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INFLUENCE OF THE SUBGRADE REACTION COEFFICIENT MODELLING ON THE SIMPLE 3D FRAME

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Abstract

The aim of this paper is to present the influence of the subgrade reaction coefficient modelling on the simple 3D frame. For simplicity, it was assumed that the construction was made on the square foundations on granular soil. The soil reaction coefficient is modelled by different expressions drawn by different authors. For this reason different values of the coefficient were obtained. In order to observe the behaviour of these coefficients for each author curve families are created. They give us the relationship between the dimension of the square foundations and the value of the reaction coefficient. The paper then follows the response of the characteristic structural framework to these impacts.

Keywords: numerical modelling; subgrade reaction coefficient; curve families, 3D frame

1. Introduction

One aspect of modelling any constructive system has to deal with the foundation system of the structure and their connection to the soil. In the case of mostly used shallow foundations system Winkler springs model has to be implemented in modelling that kind of connection [2], [5]. That is the reason why it is necessary to find out the correct value of the Winkler's spring stiffness trough the so-called soil reaction coefficient [3], [4], [8], [10]. It basically corresponds to the relationship between stress under the foundation and its deflection. A lot of authors investigate this phenomena and give their own a little bit different solutions.

The problem occurs at the end user, an engineer who is modelling the structure and soil connection. She or he remains in dilemma which solution of the subgrade coefficient k to choose and what consequences has that solution on the behaviour of the static system. The intention of the authors is to demonstrate through this work examples that the results of the forces and displacements on the structural elements depends on the chosen k value. Because of this influence we developed and tested the software SE_Calc which calculates the values of subgrade coefficients k for each different author [1]. The implications of these results, tested on the simple 2D frames, showed some dissipations of the results in the moment diagrams and the displacements [6], [7]. In this way of taking into account the different k values the extreme forces could be considered in the process of dimensioning the structural elements.

For comparing the calculated values the model with the average subgrade value was chosen to be the basic one. From the point of departure of the results on 2D frames that approach of using the average *k* seems to be correct. But the negative aspect of the average value approach is that it represents the statistical value instead of the exact one.

The idea of the authors of this paper was also to create curve families for each author and find the average one. The curve families are showing the dimension of the square foundations and the reaction coefficient relationship. In that way it would be easier in the case of different foundation dimensions to predict the behaviour of in this case 3D frame structure.

2. Curve families of the subgrade coefficient

The software SE_Calc – the programmatically solution was developed for the purpose of determining the soil reaction coefficients by different authors' expressions [1]. The program was tested on various examples from the literature and upgrade to calculate the average value of the subgrade coefficient. The authors and their expressions are:

- By Vesic

$$k_s = \frac{0.65 \cdot E_s}{B \cdot (1 - \vartheta^2)} \cdot \sqrt[12]{\frac{E_s \cdot B^4}{E_b \cdot I}} \tag{1}$$

- By Biot

$$k_s = \frac{0.95 \cdot E_s}{B \cdot (1 - \vartheta^2)} \cdot \left[\frac{E_s \cdot B^4}{(1 - \vartheta^2) \cdot E_b \cdot I}\right]^{0.108} \tag{2}$$

