Journal of Civil Engineering and Structures

Journal homepage: www.journalces.com

Original paper

Estimation of the subgrade reaction modulus using field and numerical analysis methods

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ARTICLE INFO

Article history:
Received 2 February 2024
Accepted 26 February 2024

Keywords:
Subgrade reaction coefficient
Plate loading experiment
Numerical modeling
Vesic equation

ABSTRACT

Subgrade soil's reaction coefficient is of high importance in designing superficial structures. Different researches have been made in determining ultimate bearing capacity of shallow foundations. The ultimate bearing capacity of shallow strip footings is generally determined (Terzaghi, 1996). Especially in metropolises, the increase in the number of building stories and subsequently increase in loading measure on underlying soil makes this matter more important. So far various methods have been applied to estimate the suitable level of this coefficient which most substantial ones include various empirical relations, types of numerical modeling and using field experiments. In present study the value of this coefficient for the soil of Fereshteh alley district in Tabriz has been determined through various empirical and numerical ways and field experiments of plate loading and in the end an equation has been provided to estimate the subgrade soil's reaction coefficient.

DOI: https://doi.org/10.21859/jces.8146

1. Introduction

Foundations are one of the most important geotechnical structures that their task is to transfer loading from the structure to sub layers. This has led to high sensitivity in determining the reaction coefficient between soil and foundation. Lack of accurate estimation of soil subgrade reaction coefficient (Ks) causes many problems in geotechnical designs and requires designers to be careful enough. The relationship between the modulus of the soil (Es) and the reaction modulus (ks) is linear for the Me´nard and Vlassov models, and non-linear for the Vesic and Biot models [1]. The modulus of subgrade reaction implies the elastic behavior of the soil under loading by flexible foundation. This parameter is generally defined by the results of plate load test as follows:

$$K_s = \frac{q}{s} \tag{1}$$

This parameter is generally determined using the plate load test and based on ASTM D1194 standard [2]. In metropolises, due to the increase in construction density and the increase in the number of structural floors, the need for accurate estimation of this coefficient and the introduction of a method and a relationship to select the appropriate amount of it seems necessary. Due to the significant effect of geotechnical characteristics of each building on the amount of Ks, the present study has been done focusing on Fereshteh Alley in Tabriz as one of the densest areas of the city and has special geotechnical characteristics. Numerous researchers have studied and presented an approximate relationship for the Ks coefficient, each of which has its own specific conditions and properties to be studied. Here is an example of some of the most important studies conducted in this field. Biot presented an experimental relationship for the modulus of subgrade reaction wherein the mentioned coefficient depends on elastic parameters, stiffness of the loaded beam and the underlying soil [3]. Vesic' has studied the geometric effect of loading on the modulus of subgrade

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Please cite this article as: Khaiiatali, S., Rezaei Farei, A. H., Zaman, A. and Ahmadiadli, M. (2024). Estimation of the subgrade reaction modulus using field and numerical analysis methods. *Journal of Civil Engineering and Structures*, 8(1), pp.1-7

