the spoon sampler of SPT, unrealistically high values of SPT N values might be obtained. The presence of large particle under the tip of the cone may requires unrealistically high axial force to be penetrated through or to be pushed and sometimes may lead to misleading refusal case and thus shallow termination of the penetration process. The fact that the pressuremeter test is an expensive test that requires special interpretation makes the routine use of the test in site investigation uncommon. In addition, the presence of large particles may cause caving in of the pressuremeter hole before testing.

Some of the above mentioned difficulties were the drive for introducing the idea of attaching a solid 60-degree cone to the end of the SPT shoe by Palmer and Stuart (1957). The idea may be started earlier with different elements and input energy (Abo-ElNaga 2001). It is believed that this was the basis for the dynamic cone penetration test (DCPT) as referenced in British Standards and DIN Standards.

The aim of this paper is to develop a correlation between the blow count of DCPT as in situ parameter and the compressibility of gravel deposits as determined from footing load tests or settlement records. The results of footing load tests carried out in a reclaimed site were used to develop the relationship. In addition, the developed correlation was reinforced by settlement records of structures on gravelly soils from the database of Burland and Burbidge (1985).

The developed correlation shall be an excellent design aid to help engineers to size the foundations on gravelly deposit using DCPT without the need for conservative estimates of the compressibility of such deposits.

2 RECLAIMED SITE AND DYNAMIC CONE PENETRATION TESTS

A major site was reclaimed in Alexandria, Egypt. The purpose of reclamation was the development of a marina and luxurious residential villas along the developed facility. The site was reclaimed by underwater filling with mixture of sand and gravel with maximum size of about 60mm. The thickness of reclaimed layer was in the range of about 2 m to 6 m.

Dynamic Cone Penetration Test (DCPT) was performed on the subsoil formation in the site. The tests were performed using a split-barrel sampler having 50 mm outside diameter and 35 mm inside diameter and about 600 mm length. The toe of the sampler is connected to solid cone. The split-barrel sampler is connected to a string of drilling rods. The sampler is driven into the bottom of the borehole by means of a 63 kg hammer falling freely along a guide from a height of 760 mm and onto an anvil at the top of the drilling rods. The number of blows required to advance the sampler with the solid cone a distance of 10 cm in the soil is known as the N_{100} (SH). Figure (1) shows the N_{100} (SH) profiles measured across the site.

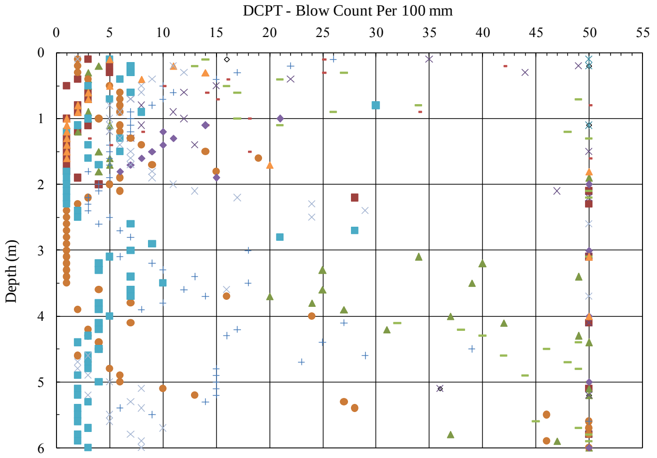

Figure 1. Dynamic cone test results across the site.

3 FOOTING LOAD TESTS

Footing load tests were carried out on the reclaimed subsoil formation at several locations across the site. The main drive of the tests was to evaluate the compressibility of the gravelly subsoil formation. The tests were performed using reinforced concrete footings with dimensions of 1.0 × 1.0 × 0.30 m. The footings were used in the tests after allowing enough time to ensure that the concrete has gained enough strength. A steel plate of 30 cm in diameter and 23 mm in thickness was used as a load bearing below the load acting at the centre of the footing to ensure load distribution and avoid possible punching due to load concentration. Figure (2) shows a schematic diagram of the footing load test setup. On each test, the footing was loaded in increments until reaching a contact stress of about 150 kPa. Thereafter, the footing was unloaded in decrements. During each stage, the settlement of the footing was recorded. For this purpose, the settlement was measured during the test at different five points on the footing. One point was at the footing centre, while the rest four points at the corners. The average settlement value was considered when plotting the resulting stress versus settlement curves. Figure (3) shows the stress versus settlement relationships for all the footing load tests.

