American Journal of Engineering Research (AJER) **2015**

American Journal of Engineering Research (AJER)
e-ISSN: 2320-0847 p-ISSN : 2320-0936
Volume-4, Issue-8, pp-244-249
www.ajer.org
Research Paper Open Access

Estimation of Modulus of Elasticity of Sand Using Plate Load Test

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Abstract: *Soil being a natural material, is very complex to understand mainly because of its heterogeneous nature. The other factors making the soil further complex are three phase system, non-linear stress-strain curve, loading and drainage conditions on field etc. Under all these circumstances evaluation of elastic constants of soil is a challenging task. The real challenge is to simulate the field condition precisely in the laboratory. Using tri-axial drained test, it is possible to simulate field condition for the evaluation of elastic constants such as modulus of elasticity (Es) and Poisson's ratio (μ). However, for sandy soil it is difficult to perform the tri-axial test because of its non-cohesive nature and limitation in the preparation of the test sample (cylindrical specimen). To overcome this limitation in the present study, an attempt is made to evaluate the modulus of elasticity using plate load test analogy. Loading frame is utilized for employing loads on the plates. Load settlement curves obtained from plate load tests are used for determination of the modulus of elasticity. The test is carried out using three plates of different sizes. The modulus of elasticity is calculated by assuming different values of Poisson's ratio. The study reveals that, modulus of elasticity is in the range of 22 to 25 MPa, which reasonably falls in the range given in different literature. The studied range of Poisson's ratio is not significantly influencing the Modulus of Elasticity of sand.*

Keywords: *Elastic theory, Loading frame, Load -settlement curve, Modulus of elasticity, Plate load test, Poisson's ratio.*

I. Introduction

Modulus of elasticity of soil is a measure of soil stiffness. The modulus of elasticity is often used for estimation of soil settlement and elastic deformation analysis. Generally, modulus of elasticity of soil is determined in the laboratory using tri-axial test. But, for sand it is difficult to carry out tri-axial test because of its non-cohesive nature leading to limitation in preparation of sample mould for testing. Therefore, in the present study an attempt is made to determine modulus of elasticity of sand using plate load test analogy. The loading on the plate may be applied by gravity loading or reaction loading. In gravity loading, a platform is constructed on a vertical column resting on plate. Loading on the plate is done by placing weighed sand bags on the platform. In reaction loading the load is applied through a proving ring and hydraulic jack by taking reaction against a fixed support. In the present study reaction loading is applied with the help of loading frame having capacity of 1000 kN. T. Warmate and H. O Nwankwoala [1] studied the use of plate load test in ascertaining elastic modulus, Es. The study is carried out in Calabar, Niger Delta, Nigeria. Four plate load tests were carried out within the area of investigation, with load settlement curve which indicates a firm to stiff partial cohesive soil. An average elastic modulus value was obtained in the elastic range (initial tangent modulus), which is indicative of firm clay. This value confirms reasonably with those obtained by method proposed using cone penetrometer test (CPT). Literature reveals that, there is wide range of modulus of elasticity of sand. As per J. E. Bowles [2], the modulus of elasticity for silty sand, loose sand and dense sand is in the range of 5-20 MPa, 10-20 MPa and 50-81 MPa respectively. From this wide range, it is difficult to pick up the appropriate value of modulus of elasticity for the sand under consideration. Hence, it is decided to carry out experiment for evaluation of modulus of elasticity of sand in the laboratory. Normally about 90 % of total settlement of sandy soil comprises of immediate settlement. The amount of immediate settlement (elastic) is a function of elastic modulus and Poisson's ratio. The modulus of elasticity, which is an indicator of the material stiffness and a fundamental material constant, gives an indication of the immediate settlement. Load settlement curve generated from the plate load test, helps in the extrapolation of reasonable elastic modulus where the soil does not exhibit significant variation. The elastic modulus, which characterizes the soil stiffness, can be graphically defined by the slope of the tangent in a stress-strain plot (tangent modulus) in the elastic range [1].