reaction. In order to investigate the subgrade reaction coefficient (Ks) for surface foundations on soil, the researcher focused on using plate loading experiment with 25mm thick metal plates with diameters of 15, 30, 45 and 60cm by a jack with hydraulic pump with capacity of 100 tons at the end of 4 screen well with various dimensions and diameters of 2 and 3 meters. After obtaining the results, they observed that with increasing plate size, they face a decrease in reaction coefficient. They also found that with increasing width of foundations, they also face a decrease in reaction coefficient. The reason is the increase in stress bubbles and consequently the increase in the amount of subsidence. Also by conducting field experiments of (PLT) and (SPT) on Qazvin's (CL) and (CH) alluvial soil, they have calculated the subgrade reaction modulus (Ks) and (Es) [4]. In this article, they have used 170 different areas for field experiments and finally have approached the subject of proper and proportional relationship between subgrade soil coefficients. Also in this article, the values of (Ks) and (SPT) for the soil of southern Qazvin, which includes clay soils with low plasticity, are used and various methods such as balloon method and other physical and mechanical tests and Atterberg limits test have been applied to determine geotechnical properties. In this study, in the (PLT) method, the plate is located in the center of the borehole and the load is entered on the plate in steps equal to 20-25% of the estimated final load and the results are processed through the electronic system. Based on the results obtained from experiments (SPT) and (PLT) it has been proven that with increasing (SPT), the modulus of plasticity also increases, which is in accordance with the correlation relationships proposed by other researchers. Khodaparast in his research, has used the geotechnical results of 6 different points of Qom city to obtain the correct results of subgrade soil coefficient. To design the foundation, they used a two-way strip foundation system and the coefficient of reaction for different widths, using the Terzaghi and Bowles relationships and the results of in-situ loading experiments [5]. They have concluded that, as the width of the strip foundation increases, the value of the subgrade soil coefficient increases, especially in soils with high rigidity. The study conducted by researcher investigated the results of plate loading on cement soil in northern Tehran [6]. For this evaluation and estimation of the in-situ modulus of the alluvial soil of the region, PLT and SPT experiments as well as triaxial experiments have been performed in 75 points of the region and the results of PLT and SPT experiments are discussed and analyzed, and based on this, a modified correlation is obtained between the standard penetration test number (N) and the subgrade reaction coefficient parameter (Ks) as well as the modulus of soil elasticity (Es). In this study, the theoretical relationships presented by researchers in the last century have been used and compared with field results. Finally, the linear theoretical relationships for the soil of the region to calculate (Ks) and (Es) have been attained based on the results of field experiments so it is expected that the values of (Es) and (Ks) increases with increase in number of (SPT).

In another study, studied comparative methods for determining the subgrade soil reaction coefficient and without field experiments, tried to estimate the value of this coefficient based on the theories of researchers and numerical software on the marl soil of Tabriz. Based on the obtained results, it has been shown that the soft soil behavioral model is the best soil model in the region for numerical analysis and theory (Vesic) obtains a more appropriate estimate for the region soil and also due to the geometric and mechanical layer properties of the region soil, general elastic modulus has been put into use. calculated the modulus of reaction in the rigid system and concluded that the Winkler model is not able to be affected by the elastic and plastic properties of soils [7]. For this reason, using the Mohr Columbus linear model, they have presented the calculation of Ks coefficient in their research. It has also been pointed out in this study that the rigidity of foundation and soil systems has a significant effect on the calculation of subgrade coefficient which is affected by dimensions and materials. They have shown in their results that the range of the reaction coefficient is not homogeneous and has required them to make different calculations at the corners of the foundation. Other results include the need for nonlinear calculations to obtain the subgrade coefficient results obtained from the results of plate loading experiments, with the difference that the foundations have more flexible sections than the sections of loading plates. Imanzadeh, conducted a study on soil and structural parameters in order to investigate the factors affecting the uncertainty of the subgrade reaction module. They showed that soil hardness had the greatest effect on determining the uncertainty of the subgrade modulus and changes in instrument parameters relative to soil stiffness had less effect on the modulus of reaction. In other words, the coefficient of variation, Ks, has a linear relationship with changes in soil stiffness [1].

Drumm, calculated the modulus of reaction based on standard experiments [8]. They examined the problems of approximate methods and showed that most of the results are based only on shear strength and will have errors. They presented their results around 11 different soils and collected the responses of different soil types. Considering the background and results of similar studies, it is clear that previous studies have been based solely on one of the study methods and on the soil studied in the test area that this study has tried It is to eliminate the shortcomings of the work done, including not comparing the numerical, field and analytical results in the form of a research, and also this study is a case study of the soil of Tabriz that no research has had an extensive study in the case soil of Tabriz.

2. Research Methodology

Applying scientific methods in research is the only way to achieve acceptable scientific achievements. Therefore, methodology is needed to conduct valid research. Methodology makes research systematic, logical, and principled, as well as strategic scientific research. The basis of any scientific method is to recognize the validity and value of the achievements of research that this research, by validating the results obtained, has a seal of approval on the results.

