

# Numerical Investigation of Subgrade Reaction Coefficient in Sand Soils of Bandar Abbas City

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## Abstract

The soil-foundation interaction is one of the most important issues in geotechnical engineering that deals with studying the soil behavior subjected to the side loading. Winkler's model is the first and simplest method for consideration of the soil-foundation interaction. It is vitally important to determine the coefficient of subgrade reaction of the soil. Since several methods have been provided to estimate the coefficient of subgrade reaction up to now, this research is conducted to choose a ground characteristic in Bandar Abbas (IRAN). To do so, the obtained results from the proposed experimental formulas are compared with corresponding values of the behavioral models to determine the coefficient of subgrade reaction. In addition finite element analysis is performed using Plaxis software. The result of this paper shows that the finite element method is more compatible than Biot's method. Results also showed an increasing footing diameter which leads to the decrease of the  $K_s$ . This fact is because of an increasing load area which concluded to the increasing of the settlement. It is found that with increasing each of the strength parameters of the soil ( $c, \phi$ ) can be expected an effect on increasing the subgrade reaction; although this increase depends on footing diameter. Also, in sand soils, the cohesion of the soil is more effective on the increase of the subgrade reaction coefficient than the internal friction angle.

**Key Words:** *Elasticity coefficient, Mat foundation, Subgrade reaction coefficient, Bandar Abbas City*

## 1. Introduction

The application of mat foundation has a long history behind. This type of the foundation has shown a very good performance in transferring the forces of the construction to the ground and this is the main reason of the popular application of the mat foundation. Currently in most cases, the engineers use a constant of the subgrade reaction coefficient to analyze the mat flexible foundations. This constant is obtained from the geotechnical experiments such as plate loading. Many researchers have studied the soil subsidence and the subgrade reaction coefficient using the plate loading test, among which one can refer to Terzaghi [1], Bond [2], Teng [3], Bjerrum and Eggstad [4], Broms [5], Bowels [6], Parry [7], Arnold [8], and Suoqing [9]. The application of a uniform reaction coefficient all over the foundation means neglecting the conditions of a continuum for the soil. This means it has been neglected the effects of cuts in the soil layers. One of the

fundamental issues in designing and calculating the foundations is the problem of soil-foundation interaction. To study this problem, it is very important to study the soil behavior against the external loads. The soil behavior depends on many factors such as the moisture content, density, particle-forming mineral types, grain size, grain shape, grading curve, the current state of the stress, stress history (past state of the stress), pore pressure, saturation point, permeability rate, time and temperature. Anyway, in order to study the soil-foundation interaction, many researchers have tried to investigate the soil behavior against the imposed loadings and to find a model for it. Material model is a mathematical relation for describing the stress-strain behavior of a small element of the environment. As mentioned before, the soil behavior depends on many factors and hence it is extremely difficult and complex to provide a model including the effects of all factors. Thus, in solving the problems of soil-foundation interaction, some properties of the soil are usually excluded to provide simpler model with fewer

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parameters. Since the soil in macroscopic scale is a continuum, the simplest possible state is that we consider the soil as a linear, homogenous and consistent elastic semi-space. In such a case, the soil will have two parameters of Poisson coefficient and the elasticity module. The first and simplest model for investigating the soil and foundation interaction is a model offered by Winkler in 1867 [10]. In this model, the deformation of any point of the soil ground is supposed to be related to the stress value at that point and the effect of the stresses and the changes of other points are neglected. In this model, soil is replaced with a set of independent springs with a specific hardness coefficient. Thus, only one single parameter is considered for the soil, that is, the subgrade reaction coefficient represented by  $k_s$ . One of the most prominent properties of this model is its un-continuous behavior [11]. The subgrade modulus is not a fundamental soil property and its magnitude depends on many factors, among them the shape of the foundation, stiffness of foundation slab, shape of the loading on the foundation, depth of the loaded area below the ground surface, and time. As such, it is not constant for a given type of soil, which makes the estimation of a single general value for design a challenging task [12]. Consequently, the researchers have suggested several ways to determine this parameter and several formulas have been offered for determining the  $k_s$  for a specific problem. Many researchers have studied on calculation of coefficient of subgrade reaction. Ismail [13] concerned with the applications of artificial neural networks (ANN) and simple-multiple regression analysis to predict deformation modulus and coefficient of subgrade reaction of compacted soils from compaction parameters (such as maximum dry density (MDD) and optimum moisture content (OMC), field dry density (FDD), and field moisture content (FMC)). His result indicated that there are acceptable correlations between deformation modulus and coefficient of subgrade reaction and these parameters. The artificial neural networks model exhibits higher performance than traditional statistical model for predicting deformation modulus and coefficient of subgrade reaction. Yun Ding [14] compared four typical determination methods of coefficient of subgrade reaction, including test method, Lis method, MIDAS method and the finite element method. He showed that the test method is the preferred one for

