Evaluation of modulus of subgrade reaction (K_s) in gravely soils based on SPT results

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Abstract: The modulus of subgrade reaction is a conceptual relationship between soil pressure and deflection that is widely used in the structural analysis of foundation members. It is used for continues footings, mats and various types of piling.

In practical and realistic terms, carrying out in-situ plate bearing tests or relating it in someway to intrinsic deformation characteristics of the soil can find 'K_s'. The plate load test is widely used and it fully described in ASTM D1194. Values of 'K_s' may also be assessed by relating them to the intrinsic parameters of the soil such as elastic modulus (E_s) and California bearing ratio (CBR) (Vesic, 1961, Bowels, 1997). 'E_s' can be derived from the results of triaxial tests. An approximate, empirical relationship between the modulus of subgrade reaction (K_s) and California bearing ratio (CBR) are presented.

The standard penetration test is currently the most popular and economical means to obtain subsurface information. The SPT results have been used in correlations for unit weight (γ), relative density (D_r), angle of internal friction ϕ, and undrained compressive strength q_u. It has also been used to estimate the bearing capacity of foundations and for estimating the stress-strain modulus 'E_s'.

In this paper the results of SPT and PLT tests on gravely soils of Tehran alluvium are evaluated. Due to the results obtained the correlation between SPT results $(N_1)_{60}$ and modulus of subgrade reaction (K_s) are also presented for gravely soils. The complete data base including SPT and PLT test results and graphical correlations will be included in the main version of the paper.

Résumé: Le module de la réaction de sous-grade est un rapport conceptuel entre la pression de sol et le débattement qui est largement répandu dans l'analyse structurale des membres de base. Il est employé pour continue des poses, des nattes et de divers types d'empilage. En termes pratiques et réalistes, la mise en oeuvre des essais à la plaque in-situ ou la relation d'eux dans someway aux caractéristiques intrinsèques de déformation du sol peut trouver "Ks". L'essai de charge de plat est largement répandu et il a amplement décrit dans ASTM D1194. Des valeurs d'"Ks" peuvent également être évaluées en les reliant aux paramètres intrinsèques du sol tels que le rapport élastique du module (Es) et du roulement de la Californie (CBR) (Vesic, 1961, Bowels, 1997). l'"Es" peut être dérivée des résultats des essais à trois axes. Un rapport approximatif et empirique de rapport entre le module de la réaction de sous-grade (Ks) et de roulement de la Californie (CBR) sont présentés. L'essai de pénétration standard est actuellement le moyen le plus populaire et le plus économique d'obtenir l'information à fleur de terre. Les résultats de SPT ont été employés dans les corrélations pour le poids spécifique) , densité relative (Dr), angle de frottement interne , et undrained la résistance à la pression qu. Il a été également employé pour estimer la portance des bases et pour estimer le module "Es" de contrainte-tension. En cet article les résultats des essais de SPT et de PLT sur gravement salit de l'alluvium de Téhéran sont évalués. En raison des résultats a obtenu la corrélation entre les résultats de SPT (N1) 60 et le module de la réaction de sous-grade (Ks) sont également présentés pour gravement des sols. La base de données complète des résultats d'essai comprenant de SPT et de PLT et des corrélations graphiques seront incluses dans la version principale de l'article.

Keywords: Plate – bearing tests, Penetration tests, Alluvium, Gravel, Subgrade modulus, Case studies.

INTRODUCTION

The modulus of subgrade reaction is a conceptual relationship between soil pressure and deflection that is widely used in the structural analysis of foundation members. It is used for continuous footing, mats and various types of piling.

For many construction projects, it is common to find that the preliminary design is based on soil parameters obtained from standard penetration tests. The standard penetration test, developed around 1927, is currently the most popular and economical means to obtain subsurface information. The method has been standardized as ASTM D1586 (1992). The use of penetration testing results in geotechnical design may be split into the following two distinct approaches.