In this study, which was performed on soils with specific geotechnical conditions, the results of field experiment of loading the plate in the desired soil were collected and using analytical methods and numerical modeling by valid geotechnical software and foundation design such as Plaxis and Abaqus, also, comparing with the relationships presented by previous researchers in various articles and books, we have tried to reach a reliable relationship as well as a suitable method for estimating the coefficient (Ks) of the soil of the studied areas.

3. Geotechnical properties of this study

At the test site, first a machine borehole with a depth of 15 meters and a 1 meter borehole were drilled manually. During the drilling, at the same time with the in-site inspections, the samples of Figure 1 were taken from different depths and packed properly and transferred to the laboratory for various physical and mechanical tests.

Fig 1. Samples of tested soil.

By referring to the logs obtained in the laboratory, it is possible to show the SPT changes in depth for the study area according to Figure 2.

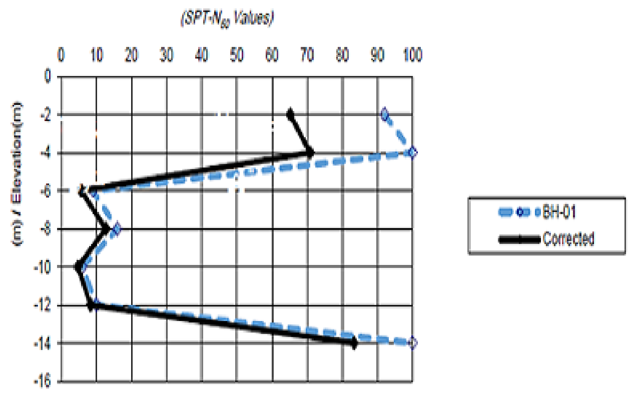

Fig 2. SPT changes in depth for samples extracted from the study area.

As can be seen in Figure 2, despite the upward changes in the SPT to a depth of 5 m, these numbers have dropped sharply to a depth of 5 to 13 m. Therefore, referring to the same data, it is possible to imagine N = 1 = 8 for the loose soil layer from a depth of 5 to 13 meters and N = 1 3 5 for the bottom layer at a depth of 13 meters as the average SPT number. Also, according to laboratory data, the properties of the layers can be used as Table 1 in 4 different layers. Which has also been applied in numerical modeling. The soil of the test area consists of four soil layers with different geotechnical properties. It should be noted that the soil located at a level above half a meter from the ground has been tampered with and the loading test has been performed from a level of half a meter above the ground. Under the soil, up to a depth of 5 meters, a fine-grained layer with sand grains can be seen, which has a suitable relative density. From a depth of 5 m to a depth of 13 m, very loose reddish-brown sandy loam soils are seen as the dominant soil layer. From the level of 13 meters to the end of the borehole (depth of 15 meters), fine-grained silty clay soils with high relative density are alternately seen. Also, water level was observed at a depth of 10 meters according to previous drilling experiences from the site.

Table 1. Geotechnical properties of the soil layers of the test area.

Parameter	Unit	layer-4	layer-3	layer-2	layer-1
Es	kg/cm^2	200	100	100	200
H	cm	200	300	500	500
ν_s	-	0.3	0.35	0.35	0.3
G_s	-	2.65	2.65	2.65	2.65
E	-	0.796	0.755	0.755	0.713
W	-	0.22	0.126	0.12	0.17
C_u	kg/cm^2	0.1	0.07	0.07	0.1
ϕ'	-	24	18	18	24
γ	kg/cm^3	0.0018	0.0017	0.002	0.002

4. Basics and methodology

Since the behavior of soil against incoming loads is quite complex and irregular, in order to interpret and simplify soil behavior and determine the interaction of soil and foundation, models that physically represent the mechanical properties of the soil environment and are computationally simple are needed. Research in this field leads to two models, Winkler and continuous elastic, which are widely used in foundation soil interaction problems in theory and in practice. The Winkler model, as shown in Figure 3, is a simple and idealized model of spring elements, defined for the dynamic and static response of circular, square, and rectangular foundations buried in soil. In Winkler's model, the contact pressure at each point is proportional to the mid-soil subsidence and is distinct from the deformation of other points.

