Studies on modulus of subgrade reaction of reinforced foundation soil using model Plate Load test

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ABSTRACT

This paper deals with the evaluation of modulus of subgrade reaction of reinforced foundation soil by varying the number of layers and size of geotextiles used in the reinforced foundation soil. The modulus of subgrade reaction of soil depends upon various factors such as the size, shape as well as the depth of the foundation. The present paper deals with the experimental analysis/study involving model Plate Load tests (PLT). It is used to study the effect of footing shape on the coefficient of subgrade reaction of cohesion less soils. The test is carried out by placing Geotextiles under two rigid steel plates (circular and square). The tests are carried out on cohesion less soil underlain by weak foundation soil. The settlement is being studied for different applied loads. The ultimate bearing capacity has been obtained from the settlement-stress graphs.

KEY WORDS*:* Modulus of subgrade reaction, Geotextiles, Plate load test

1. INTRODUCTION

The modulus of subgrade reaction and the bearing capacity of soil are the indicators of the strength deformation properties of soil. To structurally analyse and design the footings, the coefficient of soil subgrade reaction "k_s" should be known. Actually k_s is not an intrinsic property of soil. It is just the response of soil to an applied load over a given area. It depends not only on the size of contact area between the model plate and subgrade but also on the deformation characteristics of the soil. The Winkler (1867) model (Winkler, 1987) is one of the most widely used models in the determination of the modulus of subgrade reaction of soil.

In the Winkler model, a linear force-deflection relationship is presumed and the soil behaves like an infinite number of linear elastic springs and the stiffness of the spring is termed as the modulus of soil subgrade reaction. In its basic form, Winkler's Hypothesis assumes that the soil is a system of discrete, identical, independent, loosely spaced, and linearly elastic springs. The ratio of the contact pressure and the settlement produced by the application of load at any point, on the contact surface, is given by the coefficient of subgrade reaction, k_s (or spring stiffness). It depends on a few parameters such as soil type, type of foundation, footing size, shape and depth.

An important assumption and limitation of this model is that the contact between the beam and foundation is never broken. Another method is the elastic continuum idealization, where generally the soil is assumed to be a linearly elastic half space and isotropic for the sake of simplicity.

This approach provides much more information on the variation of stress and deformation within the soil mass compared to the Winkler model. It has an important advantage in the simplicity of inputting the parameters, such as the Young's modulus and Poisson's ratio.

Both the approaches, Winkler and Elastic Continuum idealisation, require the appropriate values for input parameters, such as subgrade reaction coefficient, Young's modulus (E) and Poisson's ratio. A direct method to estimate both E and k_s is the Plate Load Test (PLT) and is conducted with circular plates or rectangular/square plates.

Literature Review: Various researchers assumed some forms of interaction among the spring elements that represent the soil continuum and attempted to make the Winkler model more practical and realistic. Iancu and Ionut (2009), (Biot, 1937) performed the finite element analysis (FEM analysis) and presented a numerical simulation of Plate Load test to determine the effect of the size on settlements. The numerical results obtained revealed that the the subgrade reaction coefficient is influenced by the size of the loaded area and the loading magnitude of the applied load.

By conducting the Plate Load test, Elsamny, (Terzaghi, 1955) (2010) presented the determination of the Young's modulus E of footings on cohesionless soil in the field. They concluded that the subgrade reaction k_s of cohessionless soil is proportional to the footing depth and dimensions. The subgrade reaction k_s of cohessionless soil under rectangular footing was found to be higher than that under square and circular ones. Their results indicated that the modulus of subgrade reaction k_s of cohessionless soil increases with the increasing angle of internal friction.

Aminaton (2012) discussed Winkler model where the soil is assumed to behave as infinite number of linear elastic springs. They have presented the effect of the footing size on sandy sub grade in the finite element software (Plaxis). Biot (1937), Terzaghi (1955), Vesic (1961), Bowles, have investigated the factors that affect the determination of k_s.

