Verification of modulus of subgrade reaction experimental based on plate deflection

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Abstract. This study aims to verify the modulus of subgrade reaction test results of the plate load test or empirical formula based on the deflection of the finite element analysis results that are closest to the deflection of the concrete plate loading test results in the laboratory. Modulus of subgrade reaction experimentally obtained from the plate load test results. While the modulus of subgrade reaction using an empirical formula, according to FEMA 356, is calculated using an equation that is influenced by the value of the shear modulus, Poisson ratio, and plate dimensions. The method in this study is analysis and experimental. The verification is carried out by finite element analysis by adjusting the dimensions and parameters of the material with an experimental model for loading concrete plate in the laboratory. Verification of the modulus of subgrade reaction carried out by looking at the deflection of the finite element modeling, which is the closest to the deflection of the experimental results of loading concrete plate in the laboratory. The modulus of the verified subgrade reaction is the value obtained based on the empirical formula because it has almost the same deflection compared to the experimental soil modulus value.

1. Introduction

The modulus of subgrade reaction can be obtained from the results of tests and empirical formulas in this study, verifying which modulus value is the closest to the modulus of subgrade reaction based on the deflection of the concrete plate test in the laboratory to ensure its reliability. The modulus of subgrade reaction defined strength of the subgrade. It is one of the main factors for evaluating the properties of subgrade and representing soil behavior that supports structures with elastic springs [1–5]. Modulus of subgrade reaction is a mathematical constant that represents soil stiffness, which defined as the ratio of pressure to decrease at a certain point [6] and is one of the most efficient parameters used for structural analysis of the foundation [7,8]. The modulus of subgrade reaction is not a soil constant but depends on many factors such as the dimensions of the structure, soil conditions, load levels, and the stiffness of the upper structure [9,10].

The modulus of subgrade reaction can be determined by using an empirical formula or by an experimental method based on a load plate test [11,12]. The plate load test is one of the fast, direct, and economical methods [13]. This theoretical model must be validated by field experiments to ensure its reliability, especially those related to engineering problems [14]. Software analysis (finite element
method) validated by field experiments. Analytical solutions compared to finite element solutions, which finally validated against the results of laboratory experiments [15]. Verification analysis is done by adjusting the dimensions and parameters of the material with the experimental testing model.

This study aims to ensure the reliability of the modulus subgrade reaction value through the verification analysis of the modulus subgrade reaction value obtained from the load plate test results and empirical formulas. Verification based on the deflection of the finite element analysis results with two models of the modulus subgrade reaction as input data, then the deflection output is the closest to the deflection of the concrete plate test results in the laboratory.

2. Methods

The method used in this study is the finite element method analysis and experimental testing in the laboratory. Plate load testing needs to be done in the field, but there are some difficulties in making it happen. Therefore laboratory-scale testing can be done [16]. A plate load test performed on soft soil in a laboratory-scale concerning AASHTO T 222-81.

Soft soil material used comes from the Gedebage area, Bandung. Tests carried out on soil whose water content matches the original conditions in the field. This laboratory-scale testing uses steel box media measuring 1000 mm $\times$ 1000 mm $\times$ 1000 mm. Plate load test using a steel plate with a diameter of 304.8 mm, which was loaded using the OPT hydraulic pump. The plate load test in the laboratory-scale can see in Figure 1.

Based on AASHTO T 222-81, the modulus of the experimental soil reaction is obtained from the value of the pressure ratio when 69 kN/m$^2$ with a deflection that occurs, obtained using Equation 1. While the modulus of the subgrade reaction method using the empirical formula, according to FEMA 356, is calculated using Equation 2, which is affected by shear modulus values, Poisson ratios, and plate dimensions.

The process of verifying the value of the modulus of subgrade reaction is carried out by the finite element analysis method by adjusting the dimensions and parameters of the experimental test model material loading of concrete plates in the laboratory. The loading system in finite element modeling is assumed to use a joint load. The soil modeling used is assumed to be elastic support modeled with spring support, and the concrete plate modeled as a shell element. Spring stiffness value used is the modulus of subgrade reaction.

Concrete plates measuring 700 mm $\times$ 100 mm $\times$ 30 mm with a load placed at the end of the plate can see in Figure 2. Concrete compressive strength of 23,42 MPa and elastic modulus of 22743,72 MPa.
Verification of the modulus of subgrade reaction was done by looking at the deflection value of the finite element modeling, which is the closest to the deflection value of the experimental results of loading concrete plates in the laboratory. The deflection value of the concrete plate experimental results used as a reference.

\[ k = \frac{69}{\delta} \]  
\[ k = \frac{G B}{1-v} \left[ 1.55 \left( \frac{L}{B} \right)^{0.75} + 0.8 \right] \]

\( k \): modulus of subgrade reaction \((\text{kN/m}^2/\text{m})\)
\( \delta \): settlement \((\text{m})\)
\( G \): shear modulus \((\text{kPa})\)
\( B \): plate width \((\text{m})\)
\( v \): Poisson’s ratio
\( L \): plate length \((\text{m})\)

**Figure 2.** The load positions.

### 3. Results and discussion

The modulus of subgrade reaction based on the results of the load plate test is 2179.24 kN/m²/m. While based on the FEMA 356 empirical formula, the modulus of the subgrade reaction is 22419.21 kN/m²/m.
These values used as input data for finite element analysis and the output is deflection. This deflection compared to the deflection of the concrete plate test results in the laboratory, as illustrated in Figure 2. The results of the verification analysis of the modulus of subgrade reaction can see in Table 1.