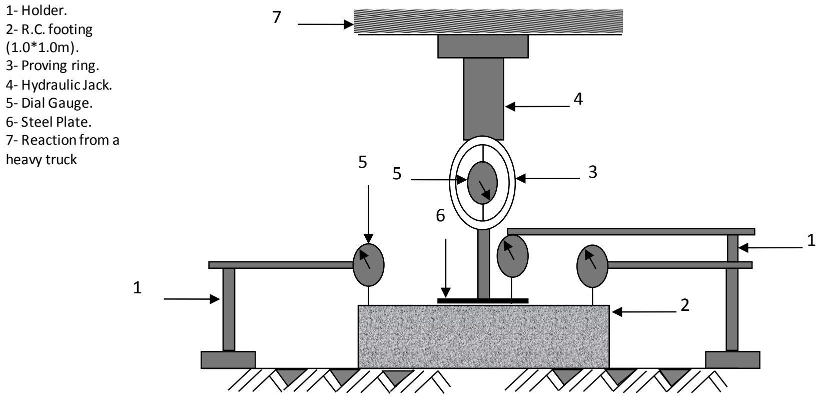

Figure 2. Schematic diagram of the footing load test setup.

4 BACK-CALCULATED DEFORMATION MODULI

The deformation modulus of the gravely deposit was back-calculated from the results of footing load tests using the following Equation as adapted from Burland and Burbidge (1985) and Terzaghi et al. (1996):

$$E_s = \frac{qZ_I}{S}\left[\frac{1.25(L/B)}{(L/B)+0.25}\right]^2 \qquad (1)$$

Where E_s is the loading deformation modulus in MPa, q is the net applied load on the footing in kPa, Z_I is the depth of the zone influenced by the load taken as $B^{0.75}$, B is width of footing in m, L is length of footing and S is settlement in mm. The slope of the unloading part of the curve was used to back-calculate the unload-reload deformation modulus $E_{s\text{-}ur}$. Table (1) shows a summary of the back-calculated values of the moduli. Shown also on the same table is the average value of N_{100}(SH), over a depth Z_I under the footing, from the DCPT carried out at the same location of the footing load test.

Table (1) Summary of back-calculated values of moduli & average DCPT over depth Z_I under the footing.

FLT No.	$N_{100}(SH)_{avg}$	Es (MPa)	$E_{s\text{-}ur}$ (MPa)
1	12	64.4	272.7
2	15	85.9	138.6
3	20.6	166.7	-
4	23.7	180.7	600.0
5	21.5	240.0	714.3
6	11.1	141.2	568.6
7	8.1	148.9	393.3
8	8.6	114.1	291.3
9	7.3	93.2	232.6