A-Direct approach, which gives the opportunity to pass directly from in-situ measurement to the performance of foundations without the need to evaluate any intermediate soil parameters. This approach is frequently used in the evaluation of the settlement of shallow foundations in cohesionless deposits and to assess the ultimate and service limit states of piles subjected to both axial and horizontal loadings. The direct approach leads to empirical methods in which quality is strictly linked to the number and quality of the case records upon which the approach has been established. Valuable examples of this approach are the works by Burland and Burbridge (1984), Bustamante and Gianeselli (1982), Reese and Wright (1977), Reese and O'Neil (1987) and Jamiolkowski et al (1985).

B- Indirect Approach, which leads to interpretation methods that allow evaluation of the parameters describing the stress-strain-strength and consolidation behavior of soils. This approach is basically more sound and rational than the direct approach. Since the appearance of the penetration tests, the engineers have been attempting to assess the deformation characteristics and/or settlement of structures from their results (Terzaghi and Peck, 1948; De Bear, 1948; Meyerhof, 1956). This approach is of great practical interest in cohesionless and other soil deposits where undisturbed sampling is still impossible, unreliable or not cost effective. (D'Appolonia et al, 1968; Parry, 1978; Mitchell and Gardner, 1975)

This paper presents the results of 75 vertical plate load tests performed in boreholes on gravel strata at various depths. The tests were conducted as part of more comprehensive field investigation at 75 different locations in the Northern part of the Tehran City, the capital of Islamic Republic of Iran. The test equipment and procedures are described and a set of typical test data is presented. The results are used to develop a relationship between sub grade reaction modulus (K_s) and standard penetration test blow counts (N_{SPT}) that may be applicable to gravels in the Northern part of Tehran City.

The relationship may be used to obtain initial estimates of modulus for the analysis of bearing capacity, settlement, lateral load capacity of piles, and other characteristics where the load-deformation characteristics of soils influence structural behaviour.

SITE INVESTIGATION

Foundation investigation in the northern part of Tehran City is often conducted by digging narrow test pits (up to 800 mm across). Trained personnel are lowered in to such openings to describe and test the soil profile, this includes relative density. The large diameter boreholes make routine on site testing of gravels practicable even at depth. Therefore, equipment was developed that could be set up inside an 800 mm diameter borehole to perform vertical plate load tests at the bottom of shallow boreholes. These tests can be performed during routine foundation investigations for little additional cost. Because of the variability of gravel properties, frequent testing at each site is desirable. For that reason, and because of the confined working space in the borehole, the dimensions and mass of the equipment developed was kept small.

The equipment consists of a light hydraulic jack with attachments to connect circular plate with 305 mm diameter and 25 mm thickness (Figure 1). The test procedure is coincident with ASTM D1194. The plate is placed at the centre of the hole. Load is applied to the plate in steps-about one-fourth to one-fifth of the estimated ultimate load by means of a jack. During each step load application, the settlement of the plate is observed on dial gauges. At least one hour is allowed to elapse between each load application step. The test have been conducted until failure, or at least until the plate has gone through 25 mm of settlement.

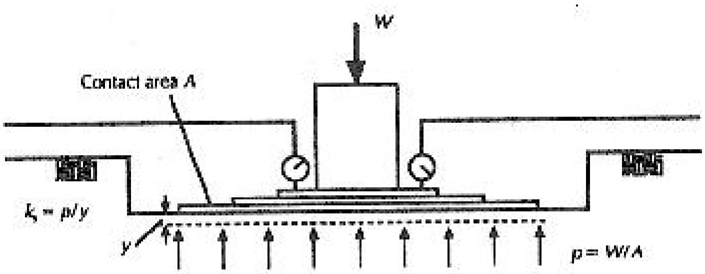

Figure 1. Plate bearing test apparatuses

The standard penetration test (SPT) was performed at intervals of approx 1.5 meter in accordance with ASTM D1586. The required number of blow counts (N) to penetrate 305 mm in to the soil is measured. Various factors like effective overburden pressure (σ'_v) length of drilling rod, diameter of borehole, method of sampling and type of hammer used, influence the corrected number of SPT blow counts. Thus, in order to determine a suitable index for evaluating soil density and resistance, the measured SPT N values should be corrected. The NCEER-97 (1997) procedure has been used in present paper to correction of SPT results.