II. Experimental Study

Test Setup

The plate load set up is developed using a loading frame. For retaining the sand, a container of size 1.1 x 1.1 x 0.5 m is prepared. Two opposite sides of container are made up of steel plates and remaining two sides are made up of plywood of thickness 18 mm as shown in Fig. 1. The bottom of container is open so that influence zone of pressure under the plates is kept unconstrained.

Fig. 1 Sand container used for study

Fig.2 shows loading frame used for study.

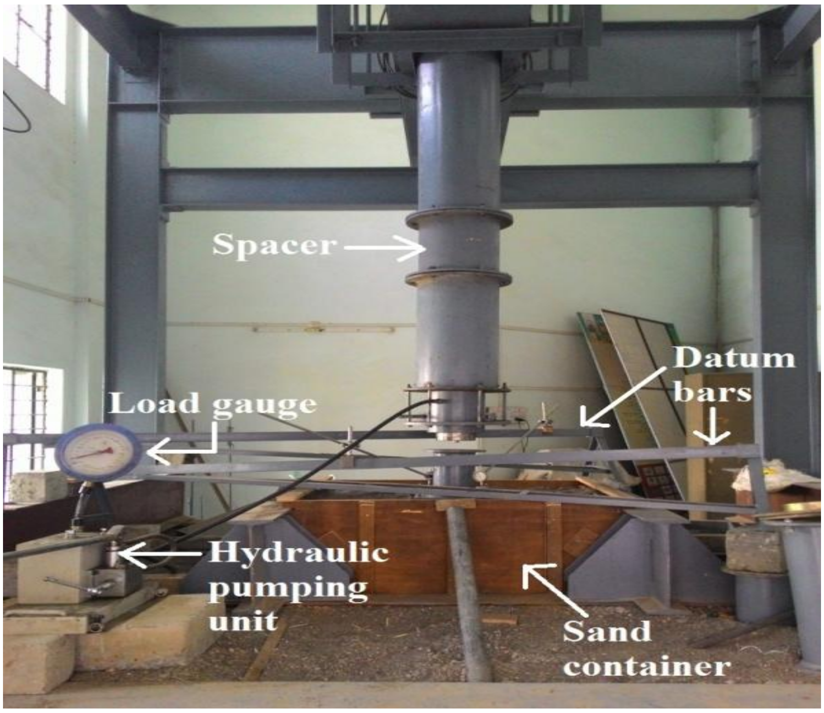

Fig. 2 Loading frame

Fig. 2 Loading frame

Proper care is taken to ensure lateral confinement of container. Stiffeners are provided on the ply woods to ensure lateral constraint & to avoid volume changes during application of load. Container is then filled with uniformly graded sand. This uniformly graded sand is having the size range 2.36 mm to 425 µ. Properties of sand used for test are shown in Table 1.

Table 1 Properties of sand

Sr. No.	Properties	Result
1	Specific Gravity	2.82
2	Water Absorption (%)	1.27
3	**Strength Parameters**	
	(a) Soil internal frictional angle (Ø) in degrees	51
	(b) Cohesion 'C' (kN/m^2)	0
4	Fineness Modulus	4.9
5	Unit Weight (kN/m^3)	18.01

Three rigid plates of different sizes are used for test which are shown in Fig. 3.

Fig. 3 Three rigid plates used in the study

Experiments are carried out to determine settlement beneath square plates resting on surface of sand. The settlement is measured with the help of sensitive dial gauges fixed on the surface of plate. The dial gauges are mounted on independently supported datum bars. As the plate settles, the ram of the dial gauge moves down and settlement is recorded. The load is indicated on the load–gauge of hydraulic jack. Fig. 4 shows plate load test setup.