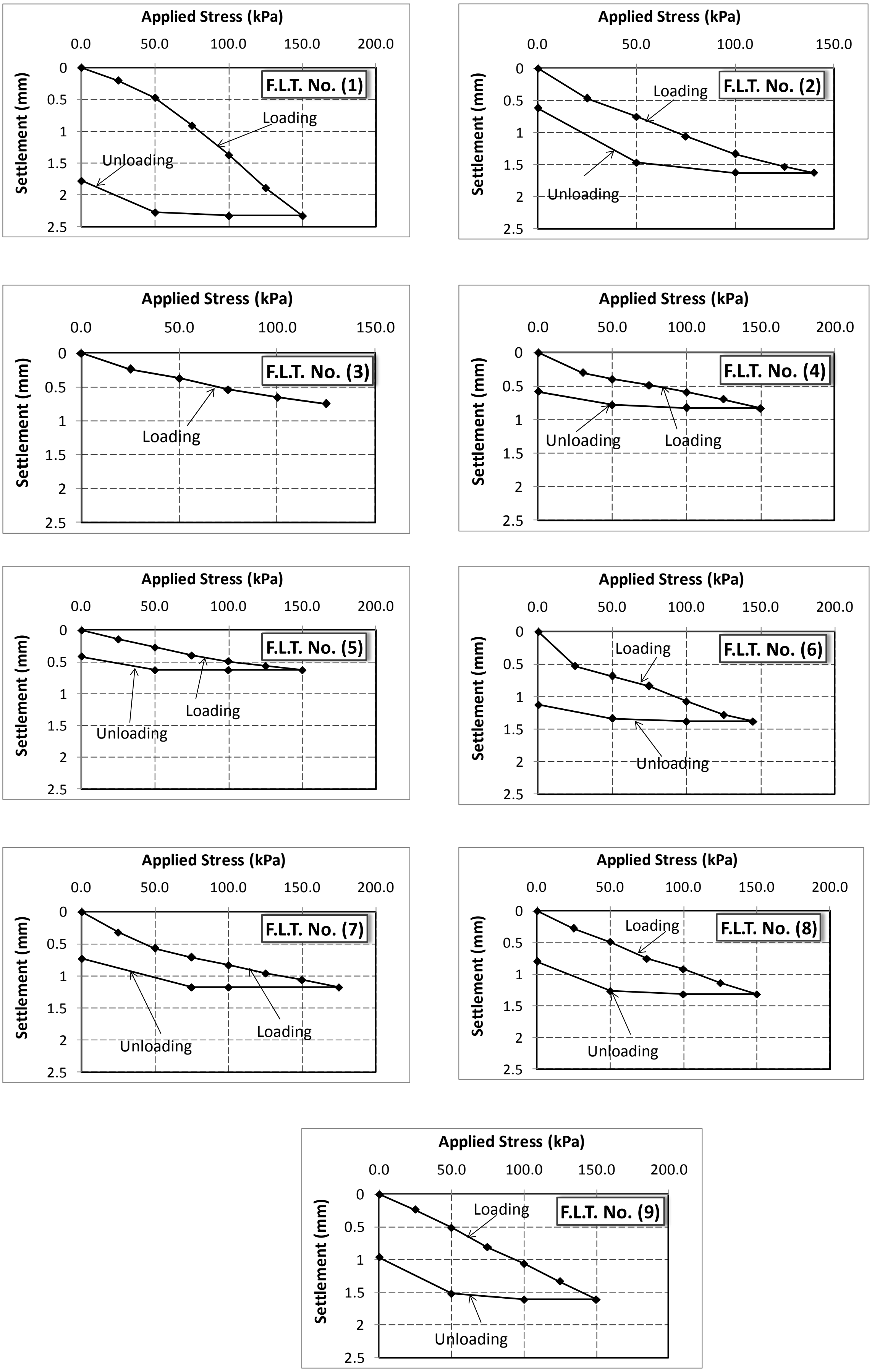

Figure (3) The stress versus settlement relationships for all the footing load tests.

5 DYNAMIC CONE RESULTS FROM SPT

The dynamic cone penetration test (DCPT) is a simple soil investigation in situ testing. In this test, a cone attached to the base of a small diameter rod is driven into the soil by means of regular blows from a hammer. The number of blows required to drive the cone a distance d are counted. Accordingly the DCPT N value is named N_d. In the literature, the distance, d, over which the blows are counted, could be 100 mm, 200 mm or 300 mm. The DCPT N_d value could be converted to N_{300} and vice versa using the following equation:

$$N_{300} = \frac{300}{d} N_d \tag{2}$$

The DCPT has the advantages over other penetration tests not only in its simplicity, portability but also in its low cost. There are four main types of dynamic cone penetrometers that are commonly used according to the relation between the diameter of the cone and the diameter of the attached extension rod (Waschkowski ,1982). In this study, the used cone has the same diameter of the extension rod.