The Winkler model, which is often used in analytical applications such as "Safe" and "Etabs" to analyze plates based on elastic subgrade, is based on the assumption that the effect of elastic subgrade can be modeled with a series of vertical springs that are completely independent of each other. While this assumption is not correct. Because in practice, by applying a load on the surface of a semi-infinitely elastic medium, a vertical displacement is created on its entire surface. But in the Winkler model, only the load under the displacement is considered.

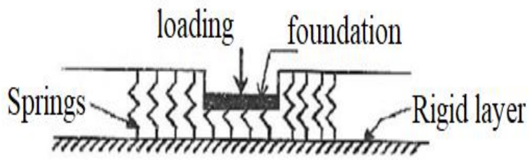

Fig 3. Schematic of the model provided by Winkler.

In the continuous elastic model, the soil environment is generally assumed to be semi-infinite, linear elastic and isotropic. However, the effect of soil multilayer and lack of isotropy can easily be included in the analysis. This method provides more information about stresses and mass deformations of soil than Winkler method and another important advantage of this method is the use of coefficient of elasticity and Poisson ratio as input parameters. This method, like the Winkler method, has weaknesses and the use of this method in practical matters is appropriate in limited circumstances. In recent years, various modified subgrade models have been introduced, such as Finonenko-bordich model, Hetenyi model, Pastemak model and Kerr model.

5. Experimental relationships to determine the soil subgrade coefficient

In the early twentieth century, engineers believed that the Ks coefficient for a given soil subgrade had a definite and uniform numerical value. But Terzaghi showed that this coefficient is not one of the exclusive characteristics of the soil and in addition to the dependence on the elastic characteristics of the subgrade, it also depends on the geometric characteristics of the load transfer system and even the type of load applied. Since then, this issue has been studied in detail and several relationships have been proposed by researchers, some of which are experimental and some of which have been obtained through a continuous elastic model. From the explanations of this section, it is inferred that the relations obtained from the theory of elasticity are more suitable for estimating Ks, and by examining the technical literature, the three experimental relations presented in Table 2 are recommended more than the rest of the relations and most researchers have determined the correctness of their relationship by comparing it with the results of these relationships.

The relationship between Biot and Vesic is defined for beams located on an elastic subgrade using continuous elastic theory. But in the technical literature, it is often applied to raft foundations as well. The Meyerhof and Baike relation is originally intended to estimate the horizontal reflection coefficient of the subgrade in circular tubes buried in the soil, which in some cases has been used to determine Ks [9].

Table 2. Proposed equations of researchers to determine the soil subgrade coefficient.

Biot (1937)	$K_s = \frac{0.95E_s}{B(1-\Upsilon_s^2)}\left[\frac{B^4E_s}{(1-\Upsilon_s^2)EI}\right]^{0.108}$
Vesic (1961)	$K_s = \frac{0.65E_s}{B(1-\Upsilon_s})\sqrt[12]{\frac{E_sB^4}{EI}}$
Meyerhof and Baike (1951)	$K_s = \frac{E_s}{B(1-\Upsilon_s^2)}$

6. Numerical modeling

In order to calculate the bearing capacity of strip and circular footings, there have been a lot of investigations using limit equilibrium method. The study of numerical methods to solve geotechnical problems are increasing tremendously such as finite element method (FEM) and the finite difference method have been widely used to compute the bearing capacity of strip and circular footings. In this study we used two numerical methods [4,10,11].

Plaxis software can be introduced as one of the powerful software in the field of civil engineering, geotechnical orientation, which has a very wide application in this orientation. In the present paper, the soil environment is modeled in two-dimensional Plaxis software using 15-node elements. Sensitivity analysis was used to select the appropriate dimensions of the model that the presence of lateral boundaries did not affect the results. Sensitivity analysis is the study of the influence of output variables on the input variables of a model. In other words, there is a way to determine the variable and the initial input conditions for a more accurate, low-cost, less time-consuming result. To perform the analysis based on a constant load of 200 kN, the amount of subsidence corresponding to different dimensions of the profile length was calculated, the relevant results are presented in Figure 4.