- By Meyerhof & Baike

$$k_s = \frac{E_s}{B \cdot (1 - \vartheta^2)} \tag{3}$$

- By Kloppe & Glock

$$k_s = \frac{2 \cdot E_s}{B \cdot (1 + \vartheta)} \tag{4}$$

- By Selvadurai

$$k_s = \frac{0.65 \cdot E_s}{B \cdot (1 - \vartheta^2)} \tag{5}$$

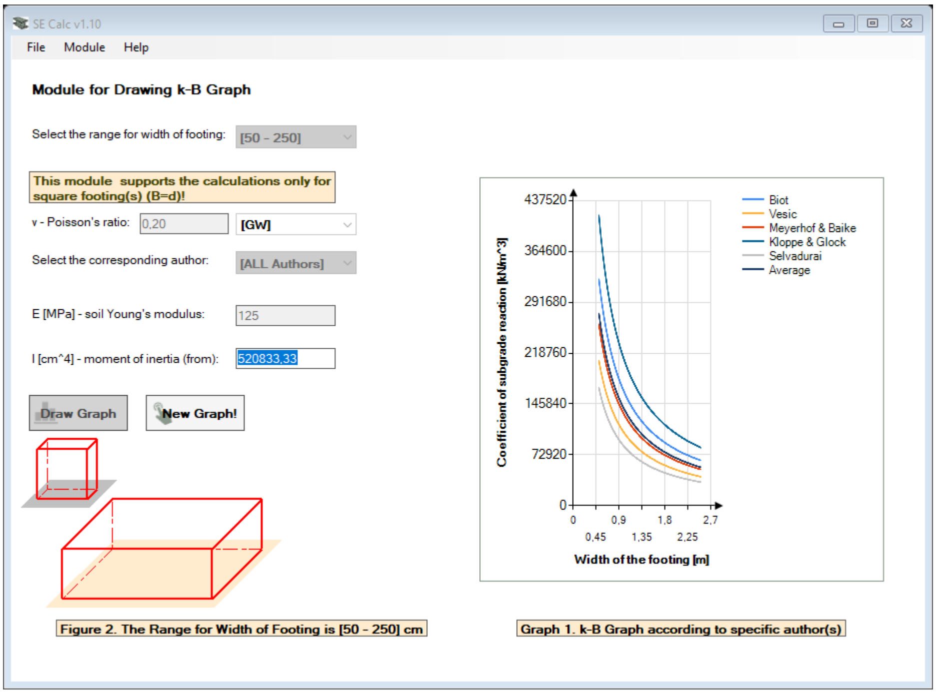

Fig. 1. Curve families of the subgrade coefficient diagram

For the purpose of the characteristically examples parametric analyses it was necessary to develop graphically representation of the relationship between the square foundations and the subgrade reaction coefficient. Since the graph in Figure 1. represents the curves it is named curve families of the subgrade coefficient diagram.

3. Simple 3D frame example

The structural response to different values of the subgrade reaction coefficient, a simple 3D frame shown in Figure 2. was analysed. Its range is l = 6.00m in both direction and height h = 4.00m. The dimensions of the columns are 30x30cm, while the dimensions of the beam are 30x50cm. Between beams is concrete plate 22cm thick. It is made of concrete C25/30. The foundations of the frame are dimensions 1.00m x 1.00m and the thickness is 0.60m. It is loaded with uniformly distributed load in the amount of 10kN/m^2. The load also includes the own weight of each construction element.

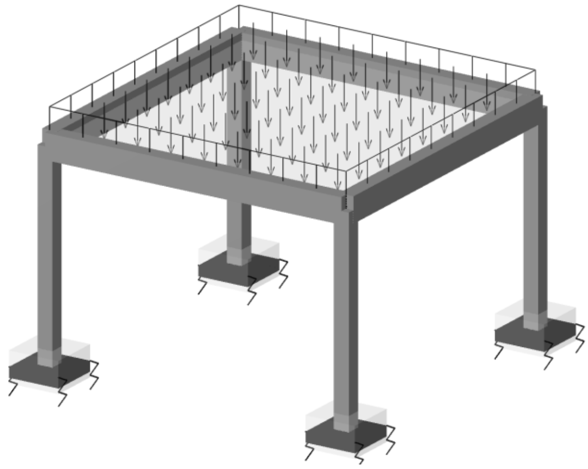

Fig. 2. Simple 3D frame numerical model

4. Impact of the subgrade coefficient value change

4.1. Symmetric 3D frame

All the parameters required for the numerical modelling of the simple 3D frames are known. For the basic numerical model the one with the average value of the subgrade reaction coefficient is taken [9], [11]. The mesh density of FEM is 0.20x0.20m. The characteristic values in a special points of the simple 3D frame are given in Table 1. In the Table 2 are shown the effects of coefficient *k* change on the displacements and maximum and minimum stress under the foundation.

Author	**Subgrade coefficient (kN/m^3)**	**Moment at knot 1 (kNm)**	**Moment at knot 2 (kNm)**	**Moment max. beam moment**	**Moment deviation (%)**
Vesic	104107.95	29.99	5.28	**97.74**	0.28
Biot	162490.76	30.75	7.06	**97.31**	-0.14
Meyerhof & Baike	130208.33	30.36	6.15	**97.53**	0.06
Kloppe & Glock	208333.33	31.19	8.12	**97.06**	-0.42
Selvadurai	84635.42	29.65	4.54	**97.93**	0.47
Average	137955.16	30.46	6.38	**97.47**	0.00

Table 1. Subgrade reaction coefficient and moment values

Author	**Deflection X_{max} (mm)**	**Deflection Y_{max} (mm)**	**Deflection Z_{max} (mm)**	**Max. stress σ_{max} (kN/m^2)**	**Min. stress σ_{min} (kN/m^2)**
Vesic	-1.24	-1.24	-5.61	**245.77**	125.78
Biot	-1.19	-1.19	-4.95	**265.87**	105.42
Meyerhof & Baike	-1.22	-1.22	-5.24	**255.59**	115.85
Kloppe & Glock	-1.17	-1.17	-4.68	**277.82**	93.27
Selvadurai	-1.26	-1.26	-6.03	**237.36**	134.27
Average	-1.21	-1.21	-5.16	**258.22**	113.17

Table 2. Deflection and stress under the foundation

4.2. Non-symmetric 3D frame

Because of better understanding the behaviour of the structure one column was added in a way to change the symmetrical structure to non-symmetrical. That kind of system is shown on Figure 3., while the results are shown in the tables which are following the Figure 3. The same frontal symmetrical 2D frame was observed and its left column.