designers, the tangential coefficient should be in a range of one to two third of the normal coefficient, and the internal force of subway structures can be obtained by the test method and modified by a correction factor that is 1.05. Barmenkova et al [15] carried out calculations of plates on an elastic basis with variable and constant coefficient of subgrade reaction. In his paper, the calculation of plates bending was carried out by the finite element method. The calculation results were compared to different models of plate and an elastic basis. For a two-layer plate on an elastic basis, which had a heterogeneity in the plan, the results of calculation taking into account the increase of the height of the upper structure. Kobayashi et al [16] calculated the subgrade reaction coefficient of a foundation soil in an open pier using an extended Kalman filter (EKF) based on measurements taken during in situ horizontal loading tests on a pile. The measured deflection and the bending moment determined in the tests were used as input data for the inverse analysis. Analysis revealed that the identified subgrade reaction coefficient of the rubble mound is less than that of the diluvial clay under the same level of loading. The numerical results will provide useful information for the future design of open piers and their foundations. Liao [17] reviewed the limitations of various simple and complex methods available for estimating the coefficient of subgrade reaction  $k$ , and proposes a new method developed using results from plane strain finite element analyses of a loaded beam or slab resting on the surface of a homogeneous elastic soil layer. The proposed method denoted as the modified beam on elastic foundation (MBEF) method, differs from standard procedures in that the derived value of  $k_s$  varies with the position under the structural slab. Although many researches are carried out about determining Subgrade Reaction Coefficient, being dependent of Subgrade Reaction Coefficient to many parameters leads to more parametric study. Experimental and theoretical formulas about determining  $k_s$  are extracted based on available data in limited sites and with some assumptions, so it is possible they do not have sufficient precision in all areas. Therefore, determining Subgrade Reaction Coefficient in specific areas such as Bandar Abbas city and assessment of the effective parameters on Subgrade Reaction Coefficient is vital. Besides, the increasing footing width increases effective depth. Therefore, determination of  $k_s$  in footing with more width is more complex,

especially in layered soil, because  $k_s$  obtained from plate load test is different with  $k_s$  under real loading of structures, so investigation of footing width and strength parameters of soil on  $k_s$  is needed. Performing plate load test with large diameter is expensive and difficult, so the present study by using the finite element software of Plaxis, effect of mentioned parameters is investigated.

Few studies have been observed on Subgrade Reaction Coefficient of the sandy soil of Bandar Abbas city, so in this paper by using Geotechnical data of a site in Bandar Abbas city (Iran), subgrade reaction coefficient by using theoretical, experimental relations and numerical methods is determined. Beside effect of strength parameters ( $c, \phi$ ) and  $B$ , on subgrade reaction coefficient is investigated too. By using and verifying numerical methods and ensure the accuracy of the software, this study is carried out. Numerical analysis has been done by finite element method using Plaxis software [18].

## 2. Analytical methods of subgrade reaction coefficient

In order to obtain  $k_s$ , one can generally apply plate loading, consolidation, triaxial and CBR tests and experimental and theoretic relations provided by researchers [19]. Among these, plate loading test and experimental method were the most common methods. In this paper, it is considered experimental and theoretic method. There are several relations, containing Vesic[20], Biot [21] and Bowles [6] and relations resulted from elasticity theory to determine subgrade reaction coefficient.

Biot [21] solved the problem of an infinite beam on a linear elastic subgrade and provided the Eq. 1 for subgrade reaction coefficient.

$$k_s = \frac{0.95E_s}{(1 - \nu_s^2)} \left[ \frac{E_s B^4}{(1 - \nu_s^2)EI} \right]^{0.108} \quad (1)$$

Vesic [20] developed Biot's work [21] and suggested the Eq. 2 for the relation between  $k_s$  and elastic characteristic of soil:

$$k_s = \frac{0.65E_s}{B(1 - \nu_s^2)} \cdot \sqrt[12]{\frac{E_s B^4}{EI}} \quad (2)$$

He also showed that difference between Winkler's method and continuum does not exceed 10 percent. Bowles [6] showed that the numerical value of  $0.65 \sqrt[12]{\frac{E_s B^4}{EI}}$  in ordinary condition may be approximated by 1, and in most cases subgrade reaction coefficient is obtained by:

$$k_s = \frac{E_s}{B(1 - \nu_s^2)} \quad (3)$$

Using elasticity theory is another way to approximate  $k_s$ . By reformulating the elastic subsidence in rectangular foundation, we have the following [22]:

$$k_s = \frac{E_s}{B'(1 - \nu_s^2)mI_s I_F} \quad (4)$$

These values are determined based on tables in an elastic subsidence section of basic soil mechanic references. "m" is the coefficient which is equal to 1, 2 and 4 for corner, edge and center, respectively.  $k_s$  is calculating in corners with  $m=1$  from Eq. (4) and multiply it by 0,5 to obtain  $k$  edges or multiply it by 0.25 to obtain  $k_s$  centers. According to the above discussion, it can be seen that there are several formulas to determine soil subgrade reaction coefficient.