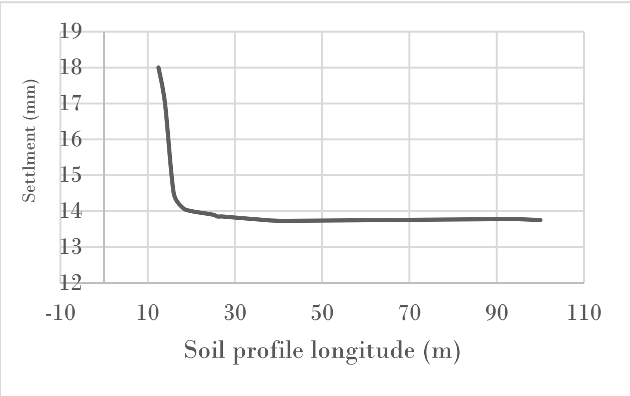

Fig 4. Results of model width subsidence in sensitivity analysis.

As can be seen in Figure 4, during more than 40 meters, the amount of subsidence is practically a constant amount. As a result, in numerical modeling, the model width is considered to be 40 meters. Boundary conditions are applied bound in x direction on both sides and bound in both directions at low soil level. In order to increase the accuracy of the results, very fine mesh has been used in the areas adjacent to the loading plate. Also, in numerical modeling according to Table 3, the values of the parameters have been applied in the software.

Table 3. The amounts of input parameters in the software.

Unit	Amount	Parameter's name	Parameter
kg/cm²	2.1*10⁶	Plate elastic modulus	E_p
cm	0.25	Plate thickness	h_p
kN	2025257.3	Plate stiffness	$(EA)_p$
kN.m²	0.1069	Plate flexural stiffness	$(EI)_p$
	0.3	Plate Poisson ratio	$(V_s)_p$

Modeling in Abaqus software has also been used to increase the accuracy of the results. Because this software is based on nonlinear problems, it has a high ability to simulate the real world. This software gives the user the ability to model the most complex phenomena with very subtle effects [12]. As mentioned in the case of sensitization, in this software, a profile with a width of 40 meters and fine mesh in the area between the loading plate and the soil, and in the form of axial symmetry in two-dimensional mode, has been used. To define the model of soil profile and loading plate, two different parts are used and finally, by overlapping them and defining the joint surface of the clamp (Tie), the final profile is created according to Figures 5 and 6.

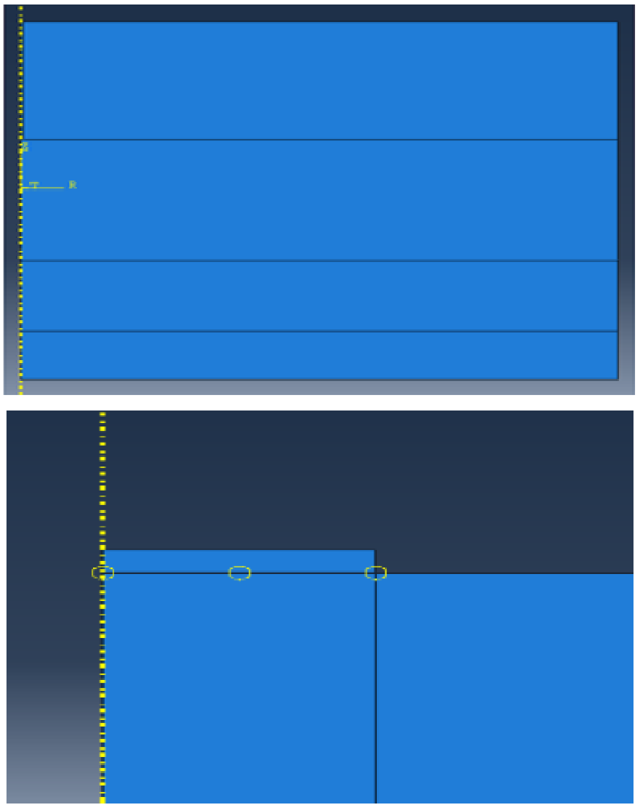

Fig 5. Modeling space and intersection of soil profile in Abaqus software.