Biot (1937) investigated the problem of an infinite beam with a concentrated load resting on a 3D elastic soil continuum. He found a correlation between the Winkler model and Continuum Elastic Theory. Terzaghi (1955) recommended k_s for a rigid 1 x 1 square foot slab resting on the soil medium. But he did not specify the procedure to compute a value of k_s to be used for a larger slab. Vesic (1961) tried to develop a value of k_s with relevant matching bending moments by matching the maximum displacement of the beam in both the models .Terzaghi obtained the equation for k_s to be applied in the Winkler model.

The Egyptian Code method (2001) involves conducting a number of plate-load tests to study the load settlement characteristics and proposed an equation to estimate the value of modulus of subgrade reaction "k_s" as follows:

Where: k_s= Modulus of subgrade reaction (kN/m^3);

q = Stress at settlement;

δ=settlement;

$$k_s = \frac{q}{\delta}$$

Reza Z. M. and Masoud J. (2008)[10] suggested a method to determine the modulus of subgrade reaction using the plate load test conducted with a 0.30 – 1.00 m diameter circular plate or an equivalent rectangular plate.

Wael N. Abd Elsamee[11](2013) analysed experimentally by conducting a plate load test and determined the effect of foundation size as well as its shape and depth, on the modulus of subgrade reaction (k_s) of cohesionless soils using nine rigid steel plates of different sizes and shapes (circular, square and rectangular). These tests were carried out on cohessionless soils for different relative densities and under different pressures. He concluded that the subgrade reaction k_s of cohessionless soil increases with the increasing foundation depth and the change in its size. His results showed a fair agreement with that of Biot (1937).

Hayder Mekkiyah (2007) conducted studies on the settlement of footing resting on reinforced soil under a model circular footing reinforced using biaxial geomesh. He studied the effect of the number of reinforcement layers and the depth of the top most reinforcement layer on the bearing capacity, settlement and the subgrade reaction of soil. He concluded that the subgrade reaction values for reinforced soil were found to improve by 2 to 5, 3 to 7, and 4 to 9 times for one, two, and three layers of reinforcement respectively when compared to those of unreinforced soils.

Determination Of Modulus Of Subgrade Reaction Of Soil: One of the major problems in soil mechanics/Geotechnical Engineering is the estimation of the value of "k_s". The plate-load test (PLT) helps us to directly measure the compressibility and also the bearing capacity of soils in which sampling is difficult. The plate-load test can used to determine the modulus of subgrade reaction of soil.

One of the earliest contributors was Terzaghi (1955). He proposed the values of ks for a rigid slab of size (1 × 1) ft resting on soil. "ksf" for the footings can be obtained from the plate-load tests using appropriate formulae:

Table.1. Different formulae to compute the modulus of subgrade reaction, ks

Researcher	Formula
Winkler	$K_1=\frac{q}{\delta}$
Biot	$K_1=\frac{0.95E_1}{B(1-V_1^2)}\left[\frac{B^4E_1}{(1-V_1^2)EI}\right]$
Terzaghi	$K_s=K_{ap}\left[\frac{B+B_1}{2B}\right]$
Vesic	$K_s=\frac{0.65E_1}{B(1-V_1^2)}\sqrt{\frac{E_1B^4}{EI}}$
Meyerhof and Baike	$K_s=\frac{E_1}{B(1-V_1^2)}$
Selvadurai	$K_s=\frac{0.65}{B}\frac{E_1}{(1-V_1^2)}$
Ping-SienLinet.al.	$k_s=\frac{q_a}{\delta_a}q_a=\frac{q_u}{f.s}$
Bowles	$K_s=\frac{E_1}{B(1-V_1^2)MI_1I_F}$

I_s and I_F = Influence factor which depends on the shape of footing.

E_s = Modulus of Elasticity, I_s and I_F= Influence factor which depend on the shape of footing

M= varies from 1,2 and 4 for edges, sides and center of footing respectively

μ_s= Poisson's ratio.

k_{sf} = Modulus of sub grade reaction for the full size foundation. E_s = Modulus of Elasticity,

μ_s= Poisson's ratio.

k_{sp}= Modulus of subgrade reaction for0.3 x 0.3(1ft wide) bearing plate.