## 3. Technical properties of the soil

### 3. 1. General and geotechnical properties

The site of the residential-mercantile building is located at the west part of Bandar Abbas city in Iran (Fig. 1) with 7 floors over the ground floor (parking lot). The depth of the foundation settlement is equal to the height of the foundation as one meter and no groundwater grade was observed until the end of the excavation depth. In order to identify the underground layers, five boreholes were excavated (three 15-meter boreholes and two 20-meter boreholes) using Rotary drilling machine. During the soil boring,

some samples were extracted for the laboratory experiments. After the completion of the field operation, the extracted samples were tested for grading, Atterberg's limits, moisture content of the natural soil, and direct shear test. The studies on the layers of the site soil show that the soil type in

the foundation subgrade is mainly silty sand (SM) from the ground level down to the depth of 8 meters, and the soil type is bad-grained sand (SP) from the depth of 8 meters downwards.



Figure1. Location of Bandar Abbas city

Table 1. Soil properties of the site

No. of Layers	Dep. (m)	Soil Type	SPT ( $N_{cor}$ )	$\omega$ (%)	$c$ (kPa)	$\phi$ ( $^{\circ}$ )	$\gamma$ ( $kN/m^3$ )	$\gamma_d$ ( $kN/m^3$ )
1	0-2	SM	21	4.1	0	29	17	16.3
2	2-4	SM	17	16.6	0	29.1	18.6	16.23
3	4-6	SM	24	14.9	0	28.8	18.6	16.18
4	6-8	SM	33	15.2	0	30.4	18.9	16.4
5	8-10	SP	38	23.7	0	32.4	20.1	16.24
6	10-12	SP	39	18.1	0	31.2	19.4	16.42
7	12-14	SP	47	24.2	0	31.2	20.6	16.58
8	14-16	SP	50	19.8	0	30	20	16.69
9	16-18	SP	50	19.2	0	32	20	16.77
10	18-20	SP	50	18.8	0	32	20	16.83
11	20-30	SP	50	18.8	0	32	20	16.83

### 3. 2. Mechanical properties of the soil

Considering the field and laboratory experiments and in order to determine the scale of soil subsidence and the bearing capacity of the site soil, the needed parameters were selected from the five

excavated boreholes as shown in Table 1. Since the data of the samplings down to 20 meters deep is available, the soil type has been given down to the depth of foundation effect with regard to the local data like the layer 10 and extended down to

30 m depth. Moreover, the soil weight in the 20 to 30 m depth (layer 11) has considered as being constant.

The following formulas have been used to determine the elasticity module of the soil [6]:

$$E_s = 500(N + 15) \quad (5)$$

For unsaturated sands, and

$$E_s = 250(N + 15) \quad (6)$$

For saturated sands.

Thus, the elasticity module for each of the soil layers is calculated based on the above formulas and the results are shown in Table 2.

Table 2. Elasticity module of the soil layers

No. of Layers	SPT (Ncor.)	Es (kPa)-dry
1	21	18000
2	17	16000
3	24	19500
4	33	24000
5	38	26500
6	39	27000
7	47	31000
8	50	32500
9	50	32500
10	50	32500
11	50	32500

#### 4. Numerical analysis procedure

##### 4.1. Verification

First, to verify software, results of Brian Anderson et al. [23] were analyzed with Plaxis . Brian Anderson et al. [23] performed insitu test and numerical investigation for predicting settlement of shallow foundations. Accordingly, a 1.8 m diameter concrete footing was statically load tested. Prior to construction, insitu standard penetration test (SPT); cone penetration test (CPT), dilatometer (DMT), and pressuremeter (PMT) and laboratory tests were performed to determine engineering properties of the soil. A reinforced circular 1.8 m diameter 0.6 m thick

concrete footing was constructed using a corrugated pipe coupler as a form. To overcome a thin hard layer surface crust, the footing was embedded 0.6 m into the ground. The groundwater table was at 1.7 m from the ground surface, as illustrated in Fig. 2. Static load is 222 kPa. Due to the symmetry, half of footing with width 0.5 B and as axisymmetric is modeled. For avoiding boundary effects, a model 6.5×5 m was selected. The model depth was taken 6.5 m, that is About equal 4B=6.8 m and the width of the model was taken 5 m, that is about equal 3B [24]. Results proved that the displacement has not reached the boundaries in the analysis. To investigate the mesh dependency, a number of trial analyses were conducted through the verification study. The model is included 1971 nodes and 235 elements. The boundary lines were defined as the limited deformation in horizontal direction and open deformation in vertical direction, and limited deformations both in horizontal and vertical directions at the lower boundary as showed in Fig. 3. Trial analyses proved with specified dimension and meshing, errors will be negligible. In order to do the modeling with finite element method, the 15-node triangular elements have been used according to Fig. 4. Table 3 presents the input parameters used for the FEM analyses. Fig. 5 presents applied stress- Settlement diagram obtained from Plaxis in this study and reference for a point located under the plate. There is negligible difference between the two diagrams so Plaxis is suitable for the analysis.

