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Evaluation of Elastic Modulus of Soil Using Incremental Cyclic Loading Test

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***Abstract*— Modulus of elasticity is an important soil property for elastic settlement analysis of foundations and determination of dynamic soil properties. The aim of this study is to evaluate the modulus of elasticity of soil by conducting incremental cycle loading laboratory testing. The results of laboratory plate load tests on sand bed under incremental loading and unloading conditions for different densities of soil are presented in this study. The elastic modulus of soil is determined using coefficient of elastic uniform compression. As the density of the soil is increased the coefficient of elastic uniform compression and modulus of elasticity increase significantly due to the substantial increase in the soil stiffness.**

***Index Terms*—coefficient of uniform compression, elastic modulus, incremental cycle loading, plate load tests.**

I. INTRODUCTION

Elastic modulus or Young's modulus (E) is a deformability parameter for the soil. It denotes the linear elastic behaviour of the soil and represents resistance against elastic deformation under loading. The elastic modulus of soil is used for evaluating the immediate settlements for all type of foundations. For cohesionless soil elastic modulus is significant parameter for evaluating the allowable capacity of foundations, based on settlement criteria [1]. Also the elastic modulus is considered to be one of the key soil property for describing the behavior of soil under dynamic loading [2]. Hence, estimation of modulus of elasticity of soil is very important.

The objective of the present study is to estimate the elastic modulus of soil by conducting incremental loading and unloading plate load tests on sand bed using coefficient of elastic uniform compression (Cu). To investigate the effect of density on the elastic modulus of soil, tests were conducted at varying soil densities. The dynamic properties of soil, such as coefficient of elastic uniform shear Cτ, coefficient of elastic non-uniform shear Cψ and coefficient of elastic non uniform compression Cφ are also determined from the test results.

II. BACK GROUND OF THE STUDY

Elastic modulus of soil can be estimated using empirical correlation, field tests and laboratory tests. Studies have established correlations for estimating the elastic modulus with S.P.T, CPT values etc.[3],[4]. Field tests for determination of modulus include plate load test and the pressure meter test [5][6]. Triaxial compression tests is used as a laboratory method to estimate the soil modulus, though with the disadvantage of difficulties in sample preparation, time consuming test procedure etc. [7]

In this study the elastic modulus of sand is determined from the incremental cycle loading test results using coefficient of elastic uniform compression. Cu is defined as the ratio of uniform pressure imposed on the soil to the elastic settlement [8].

$$Cu = p/\delta \qquad (1)$$

where p is the bearing pressure (load per unit area, kN/m^2) and δ is the elastic settlement (m)

Modulus of elasticity E is related to Cu and thus E can be determined as given below,

$$E = Cu\,(1 - \mu^2)\sqrt{A}\,/1.13 \qquad (2)$$

where μ is the Poisson's ratio (assumed to be 0.25 for sandy soil), and A is the area of load plate.

The Coefficient of elastic uniform compression (Cu), coefficient of elastic uniform shear (Cτ), coefficient of elastic non uniform compression (Cφ), coefficient of elastic non uniform shear (Cψ) are related to each other as given below [9]

$$C\tau = Cu/1.75 \quad (3)$$
$$C\varphi = 3.46\, C\tau \quad (4)$$
$$C\psi = 1.5\, C\tau \quad (5)$$

III. EXPERIMENTAL PROGRAMME

A series of incremental loading and unloading cyclic plate load tests were conducted on prepared sand beds as per IS: 5249:1992 [9]. The precalculated weight of sand was filled in the test tank, as per required density by depositing soil in equal layers. The tests were conducted at soil densities of 1600 kg/m^3 ,1650 kg/m^3 and 1700 kg/m^3.

A. Materials

Locally available river sand was used in the experiments as the test soil. The properties of sand are presented in Table I and the soil is classified as poorly graded sand (SP).