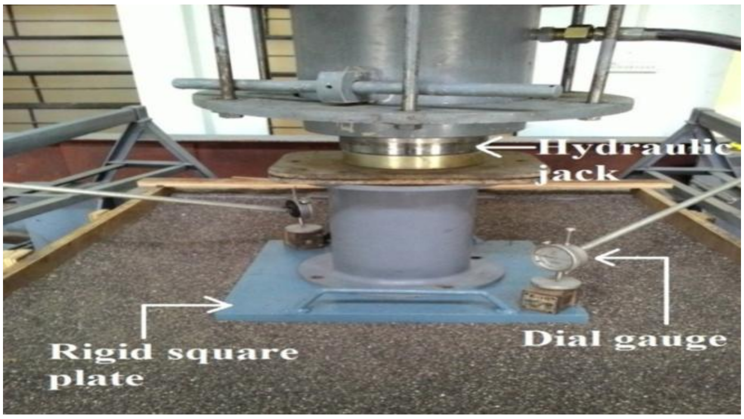

Fig. 4 Plate load test setup

Test Procedure

The plate is properly placed on sand at the center of container. The reaction load is applied with the help of a hydraulic jack. The maximum loads on plates are applied in such a way that their intensities of pressure under the plates are approximately equal to bearing capacity of sand under consideration. According to National Building Code of India, bearing capacity of cohesionless soil (medium, compact and dry) which reasonably confirms to the sand used for the study is in the range of 250 to 300 kN/m^2 [3]. The maximum loads on plates are applied equivalent to above pressure intensity. This loading is given in increment. The loads are applied in stages of 10 kN, 15 kN, 20 kN, 25 kN, 35 kN, 45 kN. For each load application settlement of plate is observed by dial gauges with sensitivity of 0.01 mm. Settlement is observed after an interval of 1, 2, 5, 15, 30 and 60 minutes and thereafter at hourly intervals until the rate of settlement becomes less than about 0.02 mm per hour [4]. After this, the next load increment is applied.

III. Results And Discussion

Load Settlement Curve

Settlements are recorded for three plates of different sizes. The values of loads and corresponding settlements of each plate are given in Table 2, Table 3 and Table 4.

Table 2 Load and corresponding settlement for plate no. 1

Load (N)	Pressure 'q' (N/mm^2)	Settlement 'S_i' (mm)
0	0	0
10000	0.111	2.280
15000	0.167	2.430
20000	0.222	3.480
25000	0.278	3.800
35000	0.389	4.620
45000	0.5	5.710

Table 3 Load and corresponding settlement for plate no. 2

Load (N)	Pressure 'q' (N/mm^2)	Settlement 'S_i' (mm)
0	0	0
10000	0.0711	1.665
15000	0.107	2.175
20000	0.142	2.600
25000	0.178	3.050
35000	0.249	3.540
45000	0.32	4.940

Table 4 Load and corresponding settlement for plate no. 3

Load (N)	Pressure 'q' (N/mm^2)	Settlement 'S_i' (mm)
0	0	0
10000	0.0494	1.370
15000	0.0741	1.500
20000	0.0988	1.585
25000	0.123	1.935
35000	0.173	2.710
45000	0.222	3.450

From these values, pressure v/s settlement curves are plotted as shown Fig. 5.