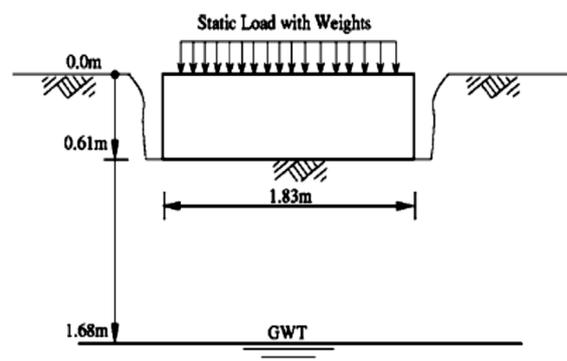


Figure 2. Soil-footing profile of verification [23]

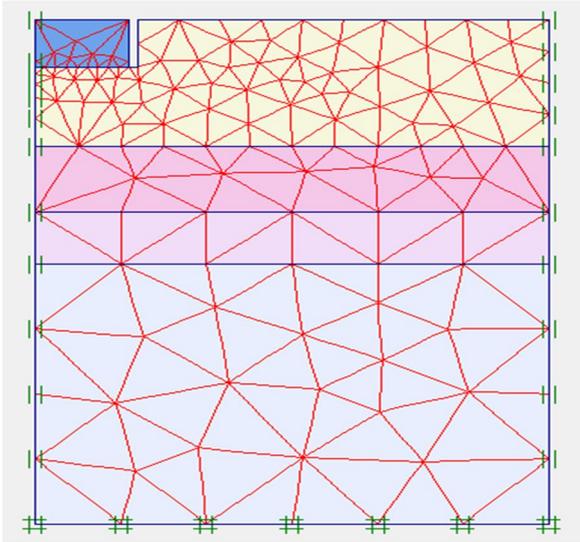


Figure 3. Geometry and mesh of the verification model

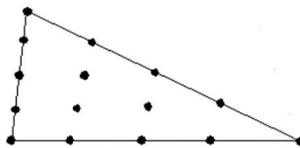


Figure 4. 15-nodes triangular element

Table 3. Soil Properties used in verification according to reference[23]

Bottom(m)	$\gamma_m(\text{kN/m}^3)$	$\phi(\text{deg})$	E(Mpa)	C(kPa)
1.64	18.9	31.4	14.5	0
2.5	17.3	30.1	12.5	0
3.17	15.7	28.6	10.50	0
6.5	14.2	27.1	8.5	0

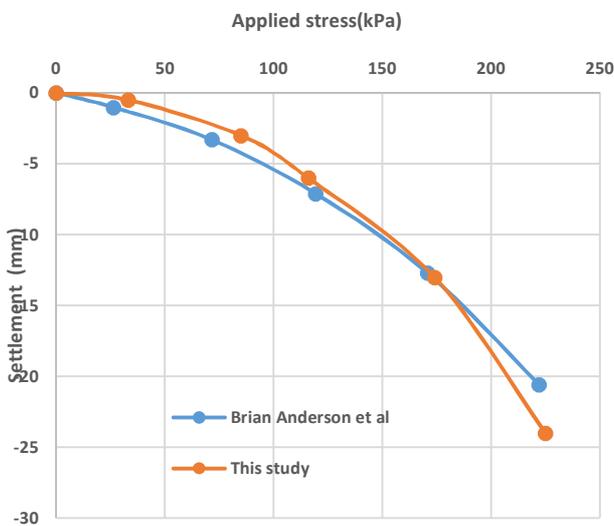


Figure 5. Applied stress- Settlement diagram

## 4. 2. Parametric study

After ensuring verification of software, the model for determining Subgrade Reaction Coefficient of Bandar Abbas city and parametric study was created. In the created model (which included 2011 nodes and 256 elements), the type of loading was uniform and in all phases of analysis, the rigid foundation was considered. Mesh dependency and were determined like verification analysis. Model depth should be greater than  $4B$  and model width greater than  $3B$  for different diameters. In this research, the analysis with finite element method was done using Plaxis software. Since it was intended to study the effect of foundation diameter on determining the value of subgrade reaction coefficient, thus it was used the axisymmetric model in the software to do the soil modeling. The relevant parameters of the general properties (wet and dry specific weight) and the relevant parameters of the soil resistance ( $c$ ,  $\phi$ ) for all soil layers have been extracted from Table 1. Considering the results of the experiments and researches and the reliability of the created numerical model with the results, and considering the soil type of the site (sandy soil), in this research it is used Mohr-Coulomb behavioral model for the soil. Since in Mohr-Coulomb behavioral model the stress-strain relation is fulfilled directly by the soil elasticity coefficient, thus in entering the data of the soil elasticity coefficient as one of the input parameters, it is using the data of Table 2. The values of the dilation angle in all layers were assumed as 0. Considering the properties of the building in this project and the scale of the imposed loading (dead and live load), the value of the pressure imposed on the soil was assumed as  $120 \text{ kN/m}^2$  where it is used the plate element (with the concrete foundation properties) to transfer this load to the modeled soil. Among the most important properties of the element it could be referred to its flexural hardness ( $EI$ ) and its axis hardness ( $EA$ ). These two parameters can be used to obtain the plate thickness that is the representative of the foundation thickness in this case. Considering the constant thickness of the foundation by 1 meter in this research, different values will be obtained for  $EI$  and  $EA$  in different models according to the formulas 7 and 8 [25]. Since the modeling has been done in axisymmetric method, thus half of the diameter of the real foundation has been modeled, and the modeling has been done in the

