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Behavior of a two-story planar frame for different approach to soil modeling

Vlaho Akmadžić
University of Mostar, Faculty of Civil Engineering, Architecture and Geodesy, prof. Ph.D., vlaho.akmadzic@fgag.sum.ba
Anton Vrdoljak
University of Mostar, Faculty of Civil Engineering, Architecture, and Geodesy, M.Sc., anton.vrdoljak@fgag.sum.ba

Abstract: This paper is a continuation of the research on the influence of different modeling of the subgrade reaction coefficient on the selected static system. This paper analyzes the behavior of a two-story reinforced concrete frame for different foundation dimensions and different values of the subgrade reaction coefficient. It presents an overview of values of these coefficients, which represent the stiffness of Winkler springs with respect to the specific geometry of shallow foundations. The values are different depending on the author, and the average value was used as relevant for comparison. Results of the numerical analysis for an individual reinforced concrete two-story frame were obtained using the SE_Calc and Tower 8 programs. After obtaining the results for each individual frame, they were combined and analyzed.

Key words: Two-story planar frame, subgrade reaction coefficient, Winkler springs, shallow foundations, numerical analysis, SE_Calc

Ponašanje dvokatnog ravninskog okvira s obzirom na različit pristup modeliranju tla

Sažetak: Ovaj rad predstavlja nastavak istraživanja utjecaja različitog modeliranja koeficijenta reakcije tla na odabrani statički sustav. U ovom radu izvršena je analiza ponašanja dvokatnog armiranobetonskog okvira za različite dimenzije temelja i različite vrijednosti koeficijenta reakcije tla. Prikazan je pregled vrijednosti ovih koeficijenata, koji predstavljaju krutost Winklerovih opruga, s obzirom na konkretnu geometriju plitkih temelja. Vrijednosti se razlikuju s obzirom na autora, a kao mjerodavna za komparaciju korištena je prosječna vrijednost. Rezultati numeričke analize za pojedinačni armiranobetonski dvokatni okvir dobivene su uporabom programa SE_Calc i Tower 8. Nakon dobivenih rezultata za svaki pojedinačni okvir, izvršeno je njihovo objedinjavanje i analiza.

Ključne riječi: Dvokatni ravninski okvir, koeficijent reakcije tla, Winklerove opruge, plitki temelji, numerička analiza, SE_Calc

1. INTRODUCTION

This paper is a continuation of the research on the influence of different modeling of the subgrade reaction coefficient (modulus of subgrade reaction) on the selected static system of a two-story planar frame. The previous analysis of a single-story 2D frame supported by square foundations [1] has shown that a higher value of the subgrade reaction coefficient (stiffer foundations) gives lower maximum moments and smaller vertical displacements of the structure. In terms of vertical displacements of the structure, the deviation was about 10%, and the deviation of moments was ± 1%.

It is important to emphasize that different values of the subgrade reaction coefficient are due to different approaches to the same problem by different authors (Vesić, Biot, Meyerhof & Baike, Kloppe & Glock, Selvadurai). In order to be able to observe this influence, the mean value of the subgrade reaction coefficient was calculated and taken as relevant for monitoring the deviations both in the soil and on the structure. For these and educational needs [2], the computer program SE_Calc [3] was developed at the University of Mostar, organizational unit Faculty of Civil Engineering, in 2018. The development of this software solution is still in progress, and some stages are described in several papers [4], [5].

It should be emphasized that coefficients of subgrade reaction are applied in various fields of construction where the foundation-soil interface need to be modeled using Winkler springs [6], [7], [8], [9], [10], [11], [12]. Namely, in the case of shallow foundations, the characteristic soil under the structure is described in a sufficiently reasonable manner by using Winkler springs. To describe its behavior, it is enough to set the appropriate value of the subgrade reaction coefficient (modulus) in the software package for structural calculation. However, since different authors have dealt with these problems, different expressions are obtained. For this reason, this paper tries to provide an answer to the dilemma of proper selection of the appropriate subgrade reaction coefficient.

Numerical analyses of the two-story planar reinforced concrete frame were made, and their results were combined in a table and interpreted.