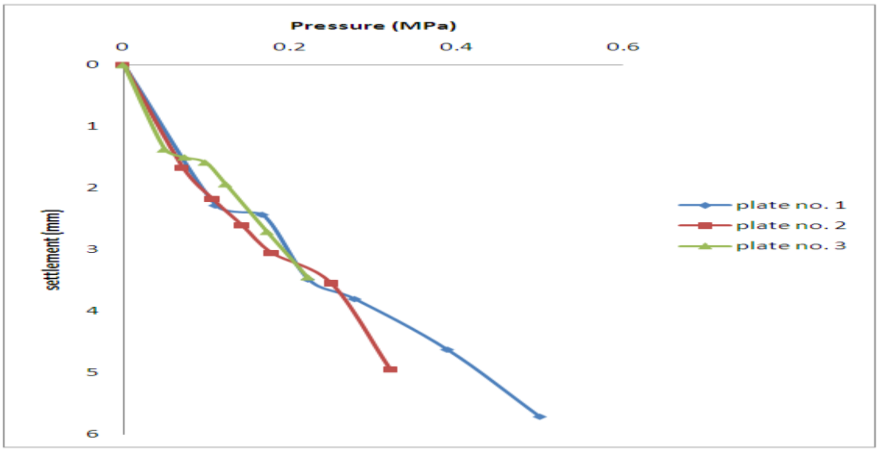

Fig. 5 Pressure v/s settlement curve for all plates

In Fig. 5, it is observed that in initial stages, rate of settlement is very less with increase in pressure. For plate no. 1 and 3 almost negligible settlements are observed in the initial stages. This is because of the resistance of sand particles to readjustment in the initial phase. After this phase sand undergoes the settlement almost in linear way.

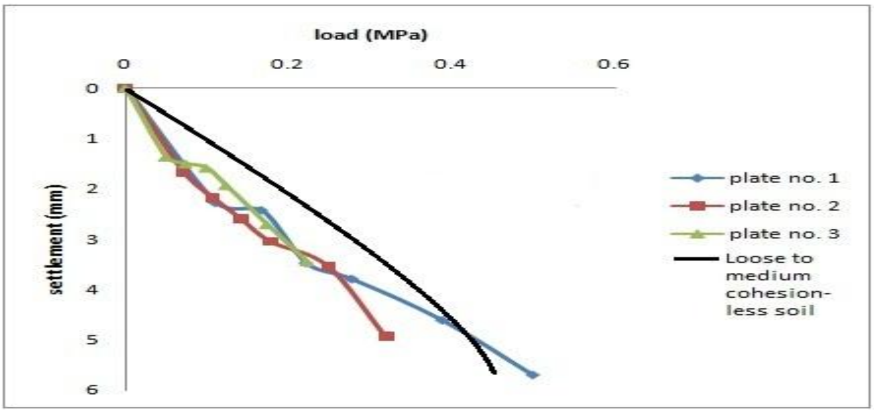

Fig. 6 Load settlement curve

Fig. 6 shows a typical load settlement curve for loose to medium cohesionless soil. Looking to the nature of load settlement curves of present study, it is observed that these curves are almost matching with the typical curve given for loose to medium cohesionless soil (Sandy soil), which almost matches with sand used for study. Hence, it may be inferred that the obtained load settlement curve of sand reasonably matches with the curves given in the literature.

Evaluation of Modulus of Elasticity (Es)

The theory of elasticity can be used to determine elastic settlement in soil caused by loads acting over footings of different geometrical shapes. The modulus of elasticity of sand can be computed from the following expression based on the theory of elasticity (Terzaghi).

$$S_i = qB\left[\frac{1-\mu^2}{E_s}\right] I_f \quad (1)$$

Where, S_i is immediate elastic settlement of soil, q is intensity of contact pressure, B is least lateral dimension of footing, Es is modulus of elasticity of soil, μ is Poisson's ratio, I_f is influence factor.

It is difficult to determine Poisson's ratio for sand. However, the entire term $\left[\frac{1-\mu^2}{E_s}\right] I_f$ from eq. (1) is determined from plate load test by using three different size plates of the same shape. A plot between S_i and q.B gives a straight line, the slope of which is equal to $\left[\frac{1-\mu^2}{E_s}\right] I_f$. In the present study, loads applied on the plates are 10 kN, 15 kN, 20 kN, 25 kN, 35 kN and 45 kN. The values of S_i and q.B for all loads and plates are plotted and shown in Fig. 7.