direction of the axis x, equal to three times more than the foundations diameter (3B), and in the direction of the y equal to the number of the layers mentioned in Table 1. Moreover, Table 4 shows the needed parameters for determining the plate input parameters into the Plaxis software.

$$d = \frac{1}{2} deq \tag{7}$$

$$deq = \sqrt{12 \frac{EI}{EA}} \tag{8}$$

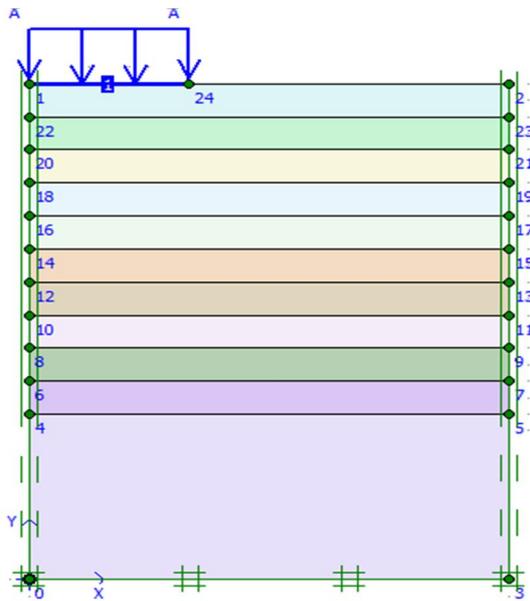


Figure 6: Geometry of the model

Table 4. Plate parameters

EI (kNm <sup>2</sup> /m)	EA (kN/m)	E (kPa)	D <sub>f</sub> (m)
Var.	Var.	2.5×10 <sup>7</sup>	1

## 5. Results and Discussion

It is made seven models for several values of foundation diameter (8, 10, 12, 14, 16, 18, and 20 m) and it is analyzed by finite element method using Plaxis. Because of axis plain strain in Plaxis, the foundation is considered as a strip with B/2 of diameter and 1 m, orthogonal to the plane as shown in Fig. 6. Amount of vertical displacement in the center and below of the foundation (sections are in the center and 1 meter below the above

subgrade of soil model) is obtained according to the determined load resulted from construction analysis (120 kN/m<sup>2</sup>). The soil subgrade reaction coefficient for any values of foundation diameter is calculated by Eq. (9) [26]:

$$k_s = \frac{P}{\Delta} \tag{9}$$

The soil subgrade reaction coefficient (k<sub>s</sub>) resulted from numerical analysis for several foundations are shown in Fig. 6. The vertical settlement (Δ) for each analysis obtained, according to the constant contact pressure (p) about 120(kN/m<sup>2</sup>) plotted and Then the secant modulus of each graph (K<sub>s</sub>) is determined.

As it can be seen from Fig. 7, increase in foundation diameter causes an increase in settlement but it decreases subgrade reaction coefficient. This is due to an increasing load area which consequences in increasing settlement [25, 27]. If foundation diameter increases from 8 to 20 meters, then settlement variations, changes from 35 mm to 58 mm, i.e. by 2.5 times of foundation diameter, its settlement increase 67% and subgrade reaction coefficient changes from 3400 MN/m<sup>3</sup> to 2068 MN/m<sup>3</sup> which means it decreases 60%. Generally, there is a linear relation between the decrease of foundation's diameter and settlement and decrease of subgrade reaction coefficient.