2. Methods & Materials

Experimental Programme

Present Experimental Study: This experimental programme involves conducting a number of plate load tests on a model footing resting on the reinforced and unreinforced granular bed overlying weak soil. The Plate load tests have been conducted using model footings of 2 shapes (square and circular).The settlement of cohesion less soil underlain by weak soil was measured for different stress levels. Two sizes of geotextiles were used in the test.

Various details of the materials used, test setup, experimental programme and test procedures are presented below

Test Setup

Model Tank: The model tank used for this study is made up of Ferrocement and its internal dimensions are 900mm in both

Table.2. Properties of Sand and Soil Used In The Test

Property	Values	
	Sand	Soil
Specific Gravity,(G_s)	2.73	2.40
Density for Loose Sand,(γ_{dmin}) (kg/m^3)	13.6	N/A
Max. Density,(γ_{dmax}) (kN/m^3)	17.8	16.0
Coefficient of Uniformity(C_u)	1.72	N/A
Coefficient of Curvature (C_c)	0.98	N/A
Angle of Internal Friction for Looses and(Φ),	31.0	N/A
Angle of Internal Friction for Dense sand(Φ),	36.0	N/A
Undrained Cohesion(C),(kN/m^2)	N/A	42.0
Liquid Limit (LL), (%)	N/A	37.55
Plastic Limit (PL), (%)	N/A	18.0
Optimum Moisture Content (OMG) (%)	N/A	21.0
Classification	SP	CI

Length and width, and 800mm deep. It has been designed in such a way that both the length and width are at least nine times that of model footing dimensions so that there should not be any boundary effect while conducting the plate load tests. The experimental setup is shown in figures I and II

Model Footing: In this study, two different shapes of isolated footings, namely square and circular are being used. They are made up of steel. The dimensions of square footing is 100mmx100mm and is20mm thick. The circular footing used has100mm diameter and is 20mm thick. The tests are conducted by placing the model footing on the surface during all the tests.

Table.3. Properties of geotextile used in the test

Property	Values
Mass per unit area(gm/m^2)	200.0
Breaking strength– Warp (5cm x20cm) (Kg)	257
Breaking strength– Weft(5cm x20cm) (Kg)	181.9
Extension at Break (%) –Warp	36.90
Extension at Break (%) –Weft	30.50
Thickness(mm)	0.56
Style (Quality no.)	P.D. 381
Colour	Yellowish-white
Polymer	Polyethyelene

Single/ double /three /Four Layers of (Geotextile): The test is conducted for granular bed overlying soil (Unreinforced and Reinforced using Geotextile).

Test Details: At first the tank is filled with sand in the required amount based on its predetermined density. It is compacted suitably till the required density is achieved. Then the load is applied. The corresponding settlement is measured and noted using two dial gauges and the average of the two readings is obtained at regular intervals till failure. The sand is removed and refilled. It is reinforced with 1, 2, 3 and 4 layers of Geotextiles and the above test is repeated maintaining the predetermined density. The above test is repeated for dense sand for reinforced and unreinforced conditions.

Then the weak silty soil is filled in the tank up to the required level along with the compaction being done in layers, to achieve density obtained from the test results. The sand is then filled up to the bottom level of the reinforcement and compacted again. The jack is placed such that its center is exactly above the reinforcement and load is applied at regular intervals and the corresponding settlement is recorded.

In this study, the depth of the first layer of reinforcement is adopted as 0.5 B (where B is the width of footing) and for the remaining reinforcements 2, 3, 4……N at different layers, each depth(d) of the reinforcement layer from the base of a footing can be calculated by using equation (Winkler, 1987) given as

$d=u+(N-1) \times h$------------------------(1)

D is the depth of reinforcement layer from the base of the footing, u is the depth of the first layer of reinforcement from the base of the footing, N is the number of reinforcement layers provided, h is the distance between reinforcement layers. (Refer figure II).