According to the International Symposium of Penetration Tests, there are four different methods for dynamic probing DP (Stefanoff, 1988); DPL, DPM, DPH and DPSH. The abbreviation L, M, H and SH stands for the weight of the equipment as described as Light, Medium, Heavy and Super Heavy, respectively. The input energy for each type of probing is dependent on the weight of the hammer and the drop height. According to the specific energy per blow (DIN standards and Abu-ElNaga, 2001), the blow count of the dynamic probing of any weight category can be converted by the ratios of specific energy per blow to the Super Heavy dynamic probing blow using the following equation

$$N_d(SH) = 0.7 N_d(H) = 0.63 N_d(M) = 0.21 N_d(L) \tag{3}$$

Using the same concept of specific energy ratio per blow, the Standard Penetration Test blow count N can be theoretically converted to super heavy blow count using the following equation:

$$N_d(SH) = K \frac{d}{300} N \tag{4}$$

The multiplier K has values of 1 or 2 the use of which depends on the assumption of the area of the shoe of the SPT; the ratio 1 corresponds to soil plugging the shoe of the SPT while the ratio of 2 corresponds to transmission of the energy through the annulus area of the shoe.

A correlation between SPT N values and dynamic probing N_d is useful. Such a correlation is useful to use the experience accumulated over the years based on SPT N. There are many correlations between SPT N values and dynamic probing N_d that are based on comparative field measurements. In this paper, for ease of comparability, the super heavy dynamic probing shall be used as it corresponds to almost the same input energy of SPT. Furthermore, N_{100} shall be used as compared to other values in the literature. Therefore, when there is a dynamic probe within another weight category with blow count over any distance d shall be converted using Equation (2) to Super Heavy N_{100}. Table (2) summarizes the correlations developed or modified from the literature. Figure (4) shows graphical summary of the correlations in Table (2). Shown also on the same Figure, is the proposed correlation expressed in the Equation:

$$N_{100}(SH) = \frac{0.18N}{1 - \sqrt{0.012N}} \tag{5}$$

6 SETTLEMENT RECORDS ON GRAVELY DEPOSITS

Burland and Burbidge (1985) developed an extensive database of settlement records from all over the world. The database comprises with over or about 200 records. The data include settlement records of footings over sands and gravel. The purpose of the database development was to develop a correlation between a compressibility parameter and average SPT N values and thus a method for estimating settlement of footings on cohessionless soils. In spite of the fact that number of records is very large, only limited number of cases (only about 20) was recorded for deposits that include gravel. Based on these data, Burland and Burbidge (1985) statistically attempted to introduce a correction factor for gravelly soils. The correction factor was to increase the measured SPT N values by 25%. Because such a correction did not seem to make physical sense, Burland and Burbidge (1985) recommended to neglect such a correction factor and commented on the limited number of records on gravelly soils stating the need for further data collection. The back-calculated deformation moduli of these records are shown in Table (3). The average SPT N value of each of the published case records were converted to N_{100}.(SH) using the correlation in Equation (5) and were shown also in Table (3).

Table (2) Summary of correlations developed or modified from the literature

NO.	*CORRELATION*	*SOIL*	*REFERENCE*
1	$N_{100}(SH) = 0.38N$	Sandy Soils (Japan)	Muromachi & Kobayashi (1982)
2	$N_{100}(SH) = 0.2N$	Sandy-silty gravels	Tissoni (1987)
3a	$N_{100}(SH) = 0.33N$	Alluvial Gravel (UK)	Card & Roche (1988)
3b	$N_{100}(SH) = 0.37N$	Flood Plain Gravel (UK)	
3c	$N_{100}(SH) = 0.47N$	Sands (UK)	
4	$N_{100}(SH) = 0.013N^2 + 0.009N$	Coarse Grained Soils	Cearns & Mckenzie (1988)
5a	$N_{100}(SH) = 0.6N$	Fine Sand	
5b	$N_{100}(SH) = (0.1 - 1.0)N$	Medium Sand	
5c	$N_{100}(SH) = 0.27N$	Coarse Sand	
5d	$N_{100}(SH) = 0.33N$	Gravel	
6	$N_{100}(SH) = 0.2N$	Coarse Soil (Italy)	Cestari (1996)
7	$N_{100}(SH) = \dfrac{0.15\left(\dfrac{\sigma'_{vo}}{Pa}\right) + 0.083I_c + 0.262}{\left(\dfrac{2}{\sqrt{N}} - 0.36\right)}$ σ'_{vo} is effective overburden pressure Pa is a reference pressure taken as 100 kPa I_c is a soil type factor	All Soils (Egypt)	Abu-ElNaga (2001)
8	$N_{100}(SH) = 0.5N$	Coarse Soil (Germany)	DIN (2002)
9	$N_{100}(SH) = 0.17N$	Sandy-Silty With Fine Gravel (Italy)	Spagnoli (2008)
10	$N_{100}(SH) = 0.3N$	Highly Weathered Limestone (Sudan)	Kassim & Ahmed (2010)
11	$N_{100}(SH) = \dfrac{0.267N}{1 - 0.02N}$	Sandy Soils (South Africa)	MacRobert et al. (2011)

