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Estimation of the Coefficient of Subgrade Reaction using Small-Strain Stiffness

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ABSTRACT

Subgrade reaction modulus (K_s) is a conceptual relationship between soil pressure and deflection, which is widely used in structural analysis of various foundations. Values of K_s are assessed by relating them to intrinsic parameters of soil such as elastic modulus (E_s) and California bearing ratio (CBR). The small-strain stiffness (G_{max}) is a fundamental soil parameter, applicable to all types of geomaterials for static and dynamic loading. In-situ direct estimation of maximum stiffness or G_{max} of soil are more accurate and reliable than the stiffness derived from resistance-based correlation or laboratory tests. This paper has provided a new method to estimate K_s based on G_{max}. In order to validate the proposed method, results of the survey of loading tests and seismic geophysical tests of several sites were evaluated and compared. The results indicated that the proposed method in this study could be effectively used to predict the K_s of granular soils. This is much more accurate than the predictions of conventional methods.

KEYWORDS

Granular Aoil, Small- Strain Stiffness, Surfacial Foundation, Modulus of Elasticity.

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1-INTRODUCTION

Soil bearing capacity and coefficient of subgrade reaction are some various measures of strength-deformation properties of soil. To perform the structural analysis of footings one must know the principles of evaluating the coefficient of subgrade reaction “ks”. The coefficient of subgrade reaction ks is the ratio between the pressure “q” at any given point and the settlement “s” produced by load application at that point.

The calculation of ks is a function of soil parameters such as the modulus of the soil (E_s) and Poisson’s ratio of soil (ν_s). The value of E_s can be obtained from the in situ testing such as plate load test and field-test drilling such as SPT, CPT and pressuremeter testing.

In often, the mentioned methods overpredict coefficient of subgrade reaction. Seismic wave velocity measurements have been used to characterize in-situ soil and rock stiffness's for use in the evaluation of the response of geotechnical sites to earthquake loading and machine vibrations. The velocity of propagation of a shear wave (V_S), which can then be converted to the shear modulus at small strains (Gmax), and finally to Young's modulus at small strains (Emax).

$$G_{max}=\rho.V_s^2 \qquad (1)$$

Where ρ = mass density of the soil.

$$E_{max}=2(1+\upsilon)G_{max} \qquad (2)$$

Where: ν = Poisson’s ratio (0.15-0.35 for unsaturated cohesionless soils). In-situ direct estimation of maximum stiffness or small-strain stiffness (Gmax or Emax), of soil is more effectively and reliably than those derived from resistance-based correlation or laboratory testing.
In this paper, we investigated how to utilize the small-strain stiffness order to estimate the coefficient of subgrade reaction of shallow foundation on granular soils. For this purpose, a power law equation between normalized shear modulus and shear strain was presented. Based on elasticity theory and proposed equation, a new method in term of small-strain stiffness was suggested order to estimate ks. In order to evaluate the proposed method, a series case history was studied, that included the loading tests and seismic geophysical tests. These field measurements are compared to the predicted values. The result indicated that the proposed method in this study can be effectively used to predict the ks of footing on granular soils and that were more accurate than the SPT or CPT based predictions.

2-METHODOLOGY, DISSCUTION AND RESULTS

Based on the measured small-strain stiffness and elasticity theory, a new method has been developed which uses these values to calculate Young’s Modulus, E, at the practical strain levels experienced in actual foundation conditions and so enables ks to be predicted.

The settlement of foundation is obtained by multiplying the calculated strain in the soil layer thickness. The soil layer thickness considers from the bottom of the footing to a depth of 2B below the footing. Hence, the vertical stress at the centre of the layer at depth equal to B below the footing, σ_z, is then calculated from the Boussinesq formula. Coefficient of subgrade reaction k_s, can be calculated from the ratio between “q” load and the “s” settlement by the eq(3):

$$K_s=\frac{q}{S}=\frac{q}{\left(\frac{392.36(1-2\upsilon K_0).\left(\sqrt{1+\upsilon}\right).q}{E_{\max}}\right)^2.\frac{B}{50}} \qquad (3)$$

Where s= settlement, q= load, K_o= horizontal stress coefficient at rest, υ= Poisson’s ratio of soil and B= diameter of footing.
In order to evaluate the accuracy of the proposed method in this paper, eq. (3), to estimate ks, a database of 14 load tests on footings and large plates from three sites was compiled, as summarized in Table 4.
A comparison between the metods of prediction the ks is shown in Fig. 1. This can be confirmed the more accuracy of the proposed method than the other methods.

3-CONCLUSION

In the present study, estimation of the coefficient of subgrade reaction of circular footings on granular soils was investigated based on shear wave velocity (Vs) and the shear modulus at small strains (G_{max}), and Young’s modulus at small strains (E_{max}).
The advantage of using a real soil property (such as Emax) in ks predictions/analyses, field seismic measurements make it possible to provide information about a whole site much more accurately than can be obtained with point measurements in soil borings or soundings. The seismic measurements have considerable advantage of being made in situ on undisturbed soil.
The soil behavior is non-linearity and the stiffness of soil reduced with increasing the strain level.

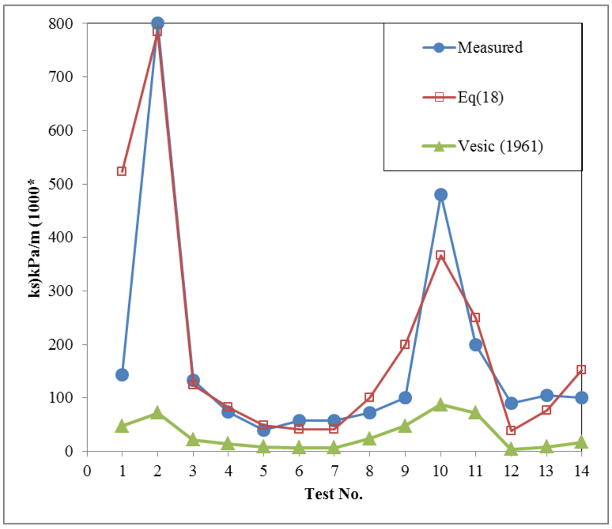

Fig. 1. Comparison of the predicted and measured ks in 200 kPa pressure

For this purpose, we presented a power law formula to predict the variations of stiffness according to strain level. Based on theory of elasticity and the proposed formula, a new method was developed in term of small-strain stiffness in order to estimate the coefficient of subgrade reaction of footing.

In order to validate the proposed method, the results of the survey of loading tests in four sites were evaluated and compared. Appropriate coincidence between the result of loading test and predicted ks, shows the accuracy of proposed method in comparison to other methods. In general, predictions based on in situ parameters from seismic measurements are closer to measured ks under service loads.

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