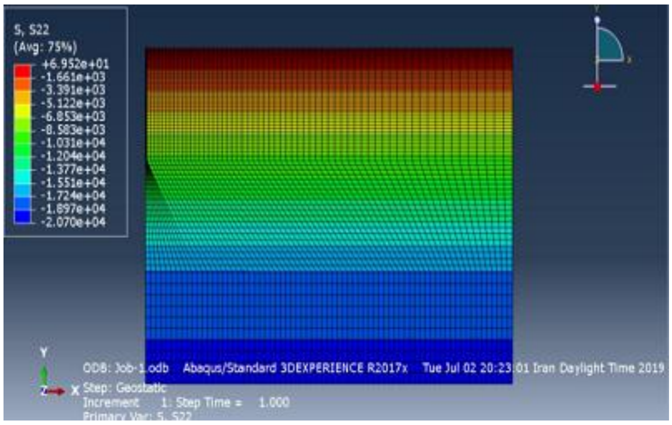

Fig 6. Meshing and stresses in Abaqus modeling.

Considering the fine mesh, in the loading and application of boundary conditions, the boundary conditions of the axial symmetry bounded by x on the left side of the profile and the bounded conditions x and on the right side of the modeling, along with the bounded conditions x and y in the lower part of the model have been used. Also, to define the gravitational force of the earth, from the Gravity load section, the value of 9.81 m per square second was entered into the whole system and at the end, the load applied by the loading plate was applied to the system as pressure.

Finally, after making the model, corresponding to field experiments, numerical analysis with two behavioral models of Mohr Columbus and hardening soil in constant geotechnical conditions with different loads and pressure diagram against subsidence has been determined for each case.

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7. Plate Load Test (PLT)

This test as shown in Figure 7 is used to determine the modulus of elasticity and soil settling properties as well as the subgrade reaction modulus [13]. The plate load test gives the stress - strain relationship of soils. The amount of strain is dependent on the void ratio, composition, past stress history of the soil and manner in which the stress is applied. Using this test, it is possible to effectively determine the final load capacity and load capacity based on the subsidence considerations. In this method, the plate is placed in the center of the borehole and the load is applied to the plate in steps of 20 to 25 percent of the estimated final load. The load is increased by the jack in steps, and at each step, the amount of subsidence is recorded from a special gauge. Also, each loading step can be continued for 1 hour or wait for the next step until the rupture or 25 mm subsidence. The test result is prepared in the form of a graph showing the pressure on the plate and the corresponding session.

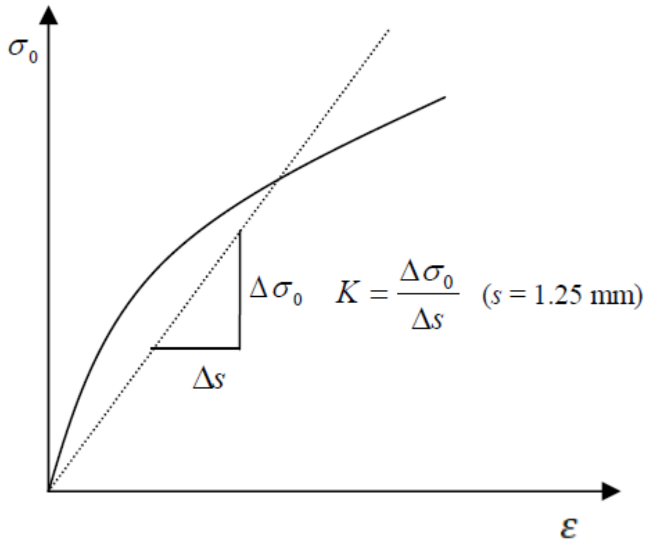

Fig 7. Definition of subgrade reaction modulus [14].