ANALYSIS OF PLATE LOAD TEST RESULTS

The idea of modelling soil as an elastic medium was first introduced by Winkler and, not surprisingly, this principle is now referred to as the Winkler soil model. Several application of this principle are considered and illustrated by means of worked examples such as laterally loaded pile, and settlement analysis of shallow flexible foundations. Perhaps the best known are is that of a continuous, horizontal beam or footing resting on an elastic sub grade. The sub grade reaction at any point along the beam is assumed to be proportional to the vertical displacement of the beam at that point. In other word, the soil is assumed to obey Hook's law. Hence, the modulus of sub grade reaction (k_s) for the soil is given by $k_s=P/\delta$ where P is the ground bearing pressure at a point along the beam, and δ is the vertical displacement of the beam at that point.

The main difficulty in applying the Winkler soil model is that of quantifying the modulus of sub grade reaction (k_s) to be used in the analysis, as soil can be a very variable material. In practical and realistic terms, k_s, can be found only by carrying out in-situ plate bearing tests or relating it in some way to intrinsic deformation characteristics of the soil. The plate bearing test is widely used and is fully described in ASTM D1194. In foundation design, as distinct from pavement design, the value of K_s is the secant modulus of the graph over the estimated working range of bearing pressure (p') as indicated in Figure 2.

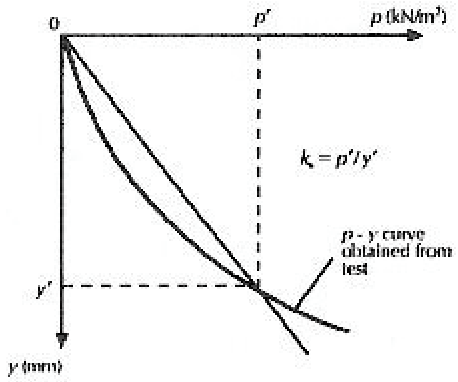

Figure 2. K_s measurement of plate load test results

ANALYSIS OF STANDARD PENETRATION TEST TRESULTS

The standard penetration test is the most popular dynamic test to determine soil resistance parameters. Using a hammer weighting 63.5 kg (140 lbs) and falling 0.76 m (30 in) the required number of bellows (N) to penetrate 305 mm (12 in) into the soil are measured as an indication of the density and resistance of soil.

Various factors like effective overburden pressure (σ'_v), length of drilling rod, diameter of borehole, method of sampling and type of hammer used, influence the SPT below counts. Thus in order to determine a suitable index for evaluating soil density and resistance, researchers have suggested different corrections on the basic number of blows obtained in SPT tests. The most comprehensive relations are presented in the NCEER-97 report for granular soils. In this procedure the corrected SPT below count for the 60% energy level is obtained from the following relation:

$$(N_1)_{60} = N * C_N * C_E * C_B * C_R * C_S$$

where:

N: measured SPT below counts
C_E: Energy effect coefficient depending on hammer type
C_B: Correction factor for borehole diameter
C_R: Correction factor for rod length
C_S: Correction factor for type of samplers (with or without liners)
C_N: Effective overburden pressure coefficient obtained from the following relation:

$$C_N = (Pa/ \sigma'_{v0})^{0.5}$$

where:

Pa: Atmospheric pressure
σ'_{v0}: Effective vertical pressure at considered depth

The preferred correction factors are presented in Table 1 due to NCEER recommendation.

INTERPRETATION OF RESULTS

75 vertical plate load tests are performed on medium to dense gravely soils in Tehran alluvium. The vertical settlement (δ) and contact pressure (p) for each test were measured and plotted in figures such as Figure 3. Then the secant modulus of each graph (k_s) is determined.