To conduct the model test further by using silty soil at a particular predetermined depth for both unreinforced and reinforced soil it is very important to predetermine and decide the magnitude of parameters like b/B, h/B, u/B, d/D ratios, Where b is the width of the reinforcement. The following are the adopted parameters for this study:

Number of reinforcement layers (N) = 0,1,2,3,4

Width or layer of each reinforcement layer

(b)= 800mm(0.8m)/ 400mm(0.4m),

b/B = 8& 4, h/B=5, u/B=5, d/D=0,0.625, 0.125, 0.187, &0.25

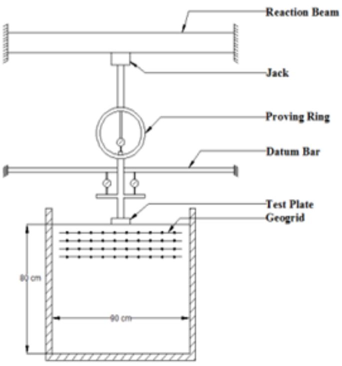

Figure.1. shows the test setup for granular soil as foundation bed

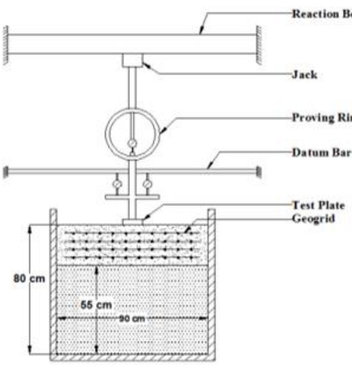

Figure.2. shows the test setup for weak soil as foundation bed

Results: Settlement was recorded for two shapes of footings (Circular and square) under different stresses. From the measured settlements the semi log graphs were plotted for stress versus the settlement.

3. RESULTS AND DISCUSSIONS

Determination of Ultimate Bearing Capacity using model Plate Load Test results: The ultimate bearing capacity of the soil can be obtained from the relationships between the stresses and the settlement recorded at the surface and at different depths for all the cases by tangent-tangent method according to the Egyptain code method. Figure 4 illustrates for finding the ultimate bearing capacity. The allowable bearing capacity (q_a) is obtained from ultimate bearing capacity (q_u) by dividing it by factor of safety (F.S. = 3.0), after which the corresponding settlement (s) is determined. Thus, k_s is calculated by dividing the allowable bearing capacity (q_a) by the corresponding settlement (s).

Table.4. Values of ks (kN/m3) of soil using plate load test under model circular footing of diameter 100 mm and square footing 100 mm x 100mm using Geotextile

Type of model footing	**Circular**				**Square**			
No of Layers of Geotextiles	1	2	3	4	1	2	3	4
Ultimate Bearing Pressure q_u for 0.8 X 0.8(kN/m^2)	850	1000	1020	1050	850	900	1010	1030
Allowable bearing pressure q_a(kN/m^2)	283.3333	333.3333	340	350	283.3333	300	336.6667	343.3333
Settlement S(m)	0.0022	0.0022	0.0021	0.002	0.0025	0.00245	0.0025	0.0025
Modulus of subgrade reaction k_s(kN/m^3)	128788	151515	161905	175000	113333	122449	134667	137333
qu for 0.4 X 0.4(kN/m^2)	900	1020	1035	1150	810	1000	1030	1050
Allowable bearing pressure q_a(kN/m^2)	300	340	345	383.333	270	333.333	343.333	350
Settlement S(m)	0.002	0.002	0.002	0.002	0.002	0.003	0.002	0.002
Modulus of subgrade reaction k_s(kN/m^3)	136364	161905	186486	211786	117391	125786	140136	155556

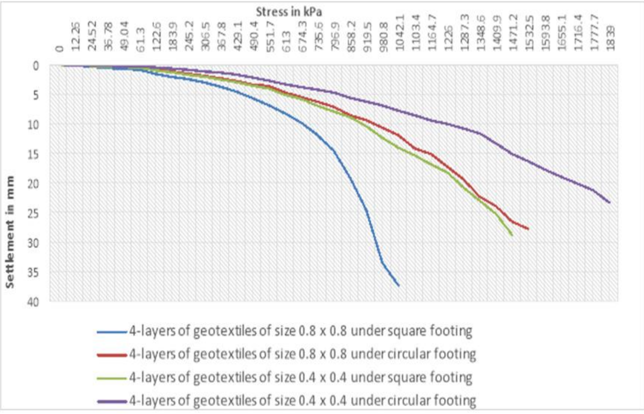

Figure.3. The relationship between stress and settlement of plate for determination of ultimate bearing capacity for square plate of 100mm x 100mm.