The subgrade reaction modulus is determined as the ratio between the normal stress and the settlement from 0 to 1.25mm. However, the strain modulus is determined by the curve fitting method for the overall normal stress-settlement data. Therefore, if the soil has large plastic or viscous characteristics, the result gives a large difference. In general, in case of weak soils the settlement and not the bearing capacity governs the soil design. Therefore, it is necessary to study the improvement in bearing capacity at different settlement levels and not only at tangent intersect points or corresponding to ultimate bearing capacity only [15]. Field methods are considered the most accurate and yet the most complex and costly form of scientific study. One of the main features of this method is the precise control of the results. In the present study, after drilling the identification borehole, identification tests were performed and the relevant soil engineering and stratification specifications were determined. Then, 6 plate loading experiments were performed at 3 different sites in the study area, according to Table 4. Conventionally, round plates with a diameter of 30, 45 and 60 cm have been used. Of course, it should be noted that the larger the grain size in the soil, the better the use of larger plates, and it is preferable that the plate diameter is larger than 10 times the size of the largest soil grain. The satellite image of the study area is shown in Figure 8 and an example of how the test is performed is shown in Figure 9. It should be mentioned that the soil of Fereshteh district of Tabriz is marl clay and has very variable mechanical parameters. Marls are soils with different characteristics and have distinct properties from ordinary soils. These differences and the variability of characteristics have introduced them as an independent group of soils and has led to many research and studies to know more and more accurately their characteristics and behavior. Therefore, the need for engineering studies around this type of soil increases sharply. In the study area, four machine-type boreholes with a depth of 15 meters and four 1-meter boreholes were manually drilled. A sample of the drilling samples is shown in Figure 8. As shown in Figure 9, the soil of the study area consists of four soil layers with different geotechnical properties. It should be noted that the soil located above half a meter above the ground has been tampered with and the loading test has been performed from a level of half a meter above the ground. Below the tampered soil to a depth of 5 meters, a fine-grained layer with sand grains can be seen, which has a suitable relative density. From a depth of 5 meters to a depth of 13 meters, fine-grained reddish-brown sandy soils are seen as the predominant soil layer. From the level of 13 meters to the end of the boreholes (depth of 15 meters), fine-grained silty clay soils with high relative density are seen alternately.

Table 4. Conditions and location of the plate loading.

Test name	Site name	Depth of test (cm)	Loading plate diameter (cm)
Test 1	A	0	45
Test 2	A	90	45
Test 3	B	0	45
Test 4	B	80	30
Test 5	C	40	45
Test 6	C	100	30

Fig 8. Images of the study area, samples obtained and soil layering of the area.

Fig 9. Loading plates during plate loading tests.

8. Results

Due to the large number of experiments performed, the theoretical results are first examined according to Table 5, and then the results of the numerical modeling of Abaqus and Plaxis are examined, and finally the results of the field experiments are compared, according to Table 6. Finally, by providing a suitable mathematical formula for the soil of the district and proposal, we present this research. Also, to verify the results of the proposed formula, a series of field experiments' data of Tabriz subway Line 2 has been used.

Table 5. Theoretical results obtained for the study area (kg/cm^3).

Test	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6
Vesic	7.12	6.95	7.12	9.45	7.05	9.40
Vlassov	2.73	3.38	2.73	4.03	2.71	4.01
Biot	9.72	9.47	9.72	12.5	9.61	12.4
Elvadurai	2.72	2.66	2.72	4.00	2.70	3.98
Meyerh and Baike	4.19	4.10	4.19	6.16	4.15	6.13
Klopple and Glock	5.66	5.51	5.66	8.29	5.59	8.24

Table 6. Numerical and field results for the study area.