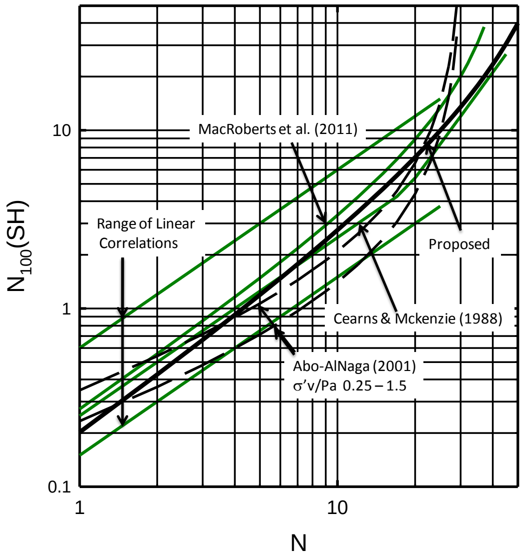

Figure (4). Summary of correlations in the literature and the proposed correlation.

Table (3) Settlement records on gravelly deposits (From Burland and Burbidge 1985)

Case	Structure	SPT N	B, m	L, m	Depth, m	Pressure kPa	S, mm	N100(SH)	Es, MPa	Es-ur, MPa
27	Nuclear reactor	47	60	circle	5.2	417	45	34.0	199.8	
34	Silo	33	2.4	strip		490	14	16.0	100.4	
37	Nuclear reactor	60	135	179	20.9	500	15	71.3		1460.2
47A	FLT	29	1.2	1.2	2.6	215	2.5	12.7	98.6	
47B	FLT	26	1.2	1.2	2.6	215	1.5	10.6	164.3	
47C	FLT	18	1.2	1.2	2.6	215	8.6	6.1	28.7	
51A - H	12 storey Building	37	4	7	5	518	7.6-11.9	20.0	189.0	
52C	FLT	50	1.2	1.2	0.5	300	4.5	39.9	76.4	
52H	FLT	50	1.4	1.4	3.7	300	1.5	39.9	257.4	
52A3	FLT	30	0.9	0.9	1.2	300	4	13.5	69.3	
52D3	FLT	20	0.9	0.9	3.1	300	6.7	7.1	41.4	
52J	FLT	20	0.9	0.9	1.2	300	2.7	7.1	102.7	
58A	Factory building	13	1.1	1.1	1.2	78	2	3.9	41.9	
58B	Factory building	13	1.5	1.5	1.2	77	2.1	3.9	49.7	
58C	Factory building	13	1.5	1.5	1.2	77	1.3	3.9	80.3	
65	FLT	25	1.2	1.2	0	320	2.8	9.9	131.0	
80	Building	36	41.2	41.2	10	158	10	18.9	256.9	
83	30 storey building	20	17.6	84	10.7	240	21.2	7.1	137.2	
84	20 storey building	14	16	43	7.3	228	17.9	4.3	133.3	
85	Chimney	50	20.5	-	3.5	173	8	39.9	208.3	
86	Chimney	26	14.5	14.5	3.5	255	15.5	10.6	122.2	
87	Nuclear reactor	34	33		5.3	216	43.8	16.9	67.9	
89A	Buildings	37	2.6	10.7	1	293	10.9	20.0	76.4	
94B	5 storey buildings	50	3.8	Strip	7	383	4.8	39.9	323.0	