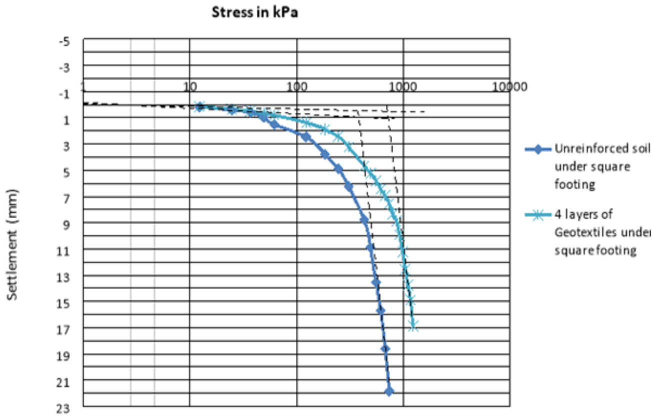

Figure.4. Values of k_s(kN/m^3) of weak soil using Plate Load test under model circular footing(100 mm) and model square footing (100mm x 100mm)

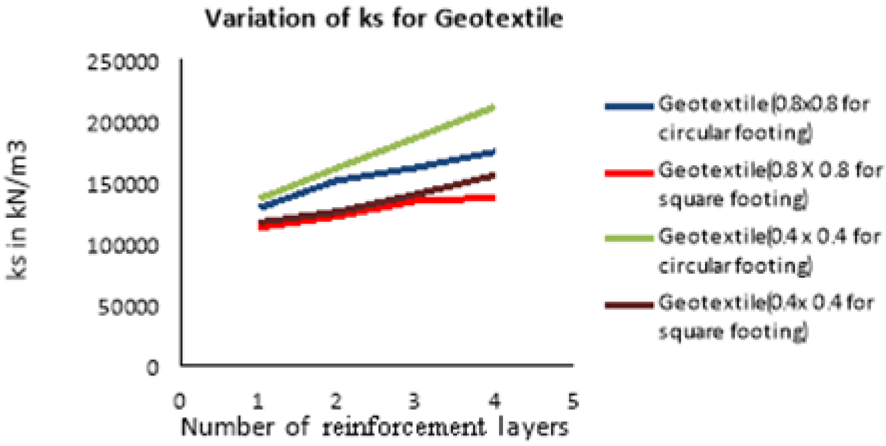

Figure.5. Values of k_s(kN/m^3) of weak soil using Plate Load test under model circular footing(100 mm) and model square footing (100mm x 100mm)

Variation Of The Modulus Of Subgrade Reaction Of Reinforced Soil: The different values of subgrade reaction (k_s)for both the model circular and square footing under Geotextile for both the sizes have been plotted against the number of layers. It is observed from the graphs that the modulus of subgrade reaction increases for both the footings for both the sizes of Geotextiles with the increase in the number of reinforcement layers. It is maximum for four layers for all the cases. It is observed that the modulus of subgrade reaction is maximum for Geotextile of size 0.4m x 0.4m under circular footing for four layers. It is least for Geotextile of size 0.8m x 0.8m under square footing.

Under circular footing, 4 layers of Geotextile of both the sizes 0.4mx0.4m and 0.8m x0.8m give better results for the modulus of subgrade reaction. The modulus of subgrade reaction has been enhanced due to the introduction of reinforcement. The modulus of subgrade reaction is more under circular footing for both the sizes of Geotextiles.

4. CONCLUSIONS

The following main conclusions are drawn from this study:

a) Practically under field conditions, square footings show better results with respect to bearing capacity and modulus of subgrade reaction than circular footings. But in the tests involving model footings, circular footing shows better results probably due to boundary effects of the foundation test pits.

b) The geotextile of lesser size (0.4m x 0.4m) shows better results than that of bigger size (0.8 x 0.8m). This may be due to the fact that the presence of geotextiles beyond the stress isobars may not be effective.

c) The increase in the number of layers of geotextiles increases the bearing capacity and modulus of subgrade reaction and is maximum for 4 layers.

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