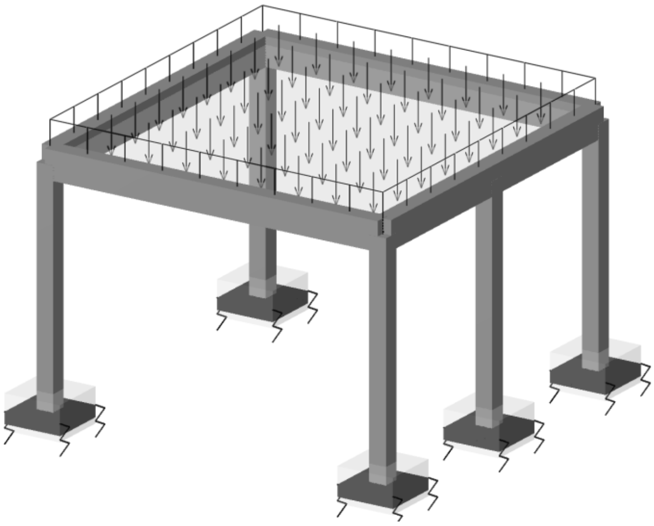

Fig. 3. Non-symmetrical Simple 3D frame

Author	Subgrade coefficient (kN/m^3)	Moment at knot 1 (kNm)	Moment at knot 2 (kNm)	Moment max. beam moment	Moment deviation (%)
Vesic	104107.95	33.71	8.28	**93.09**	0.41
Biot	162490.76	34.48	10.57	**92.49**	-0.24
Meyerhof & Baike	130208.33	34.08	9.40	**92.79**	0.09
Kloppe & Glock	208333.33	34.93	11.91	**92.16**	-0.59
Selvadurai	84635.42	33.39	7.30	**93.36**	0.70
Average	137955.16	34.19	9.70	**92.71**	0.00

Table 3. Subgrade reaction coefficient and moment values

Author	Deflection X (mm)	Deflection Y (mm)	Deflection Z (mm)	Max. stress σ_{max} (kN/m^2)	Min. stress σ_{min} (kN/m^2)
Vesic	-2.38	-1.10	-5.03	**258.51**	93.35
Biot	-2.19	-1.05	-4.48	**280.07**	82.28
Meyerhof & Baike	-2.28	-1.07	-4.72	**269.08**	87.84
Kloppe & Glock	-2.10	-1.02	-4.26	**292.75**	76.07
Selvadurai	-2.50	-1.12	-5.39	**249.38**	98.29
Average	-2.25	-1.07	-4.65	**271.91**	86.39

Table 4. Deflection and stress under the foundation

5. Conclusion

The paper demonstrates the response of the, symmetrical and non-symmetrical, 3D frame on the subgrade coefficient value change. The 3D frame is founded on the square shallow concrete foundation. For the numerical modelling of that connection between the foundation and the soil the Winkler spring model is mostly used. The rigidity of the spring is defined by the subgrade reaction coefficient. Because different expressions given by different authors, the software SE_Calc was developed. It gives us values of the subgrade coefficient by each author as well as the average one. For the purpose of this work it was upgraded by the diagram of the curve families of the subgrade coefficient. Like in the case of the 2D frame the calculation results show that the higher value of the soil reaction coefficient gives less peak moments and fewer vertical displacements of the structure. The situation is more visible on the non-symmetrical system. Consequently this has an impact on the structural elements above the foundation.

The model with the average subgrade coefficient was the basic one for the results comparing. For the deviation of the maximum beam moment the values are within 1.00% for symmetrical part of the structure. Non-symmetrical part of the structure gives greater results dissipation. Values of the vertical displacement vary inside 16%.

Also, from the stress under the foundation point of view the higher subgrade coefficient gives the higher stress and lower vertical displacement of the foundation. Like in the case of 2D frame, from the point of departure of the results the approach of using the average subgrade coefficient seems to be correct. For further development the multiple multi span 2D and 3D constructions as well as the girder one should be analysed.

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