7 NEW CORRELATION BETWEEN DEFORMATION MODULUS AND DYNAMIC CONE

The deformation modulus together the unload-reload deformation modulus back calculated from the results of footing load tests in this study were plotted against N_{100}(SH) in Figure (5a). Figure (5b) shows the same set of data, in addition, the data from settlement records (Table 3) are shown on the same plot. In spite of the presence of expected scatter, it is interesting to note that the two ranges of data coincide with each other. Shown also on Figure (5b), are the following proposed expressions for the correlations developed in this paper to estimate the compressibility of gravelly deposit from DCPT results:

$$E_s = 20\left[N_{100}(SH)\right]^{0.65} \tag{6}$$

$$E_{s-ur} = 80\left[N_{100}(SH)\right]^{0.6} \tag{7}$$

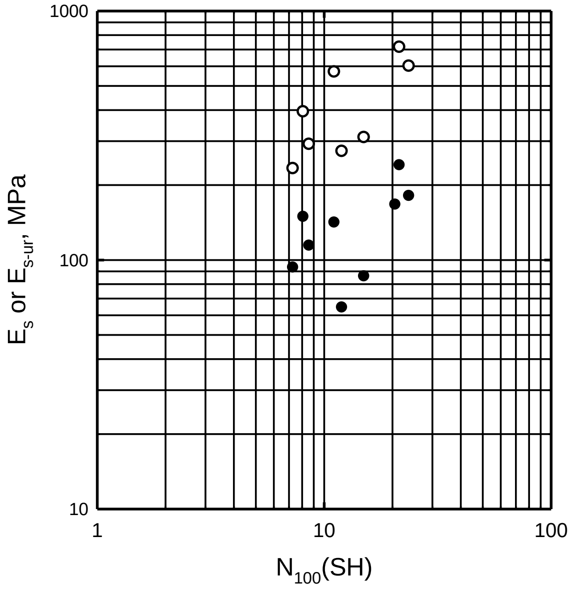

Figure (5a) Deformation modulus (solid symbol) and unload-reload modulus (empty symbol) from footing load tests.

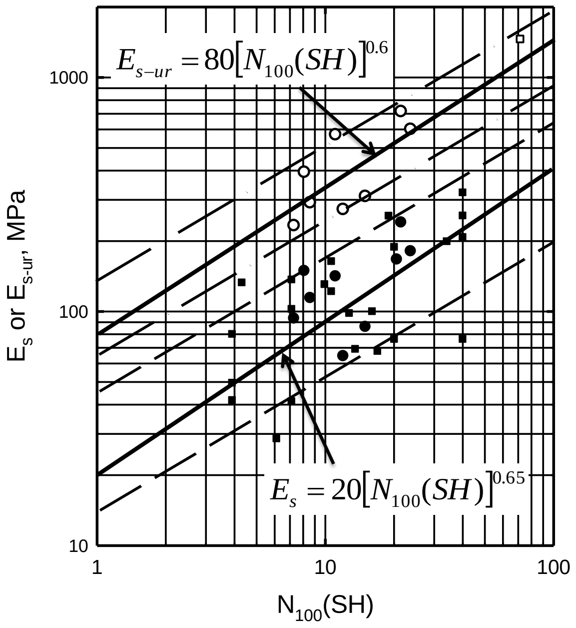

Figure (5b) Deformation modulus (solid symbol) and unload-reload modulus (empty symbol) from footing load tests (circles) and those from settlement records from Burland and Birbidge (1985) (squares).

8 CONCLUSIONS AND CONCLUDING REMARKS

Based on review of available data and relationships in the literature, a new correlation is proposed between Standard Penetration Tests blow count and that of Dynamic Cone Penetration Tests.

The results of footing load tests carried out on reclaimed site of gravelly deposit are used to back calculate the deformation modulus and the unload-reload deformation modulus of the gravelly deposit.

The results of Dynamic cone penetration tests that were carried out side by side to the footing load tests, were interpreted and were used to develop the intended correlation in this paper.

Settlement records on gravelly deposits from Burland and Burbidge (1985) database were used to reinforce the data obtained fromthe footing load tests. As Burland and Burbidge (1985) used SPT N values as abasis for the correlation, the SPT N values of the selected case records were converted to DCPT N_{100}(SH) using the SPT-DCPT correlation developed in this paper.

The data from both footing load tests and settlement records were used to develop correlations to estimate both the deformation modulus and the unload-reload modulus from DCPT N100(SH).

The proposed correlations are great aid to help engineers in the practice to size foundations on gravelly deposits.

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