The standard penetration tests are also performed in each site and the SPT below counts are measured in corresponding depths. Then the corrected SPT values $(N_1)_{60}$ are evaluated based on NCCER-97 (1997) procedure. Based on most applicability of standard penetration test in geotechnical projects in Iran, the presentation of relationship between SPT results and other geotechnical properties of gravel such as K_s would be very useful. The obtained corrected SPT results $(N_1)_{60}$ and modulus of subgrade reaction (Ks) data are presented in Table 2.

Table 1. Correction to SPT results (NCEER-97)

Factor	Equipment variable	Term	Correction
Overburden pressure		C_N	(Pa / σ'_{v0})
			$C_N < 2$
Energy ratio	Donut Hammer	C_E	0.5 to 1.0
	Safety Hammer		0.7 to 1.2
	Automatic Hammer		0.8 to 1.3
Borehole diameter	65 mm to 115 mm	C_B	1
	150 mm		1.05
	200 mm		1.15
Rod length	3 m to 4 m	C_R	0.75
	4 m to 6 m		0.85
	6 m to 10 m		0.95
	10 to 30 m		1
	> 30 m		<1.0
Sampling method	Standard sampler	C_s	1
	Sampler without liners		1.1 to 1.3

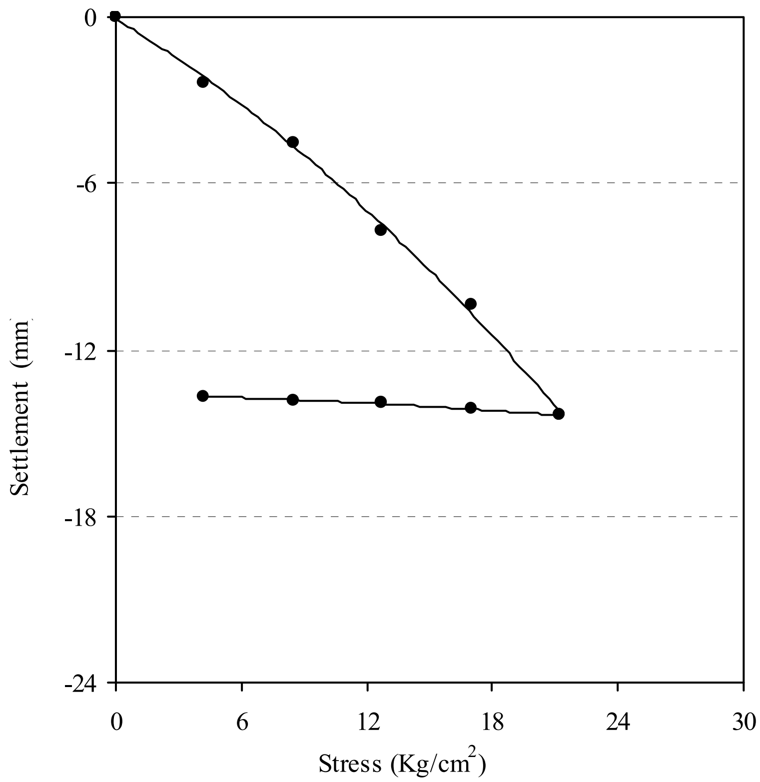

Figure 3. Typical (p-δ) curve obtained from plate load test

The results of statistical analysis on relationship between $(N_1)_{60}$ and (K_s) results showed that the following simple power function provides the best fit for correlation between plate load test data (K_s) and standard penetration test results $(N_1)_{60}$ (Figure 4).

$K_s = 3.143_* (N_1)_{60}{}^{0.489}$

Based on obtained results, the modulus of subgrade reaction (K_s) is increased as the SPT below count $(N_1)_{60}$ increased. Using the Figure 4, the modulus of subgrade reaction (K_s) may be evaluated from standard penetration test results in medium to dense gravely soils. It should be noted that the proposed relationship is only applicable for determining of K_s for small sized plate (B=30 cm). Therefore these values should be modified due to actual size of foundations (Bowels, 1997).