		Test 1	Test 2	Test 3	Test 4	Test 5	Test 6
Plaxis	Mohr–Coulomb	1.93	1.73	1.93	3.83	2.10	4.07
	Hardening soil	1.67	2.54	1.67	4.25	2.27	4.59
Abaqus		1.82	2.05	1.82	3.96	2.22	4.44
Field		3.81	11.3	5.99	4.48	6.37	2.29
Unit		Kg/cm^3	Kg/cm^3	Kg/cm^3	Kg/cm^3	Kg/cm^3	Kg/cm^3

The modulus of subgrade reaction is a conceptual relationship between contact pressure and footing deflection that is widely used in structural analysis of foundation members [5]. it can be concluded that by increasing the load eccentricity, the modulus of subgrade reaction decreases, and for eccentricity more than the footing core, the modulus of subgrade reaction has a greater reduction in comparison with inside the footing core [4]. The results confirm the thesis theory that the soil subgrade coefficient is not considered as one of the exclusive characteristics of the soil and it depends on the elastic and geometric characteristics of the soil and actually depends on the depth of the soil layer [16]. It is also observed that the results of the theoretical equations are only for initial estimation. Among them, the relationship introduced by Vesic, which is based on continuous elastic theory, with a 66% difference between the results obtained from the software and the results of Vesic theory, is a more appropriate approximation than other relationships. Also, in comparing the numerical and field results, the behavioral model of hardening soil is closer to the field results of page loading test and due to the errors of the results in numerical software due to simplifications in the geotechnical properties of the soil, field loading experiments will achieve more reliable results. According to the results, it can be shown that increasing the size of the plates will reduce the soil subgrade reaction coefficient and consequently, increasing the width of the foundation will reduce the soil subgrade coefficient.

9. Mathematical formula proposed by this research

What has been discussed in previous chapters is based on numerical modeling and laboratory results and theories presented by previous researchers. Each of them has its own advantages and accuracy. Accordingly, the practice of comparing the results as well as numerical studies by Plaxis software, this research on the soil of the region, provides a specific theory for the use of designers for the studied soil. The theory presented in this research is based on the relationships between the subgrade coefficient with four parameters of loading plate diameter, modulus of elasticity equivalent to soil, Poisson ratio equivalent to soil and also the level of hardness of the plate. These four parameters in Plaxis software have been examined in the form of tables and by assuming other parameters are fixed and their diagrams have been drawn.

Then, according to the ratio of importance of the parameters against the changes of the desired parameter in relation to the subgrade coefficient, their diagrams are drawn and finally, an equation is presented to obtain the results of the soil subgrade coefficient in the desired soil.

Based on the results of Plaxis modeling, the soil subgrade coefficient has a direct relationship with the soil modulus of elasticity and the Poisson's coefficient, as well as the stiffness of the loading plate and is inversely related to the diameter of the plate (Equation 2). To calculate the relationships for the initial estimation for the soil of the region, two coefficients have been used in the relation and by "Best Fit method", the best coefficients with suitable estimation for the soil of Fereshteh region of Tabriz have been obtained and also to estimate the equivalent values of soil modulus and Poisson's ratio, a proposal by this research that has been obtained with the help of mathematics along with experimental data and numerical results.

$$K_s = n_1 \frac{E_s}{B}(1 + V_s)EI^{n_2} \tag{2}$$

Based on mathematical "best-fit" results, 0.3 is considered for the first coefficient and 0.02 for the second coefficient with a variance of 2% and an average similarity of 98%. Then, according to the obtained properties of the tested areas and according to what was mentioned before, Table 7 is obtained for the acquired results.

Table 7. The results of the proposed equation and comparison with the results of Plaxis.

Test name	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6
Theorical subgrade coefficient (Kg/cm^3)	2.06	2.01	2.09	3.11	2.11	3.09
Plaxis subgrade coefficient (Kg/cm^3)	1.93	1.73	1.93	1.83	2.10	4.07
Theorical coefficient ratio in comparison to Plaxis	1.07	1.16	1.08	0.81	1.01	0.76

Comparing the results with the results of Plaxis software, shows that the data of the mathematical formula proposed in this research, provides results that are much closer than other theories of researchers. Which indicates better accuracy of the formula provided for the initial estimates.

Conflict of interest

There is not conflict of interest.

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Please cite this article as: Khaiiatali, S., Rezaei Farei, A. H., Zaman, A. and Ahmadiadli, M. (2024). Estimation of the subgrade reaction modulus using field and numerical analysis methods. *Journal of Civil Engineering and Structures*, 8(1), pp.1-7