Table I Properties of soil used for testing

Properties	Values
Specific gravity	2.65
Minimum density (kg/m^3)	1550
Maximum density (kg/m^3)	1750
Clay (%)	0
Silt (%)	2
Sand (%)	98
Coefficient of uniformity	2.90
Coefficient of curvature	0.90

B. Test Set up

The test set up used in this study consists of a loading frame, a test tank, loading plate and loading arrangement. A steel test tank of inner dimensions 1m×1m×1m was used for conducting the experiments. Stiffeners were provided on the outer side of the tank, to make it rigid. A mild steel square plate of size 20 cm was used to apply load on the soil bed.

The vertical compressive load was applied to square plate through a hydraulic jack of 100kN capacity, which was supported centrally at the bottom flange of the steel girder made of channel sections.

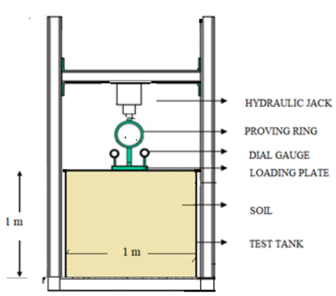

Figure 1 – Schematic diagram for test setup

It was operated manually by a hydraulic pump. The load was transferred to the model through a proving ring which was fixed on the bottom of jack and the model footing was connected to the proving ring through a loading platform. Settlement of model footing was measured using dial gauges. The schematic view of the experimental set up is given in Fig. 1.

C. Tests Procedure

Cyclic plate load tests were conducted on sand beds at varying densities. The cyclic plate load tests were conducted by applying a predetermined vertical load increment which was maintained until the increase in the settlement of the footing became negligible. The vertical settlement was measured by averaging out the values observed from dial gauges and the load value was recorded from the proving ring. The applied load was then reduced to zero and the corresponding elastic rebound of the footing was recorded. The cycles of loading, unloading and reloading is continued till the until the sand bed showed large settlements.

IV. RESULTS AND DISCUSSIONS

Fig. 2 shows the load vs settlement curves at varying soil densities for loading, unloading and reloading cycles for each load increment. It can be noted that as the density of the soil increases, there is decrease in the total as well as elastic settlement values which is attributed to higher stiffness of the soil due to the increase in density.

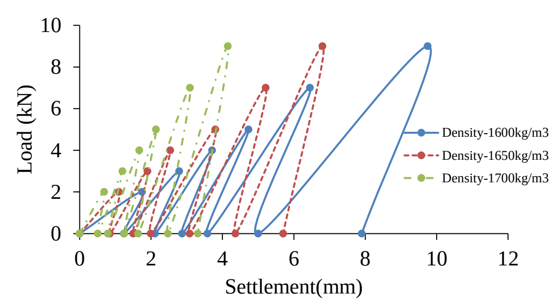

Figure 2 - Load-settlement curves for soil under cyclic loading

Fig. 3 shows the elastic rebound of the footing on sand corresponding to each load intensity at varying densities of 1600kg/m^3, 1650 kg/m^3 and 1700 kg/m^3. The coefficient of elastic uniform compression, Cu is obtained as the slope of the load intensity vs elastic settlement plots. As density increases, the there is a reduction in elastic settlement and the coefficient of uniform compression increases significantly.

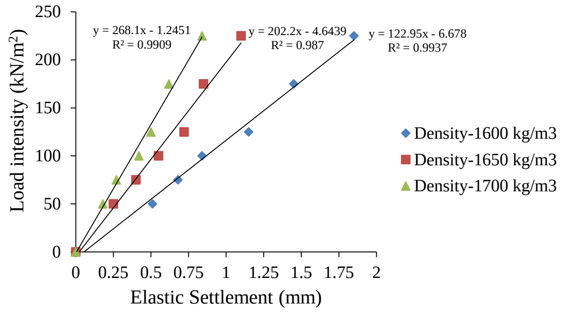

Figure 3 – Load intensity vs elastic settlement curves for soil for different densities

Elastic modulus is obtained from Cu using equation 2. From table II, it can be observed that the increase in the density of soil bed leads to the increase in coefficient of elastic uniform compression(Cu) of sand and corresponding increase in elastic modulus of soil. The coefficient of elastic uniform compression increases from 122950 kN/m^3 at density 1600 kg/m^3 to 268100 kN/m^3 at density of 1700 kg/m^3.Similarly the elastic modulus of soil increases from 20401 kN/m^2 to 44485 kN/m^2 with percentage increase of 118.1 % as the soil relative density is increased from 27 % to 77%. The increase in the elastic modulus at higher density is attributed increase in soil stiffness as density is increased.