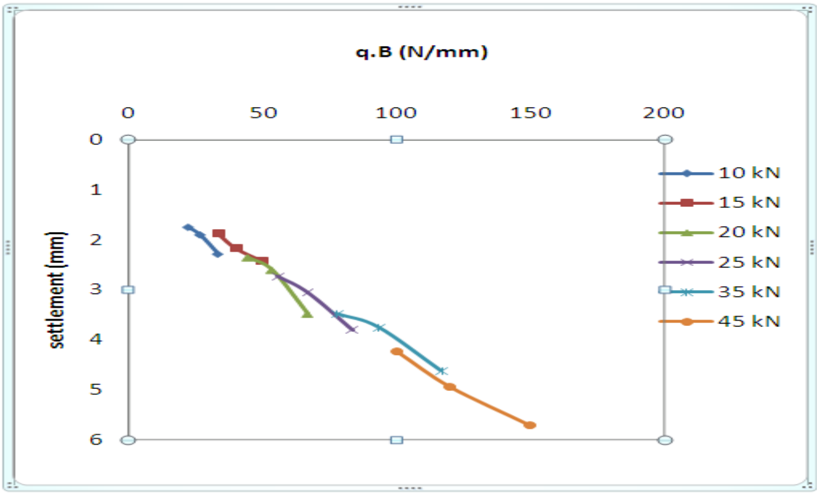

Fig. 7 Plot of S_i v/s q.B for all loads

It is observed from Fig. 7 that, variation of S_i with respect to q.B is almost straight line (linear). It is observed that slope of all the lines is almost same i.e. for various load values the modulus of elasticity remains the same. Thus, for experimentation any convenient load/pressure intensity can be used to obtain the modulus of elasticity.

Effect of Poisson's Ratio

From the literature it is revealed that, the Poisson's ratio of sand varies from 0.3 to 0.45 [5]. To understand the variation of modulus of elasticity with respect to Poisson's ratio, the Es value is calculated for Poisson's ration μ in the range of 0.3 to 0.46. Influence factor (I_f) is taken as 0.9 for the rigid square plate [6]. Table 5 gives the values of modulus of elasticity for different values of μ.

Table 5 Es value for different Poisson's ratios

Load (kN)	10	15	20	25	35	45
Slope= $\left[\frac{1-\mu^2}{E_s}\right] I_f$	0.3290	0.0333	0.0400	0.0333	0.0360	0.0360
Poisson's Ratio (μ)	Es (MPa)					
0.30	24.89	24.82	20.48	24.59	22.75	22.75
0.32	24.55	24.48	20.20	24.26	22.44	22.44
0.34	24.19	24.12	19.90	23.90	22.11	22.11
0.36	23.81	23.74	19.58	23.52	21.76	21.76
0.38	23.41	23.33	19.25	23.12	21.39	21.39
0.40	22.99	22.91	18.90	22.70	21.00	21.00
0.42	22.53	22.46	18.53	22.26	20.59	20.59
0.44	22.06	21.99	18.14	21.79	20.16	20.16
0.46	21.57	21.50	17.74	21.31	19.71	19.71

From Table 5, it is observed that for different values of μ, modulus of elasticity does not change very much. The modulus of elasticity of sand is in the range of 20 to 24 MPa. This variation is almost 16 %. The range of modulus of elasticity of sand as per literature is 10 to 25 MPa [2]. Therefore, it can be said that Es value which is experimentally determined confirms the range given in the literature for the soil under consideration.

IV. Conclusions

Plate load test on field requires reaction loading system on site which is time consuming and difficult task and also it is more cumbersome. Present study advocates the laboratory test is reasonably accurate and less cumbersome. From this study it is proved that, the loading frame can be used to develop the reaction loading system in the laboratory to perform the plate load test under much controlled conditions.

The elastic modulus obtained in the laboratory using plate load test is in the range 20 to 24 MPa. This value is reasonably confirming with the range of modulus of elasticity mentioned in the literature (Bowles).

Study reveals that, for different values of Poisson's ratio of sand (0.3 to 0.45), modulus of elasticity varies between 14 to 16 %. This variation is marginal. Hence, it can be inferred that Poisson's ratio is not significantly affecting the modulus of elasticity.

This method of evaluation of modulus of elasticity of sand in the laboratory using plate load test analogy is reasonably accurate than the cumbersome method of tri-axial where the major difficulty is the preparation of sample of sand.

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