2. MATERIAL AND GEOMETRIC CHARACTERISTICS OF THE TWO-STORY PLANAR REINFORCED CONCRETE FRAME

The dimensions of the analyzed two-story planar reinforced concrete frame (Figure 2) can be imagined as a floor addition to a single-story frame from [1]. So, the span of the frame is l=6.00 m, and the height is h=4.00 m. Structural elements, columns and beams, are made of concrete C25/30. In the first example, the frame rests on foundations sized 1.00 m × 1.00 m (Figure 1), 60 cm thick. In the second example, these dimensions are 1.20 m × 1.20 m with the same thickness. In the third example, the dimensions are 1.50 m × 1.50 m, also with the same thickness. The effect was monitored only for a vertically uniformly distributed load of 30 kN/m' at the level of each beam. To simulate load combinations, this intensity of 30 kN/m' was multiplied by a factor of 2.0. Thus, the total load of each beam is 60 kN/m' plus the dead load of the structure.

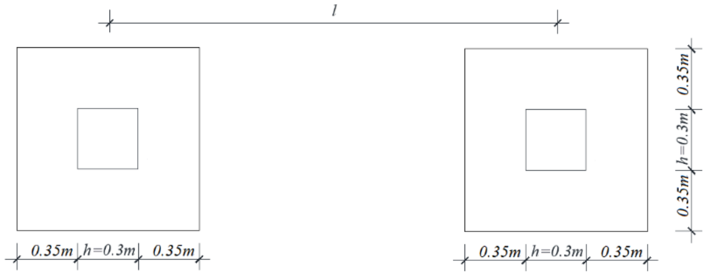

Figure 1. Plan view of the foundations

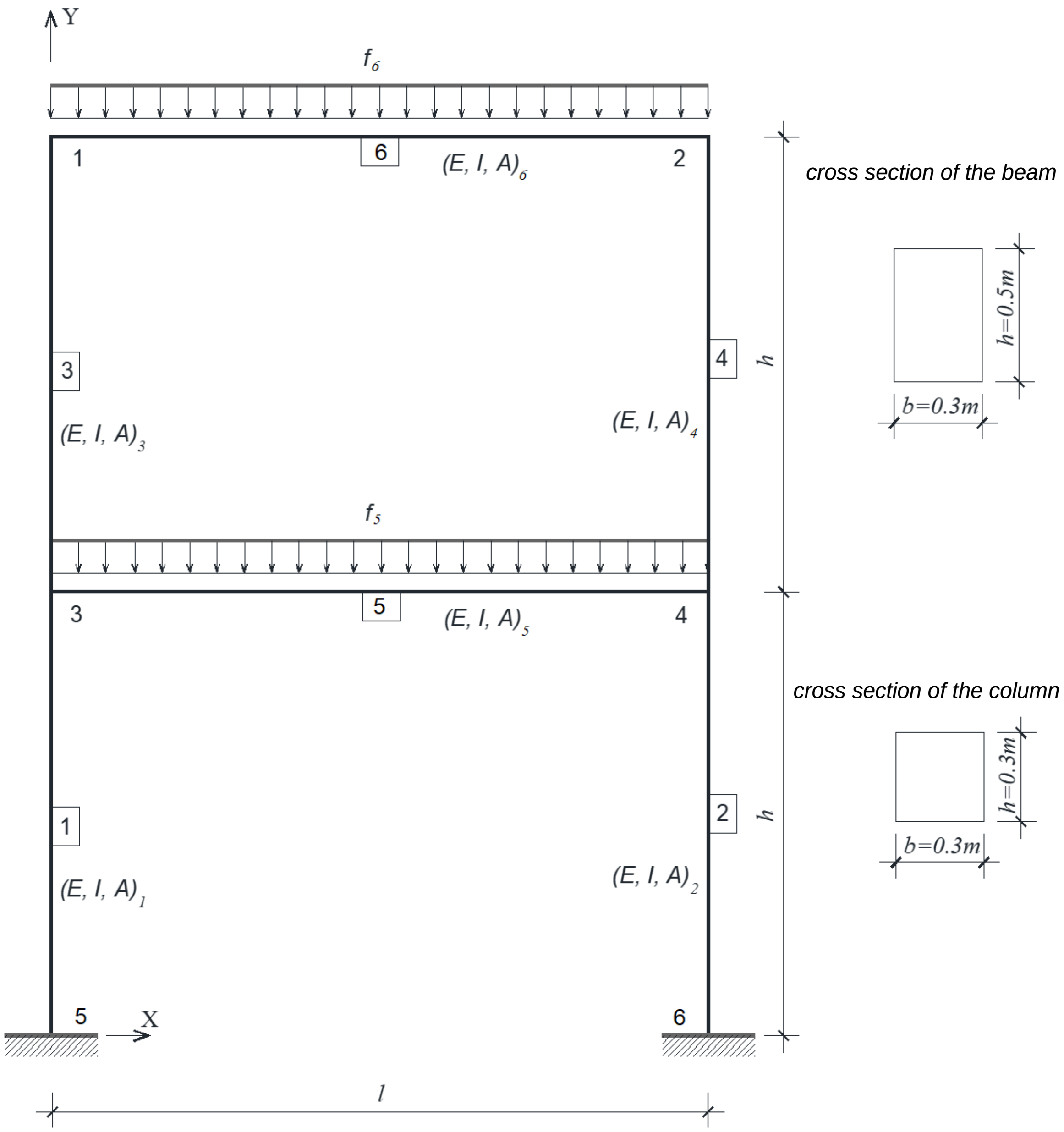

Figure 2. The two-story reinforced concrete planar frame

3. COEFFICIENT OF SUBGRADE REACTION

For the purposes of soil modeling, it is important to know its characteristics, usually obtained after preparing a geomechanical study. Considering that the paper is a continuation of the previous research [1], soil is assumed to be granular here as it was there. The program SE_Calc [3] was used to determine the numerical values of coefficients of subgrade reaction by different authors (Vesić, Biot, Meyerhof & Baike, Kloppe & Glock, Selvadurai) according to the expressions given in papers [1], [4], [5], and the mean values.

The values of the subgrade reaction coefficient for three types of square foundations 1.00 m, 1.20 m and 1.50 m wide and 0.60 m deep are given in the following tables.