Table II Cu and E of soil at different soil densities

Relative Density	Density of soil kg/m^3	Coefficient of elastic uniform compression Cu (kN /m^3)	Elastic modulus (E) kN/m^2
27%	1600	122950	20401
53%	1650	202200	33550
77%	1700	268100	44485

The value of other dynamic properties such as coefficient of elastic uniform shear (Cτ), coefficient of elastic non uniform compression (Cφ) and coefficient of elastic non uniform shear (Cψ) can be calculated from the value of Cu. The table III tabulates the values of dynamic properties obtained for the soil at various densities.

Table III Values of Cu, Cτ, Cφ, Cψ of sand bed at different densities

Density of soil kg/m3	Cu kN /m3	Cτ kN /m3	Cφ kN /m3	Cψ kN /m3
1600	122950	70257	243090	105386
1650	202200	115543	399778	173314
1700	268100	153200	530072	229800

V. CONCLUSIONS

From the study it can be noted the incremental cyclic loading test can be effectively used for determination of elastic modulus of soil. Following conclusions were made from the study.

1. Under incremental cyclic loading conditions, there is a decrease in the total and elastic settlements, as the density of soil is increased.
2. The coefficient of elastic uniform compression of the soil increases from 122950 kN/m^3 at density 1600 kg/m^3 to 268100 kN/m^3 at density of 1700 kg/m^3.
3. The elastic modulus of the soil increases from 20401 kN/m^2 to 44485 kN/m^2 with percentage increase of 118.1 % as the soil relative density is increased from 27 % to 77%.
4. The values of dynamic properties of the soil Cτ, Cφ and Cψ increase with the increase in the density of the soil medium.

REFERENCES

[1] L. Pantelidis and E. Gravanis, Elastic Settlement Analysis of Rigid Rectangular Footings on Sands and Clays, *Geosciences*,10(12),491,pp.1-18,2020.

[2] A.H. Hammam and M. Eliwa, Comparison between results of dynamic & static moduli of soil determined by different methods, *HBRC Journal*, Volume 9, Issue 2, pp. 144-149, 2013.

[3] M.Farzi & A.Saligheh Zadeh, Determination of relationship between standard penetration test and geotechnical parameters in Ahwaz soil, *Geomechanics and Geoengineering*, 16(6), pp.421-433,2021

[4] H. Denver, Modulus of elasticity for sand determined by SPT and CPT, *In Penetration Testing*, Routledge 2021, pp. 35-40.

[5] Joseph E. Bowles, *Foundation Analysis and Design*, McGraw-Hill,1997, pp.343.

[6] M.G. Kalyanshetti, S.A.Halkude, D.A.Magdum, & K.S.Patil, Estimation of Modulus of Elasticity of Sand Using Plate Load Test, *American Journal of Engineering Research (AJER)*, Volume-4, Issue-8, pp-244-249,2015.

[7] Nandanwar, R. Mukta and Ying Chen, Simulations of triaxial compression test for sandy loam soil using PFC3D.*Montreal, Quebec*

Canada. American Society of Agricultural and Biological Engineers, 2014.

[8] Putri, Elsa Eka, N. S. V. K. Rao, and M. A. Mannan,Evaluation of the modulus of elasticity and resilient modulus for highway subgrades *Electron J Geotech Eng*, 15 pp.1285-1293. 2010

[9] IS.5249:1992, Indian Standard Method of Test for Determination of Dynamic Properties of Soils, BIS, New Delhi, India.