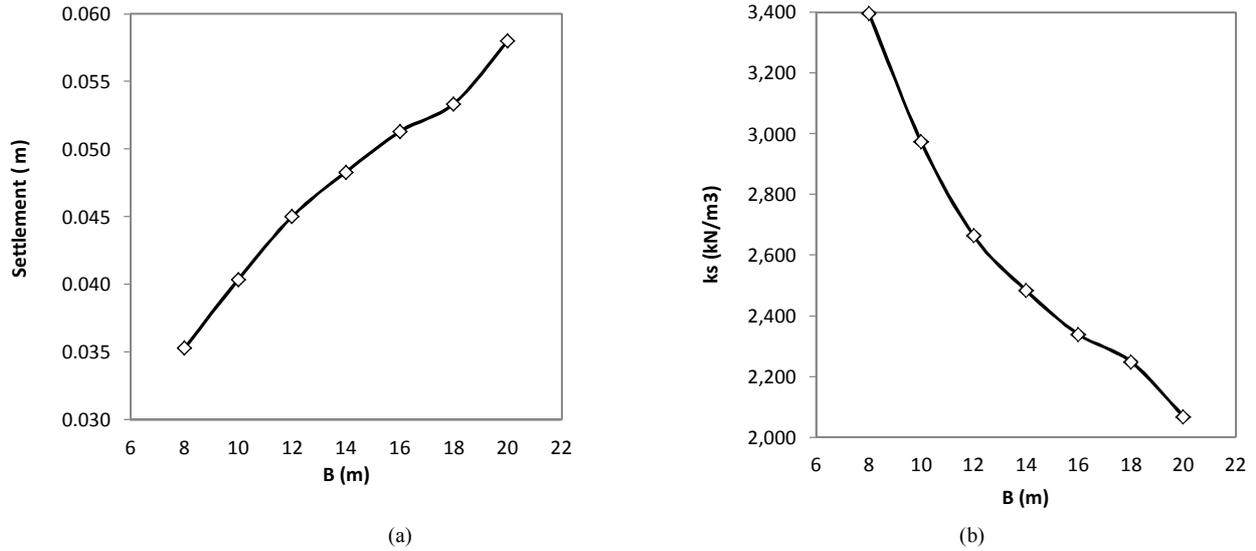


Figure 7. (a) settlement variations and (b)  $k_s$  variations for several values of foundation width resulted from numerical analysis

## 6. Analytically determining subgrade reaction coefficient

In applying formulas in section 2, which are summarized in Table 5, approximating elasticity coefficient should be precise, since this value is the only factor for effect of bedding on  $k_s$ . Hence, it is used the corresponding elasticity coefficient, which contains all layers locating in the foundation effect depth.

Table 5. Analytic formulas for  $k_s$  used in this paper

Method	Reference	Relationship
1	Biot [21]	$k_s = \frac{0.95E_s}{(1-v_s^2)} \left[ \frac{E_s B^4}{(1-v_s^2)EI} \right]^{0.108}$
2	Vesic [20]	$k_s = \frac{0.65E_s}{B(1-v_s^2)} \cdot \sqrt[12]{\frac{E_s B^4}{EI}}$
3	Bowles [6]	$k_s = \frac{E_s}{B(1-v_s^2)}$
4	Elasticity Theory [22]	$k_s = \frac{E_s}{B'(1-v_s^2)mI_s I_F}$

The following formula is for calculating the corresponding elasticity coefficient [25]:

$$E_s = \frac{\sum_{i=1}^{11} E_{si} H_i}{\sum_{i=1}^{10} H_i} \quad (10)$$

Therefore, using the elasticity modulus of Table 2 and thickness of layers and substitute them in Eq. (8) the elasticity coefficient is obtained as 28134 kPa. On the other hand, since the effect of load is decreasing with depth, so the elasticity module of upper layers would be more than lower ones. Therefore, this effect is considered by adding a factor called depth factor ( $I_D$ ) and finally it was used (9) to calculate the corresponding elasticity module [27]:

$$E_s = \frac{\sum_{i=1}^{11} E_{si} I_{Di} H_i}{\sum_{i=1}^{10} I_{Di} H_i} \quad (11)$$

In any layer, depth factor is the ratio of displacement in the center of the layer to the total displacement in Plaxis. Another way is to divide imposed stress in the center of the layer to the total imposed stress (120 kPa). According to this, the corresponding elasticity module, which obtained from (11), is between 22595 kPa and 23736 kPa. The variations of subgrade reaction coefficient resulted from the experimental and numerical analysis is shown in Fig. 8. Fig. 8 shows, although in low diameter (around  $B=8$ m)  $k_s$  of Finite element method and Vesic and bowles are close together but with increasing  $B$ ,  $k_s$  of Finite element method and Biot become closer.

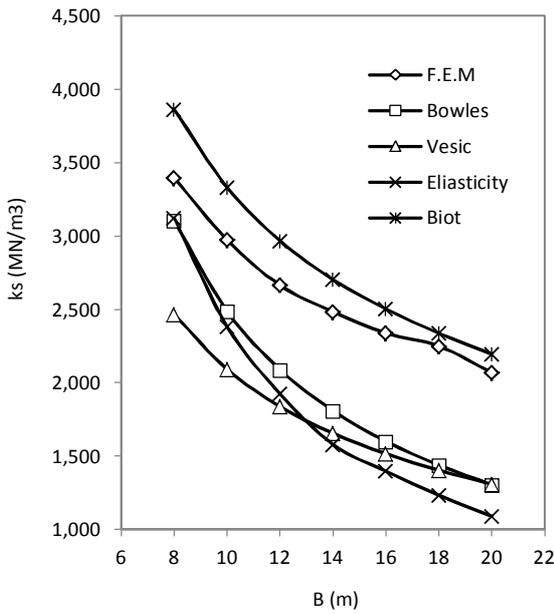


Figure 8.  $k_s$  variations for several values of foundation diameter resulted from analytical and numerical analysis without groundwater level