Table 2. Obtained $(N_1)_{60}$ and K_s data

Site No.	USCS Classification	$(N_1)_{60}$	K_s (kg /cm^3)	Site No.	USCS Classification	$(N_1)_{60}$	K_s (kg /cm^3)
1	GW-GC	20	14	39	GW	27	17
2	GP-GC	31	18	40	GW-GM	28	16
3	GC-GM	18	12	41	GW-GC	29	17
4	GW-GC	28	15	42	GP	25	15
5	GW	20	13	43	GP-GM	29	16
6	GP-GC	16	12	44	GP-GM	30	17
7	GP-GC	34	18	45	GP-GC	30	16
8	GP	35	17	46	GW-GC	32	17
9	GP	26	15	47	GW-GM	33	18
10	GW-GC	32	17	48	GP-GC	33	17
11	GC	28	15	49	GP-GM	32	17
12	GW-GM	38	19	50	GP	36	19
13	GP-GM	11	11	51	GW	36	18
14	GP	44	20	52	GP-GM	30	17
15	GW	31	16	53	GW-GM	30	16
16	GM	49	22	54	GW-GC	30	15
17	GW-GC	48	21	55	GP-GC	31	17
18	GW-GM	49	21	56	GM	19	13
19	GP-GM	30	17	57	GW	18	12
20	GM	27	16	58	GP-GM	22	14
21	GW	21	14	59	GW-GC	23	14
22	GP	22	13	60	GW-GM	24	15
23	GW	23	15	61	GP-GC	17	12
24	GC-GM	24	14	62	GW-GC	18	13
25	GP-GM	41	20	63	GW-GM	19	14
26	GP-GC	42	20	64	GP	19	14
27	GW	43	21	65	GW-GM	28	18
28	GW-GC	42	21	66	GP	33	16
29	GW	38	18	67	GW-GC	28	17
30	GP-GM	39	19	68	GW-GM	40	19
31	GP-GC	37	18	69	GP-GC	35	18
32	GP	34	17	70	GP-GM	37	19
33	GW-GM	15	12	71	GP	26	14
34	GW	16	13	72	GP	25	17
35	GW-GC	17	13	73	GM	42	19
36	GP	16	12	74	GW-GC	41	19
37	GP-GC	25	16	75	GW-GM	40	18
38	GP-GM	26	16				

CONCLUSIONS

The standard penetration test and plate load test results could be correlated in medium to dense gravely soils.

The modulus of subgrade reaction (K_s) of medium to dense gravely soil are correlated with corrected SPT below counts $(N_1)_{60}$.

The modulus of subgrade reaction (Ks) of medium to dense gravely soils are increased with increasing the corrected SPT below counts $(N_1)_{60}$.

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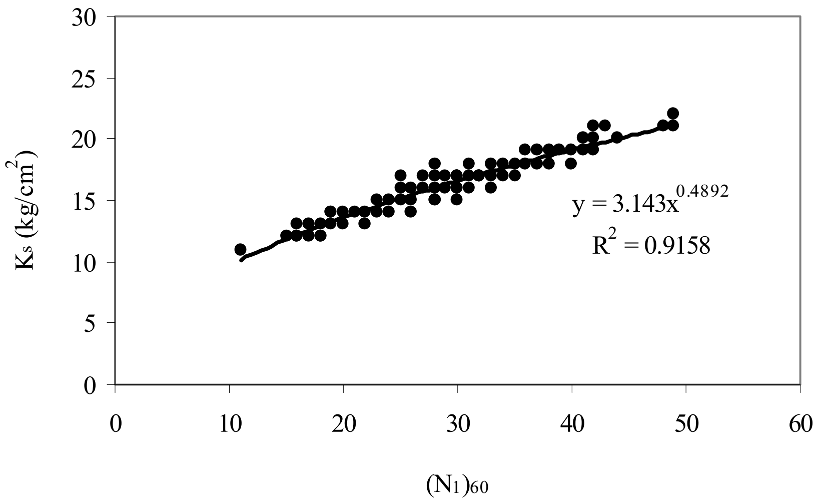

Figure 4. Correlation between SPT and PLT test results

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