Table 1. The results of plate load test.

| Condition                      | Dial 1 | Dial 2 | Dial 3 | Dial 4 | Dial 5 | Dial 6 |
|-------------------------------|--------|--------|--------|--------|--------|--------|
| Plate                         | 0.640  | 0.400  | -0.003 | -0.400 | -1.000 | -1.700 |
| Finite Element Method         |        |        |        |        |        |        |
| \( k_{\text{plate load test}} \) | 8.818  | 3.841  | -1.181 | -6.298 | -11.555 | -16.972 |
| \( k_{\text{empiric}} \)      | 0.656  | 0.345  | -0.002 | -0.421 | -0.950 | -1.635 |

Data from Table 1 then made into a graph between the deflection in each dial on the concrete plates, which can see in Figure 3.

Figure 3. Results of verification analysis of modulus of subgrade reaction.

In Figure 3, it can see that the modulus of the empirical subgrade reaction has the line closest to the plate load test line in the laboratory compared to the experimental subgrade reaction modulus line. Therefore, the verified modulus of the subgrade reaction is the value obtained based on the empirical formula. The modulus of subgrade reaction is a mathematical constant that represents soil stiffness, which defined as the ratio of pressure to settlement at a certain point \([6]\). Based on this explanation, the reliability of the modulus of the subgrade reaction from the empirical formula can ascertain.
4. Conclusion
The theoretical model of the modulus subgrade reaction is verified by experimental testing to ensure its reliability, based on the deflection. The verified modulus subgrade reaction is the modulus of the empirical formula because it has the deflection closest to the deflection of the concrete slab test results in the laboratory.

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References
[1] Salari P, Moghaddas N H, Lashkaripour G R and Ghafoori M 2020 Evaluating the Subgrade Reaction Modulus Variations with Soil Grains Shape in Coarse-Grained Soils Using Genetic Algorithm Open J. Geol.
[2] Walkenbach T N, Han J, Li Z and Parsons R L 2019 Evaluation of Composite Subgrade Reaction Modulus of Geosynthetic-Stabilized Recycled Subbase over Subgrade Geotechnical Special Publication
[3] Saha S, Gu F, Luo X and Lytton R L 2019 Parametric Study of Modified Subgrade Reaction Model Using Artificial Neural Network Approach Geotechnical Special Publication
[4] Poulos H G 2018 Rational assessment of modulus of subgrade reaction Geotech. Eng.
[5] Zafirah A, Somantri A K, Permana S and Roestaman R 2019 Study of PVD effect on modulus of subgrade reaction Journal of Physics: Conference Series
[6] Lee J and Jeong S 2016 Experimental study of estimating the subgrade reaction modulus on jointed rock foundations Rock Mech. Rock Eng.
[7] Shah M V. and Chhatbar D H 2017 Subgrade reaction and load settlement characteristics of alluvial soil deposits by plate load test Proceedings - IACMAG 2017, 15th International Conference of the International Association for Computer Methods and Advances in Geomechanics
[8] Zumrawi M and Awad M 2017 Estimation of Subgrade Resilient Modulus from Soil Index Properties World Acad. Sci. Eng. Technol. Int. Sci. Index 129, Int. J. Environ. Chem. Ecol. Geol. Geophys. Eng.
[9] Farouk H and Farouk M 2015 Validation of using modulus of subgrade reaction to consider the soil structure interaction AEI 2015: Birth and Life of the Integrated Building - Proceedings of the AEI Conference 2015
[10] Barounis N and Philpot J 2018 Estimation of the static vertical subgrade reaction modulus k_s from CPT Cone Penetration Testing 2018 - Proceedings of the 4th International Symposium on Cone Penetration Testing, CPT 2018
[11] Naeini S A, Moayed R, Kordnaej A and Mola-Abasi H 2018 Prediction of Subgrade Reaction Modulus of Clayey Soils using Group Method of Data Handling Sci. Iran.
[12] Avci B and Gurbuz A 2018 Modulus of subgrade reaction that varies with magnitude of displacement of cohesionless soil Arab. J. Geosci.
[13] Al-Obaidi Q, Al-Shamoosi A and Ahmed A 2017 Evaluation of soil bearing capacity by plate load test Bearing Capacity of Roads, Railways and Airfields - Proceedings of the 10th International Conference on the Bearing Capacity of Roads, Railways and Airfields, BCRRA 2017
[14] Zhai W and Zhai W 2020 Experimental Validation of Vehicle–Track Coupled Dynamics Models Vehicle–Track Coupled Dynamics
[15] Akrouch G A, Sánchez M and Briaud J L 2016 An experimental, analytical and numerical study on the thermal efficiency of energy piles in unsaturated soils Comput. Geotech.
[16] Dhowian A W 2017 Laboratory simulation of field preloading on Jizan sabkha soil J. King Saud Univ. - Eng. Sci.