### 7. Effects of strength parameters of soil on the subgrade reaction coefficient

Since in most projects, the soil treatment is being done on the upper layers and this treatment leads to some changes in the mechanical properties of the soil, thus it is trying to express the effect of the cohesion and the internal friction angle on the value of the subgrade reaction coefficient from this numerical analysis. In this regard, it was conducted the mentioned operation, it three steps [28]. The

first step was conducting the cohesion. So in the layers 1 and 2 and in the definition of the properties of soil layers in Plaxis software, the values of cohesion were entered with four different values (i.e. 5, 10, 15 and 20 kPa) and all 7 files were analyzed separately based on these values. The second step was to apply the internal friction angle alone. Therefore, in the layers 1 and 2 and in the definition of the properties of soil layers in Plaxis software, the values of friction angle were entered with two different values (i.e. 35 and 40 degrees). Finally, in the third step, both parameters of cohesion and angle of the internal friction were applied together in the layers 1 and 2 and in the proposed model and the values were numerically analyzed. The results showed that the joint effect of both parameters is plastic and merely with the internal friction angle of 40 degrees. The obtained results of the analysis in different states are shown in figures 7 to 8.

As shown in Fig. 9, the increase of the cohesion value in the soil layer has led to the increase of the  $K_s$  value, and this increase is lower in wider foundations; so that in the foundation with 8m diameter, the average increase of the  $k_s$  value in all four cases (of 10, 5, 10, 15 and 20 kPa) the cohesion value is equal to 18.6% and in the foundation with 20m width, it is equal to 14.8%. Moreover, it can be observed that this amount of increase in the  $k_s$  value has an approximately equal slope in different diameters.

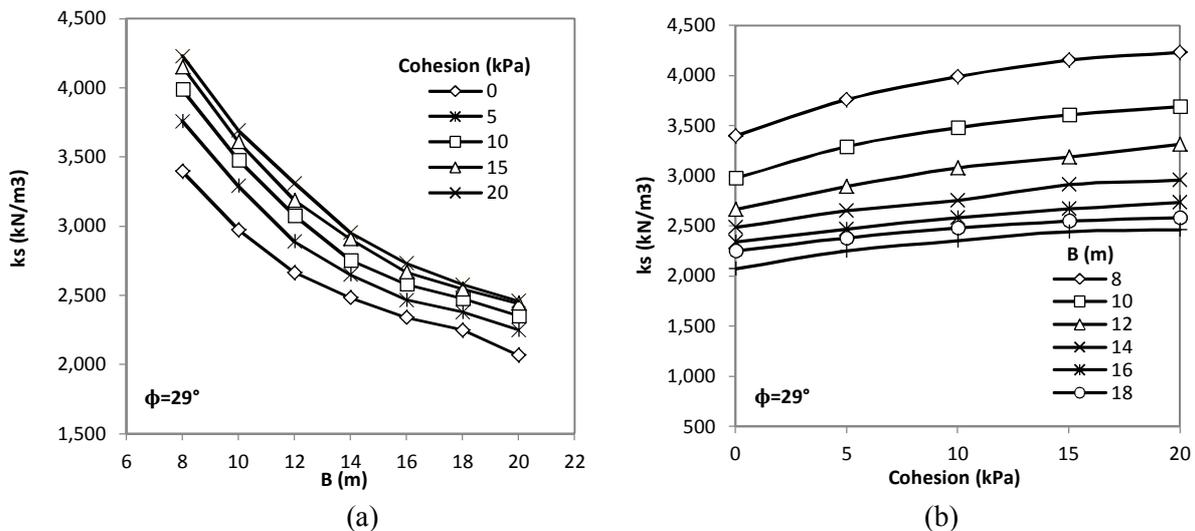


Figure 9. The effect of (a) foundation diameter and (b) cohesion on the  $k_s$  changes

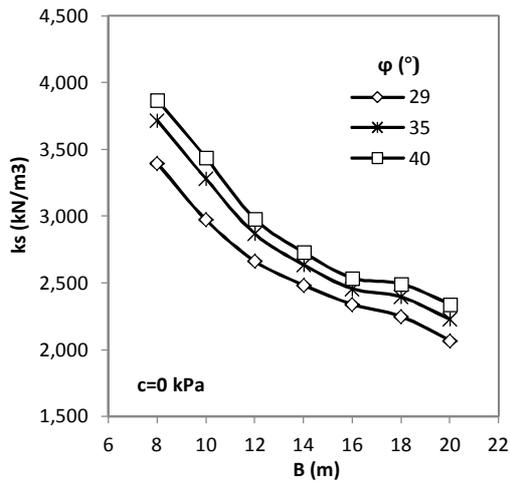
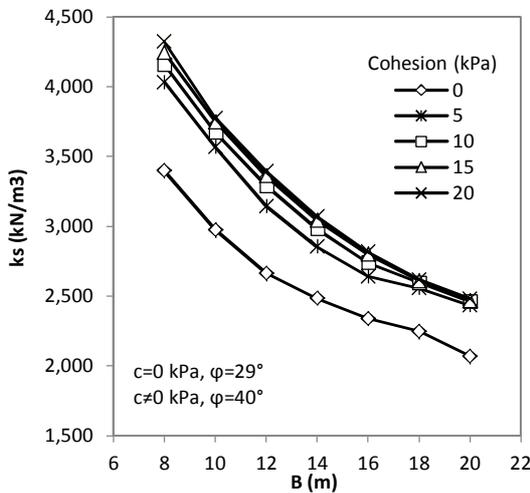
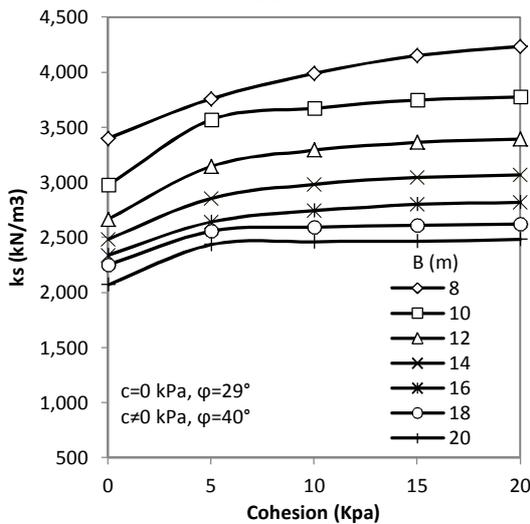


Figure 10. The effect of internal friction angle on the  $K_s$  changes resulted from the numerical analysis



(a)



(b)

Figure 11. The effect of (a) foundation diameter and (b) cohesion on the  $k_s$  changes resulted from the numerical analysis

Fig. 10 implies that the increase of the internal friction angel will lead to the increase of  $k_s$  value, and this increase is lower in wider foundations; so that in the foundation with 8m diameter, the average increase of the  $K_s$  value in both angles of 35 and 40 degrees is equal to 11.68% and in the foundations with 20m diameter, it is equal to 10.5%. Moreover, it can be observed that this amount of increase in the  $K_s$  value has an approximately equal slope in different diameters.

Fig. 11 shows the both strength parameters of the soil so that the  $k_s$  value has increased with the increase of the both mentioned parameters, and like the previous steps, this increase is lower in wider foundations; i.e. in the foundation with 8m diameter, the average amount of the increase of  $k_s$  value is equal to 23.32% and in the foundation with 20m diameter, it is equal to 18.95.

### 8. Conclusions

Currently in most cases, the engineers use a constant of the subgrade reaction coefficient to analyze the mat flexible foundations. This constant is obtained from the geotechnical experiments such as plate loading or it is obtained from the relevant non-experimental formulas, while this means neglecting the conditions of a continuum for the soil and neglecting the effect of cut in the soil layers. In this way of calculation, it were studied the subgrade reaction coefficient by experimental methods and the results were compared to the numerical analysis of a real sample. The results of this analysis and comparison are as follow:

1. The increase of the foundation diameter will lead to the decrease of the  $k_s$  value, so that approximately 10% of the  $k_s$  value is decreased by increasing each 2 meters to the diameter of the foundation. This result proves the coefficient of subgrade reaction is not a soil property and depends on the size of the loaded area and footing.
2. Among all suggested formulas to determine the subgrade reaction coefficient, Biot's method is more compatible with the results of the numerical analysis in different diameters of the foundation; and in the subjected soil of this research, we can claim that Biot's method is the dominant formula for determining the subgrade reaction coefficient.

3. Using the experimental relations to determine the subgrade reaction coefficient, it was found that the effect of bedding factor and the mechanical properties of the subgrade are very important, and the subgrade reaction coefficient is not equal to the general concept of soil- foundation interaction.
4. Elasticity module is equal to one of the effective parameters to determine the subgrade reaction coefficient, especially in layered soils; its effects are further eminent. That assumes the effect of the increase in the elasticity coefficient of the upper layers into the lower layers.
5. Strength parameters have a positive effect on the increase of the subgrade reaction coefficient of the sandy soil so that depending on the diameter of the foundation. This fact can increase the subgrade reaction coefficient up to 23% by changing the mechanical properties of the lower layers of the foundation. It is found that each of the strength parameters of the soil ( $c, \phi$ ) can expect an effect on increasing the subgrade reaction coefficient up to 18.6 and 11.86 for cohesion and the internal friction angle respectively. The reason for this is that increasing strength parameters increases stiffness of soil. In sand soils, the cohesion of the soil is more effective on the increase of the subgrade reaction coefficient than the internal friction angle. This result shows subgrade reaction coefficient is dependent to some parameters like soil type, size, shape, depth and type of foundation.
6. In this research, it was not observed the effect of the groundwater which shows the importance of paying attention to use of the experimental formulas.

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