Table 1. Comparison of values on the foundation with dimensions 1.00 m × 1.00 m × 0.60 m

Author	Area	**Coefficient**	Average	Deviation
	m^2	**kN/m^3**	kN/m^3	%
Vesić	1.00	**104107.95**	137955.16	-24.53
Biot	1.00	**162490.76**	137955.16	+17.79
Meyerhof & Baike	1.00	**130208.33**	137955.16	-5.62
Kloppe & Glock	1.00	**208333.33**	137955.16	+51.02
Selvadurai	1.00	**84635.42**	137955.16	-38.65

Table 2. Comparison of values on the foundation with dimensions 1.20 m × 1.20 m × 0.60 m

Author	Area	**Coefficient**	Average	Deviation
	m^2	**kN/m^3**	kN/m^3	%
Vesić	1.44	**86756.63**	114962.63	-24.53
Biot	1.44	**135408.97**	114962.63	+17.79
Meyerhof & Baike	1.44	**108506.94**	114962.63	-5.62
Kloppe & Glock	1.44	**173611.11**	114962.63	+51.02
Selvadurai	1.44	**70529.51**	114962.63	-38.65

Table 3. Comparison of values on the foundation with dimensions 1.50 m × 1.50 m × 0.60 m

Author	Area	**Coefficient**	Average	Deviation
	m^2	**kN/m^3**	kN/m^3	%
Vesić	2.25	**69405.30**	91970.11	-24.53
Biot	2.25	**108327.17**	91970.11	+17.79
Meyerhof & Baike	2.25	**86805.56**	91970.11	-5.62
Kloppe & Glock	2.25	**138888.89**	91970.11	+51.02
Selvadurai	2.25	**56423.61**	91970.11	-38.65

4. INFLUENCE OF THE SUBGRADE REACTION COEFFICIENT ON THE DISTRIBUTION OF MOMENTS ON THE STRUCTURE AND STRESS IN THE GROUND

4.1 Average value of the subgrade reaction coefficient

Considering that all parameters for structural modeling (material, geometry, load) and soil modeling (subgrade reaction coefficient) are now known, numerical modeling of different variants can be carried out with the help of the software package Tower 3D Model Builder 8.0 [13]. As previously mentioned, the model with the average value of the subgrade reaction coefficient shown in Figure 3, and on foundations 1.00 m × 1.00 m × 0.60 m, will be used as the base model.

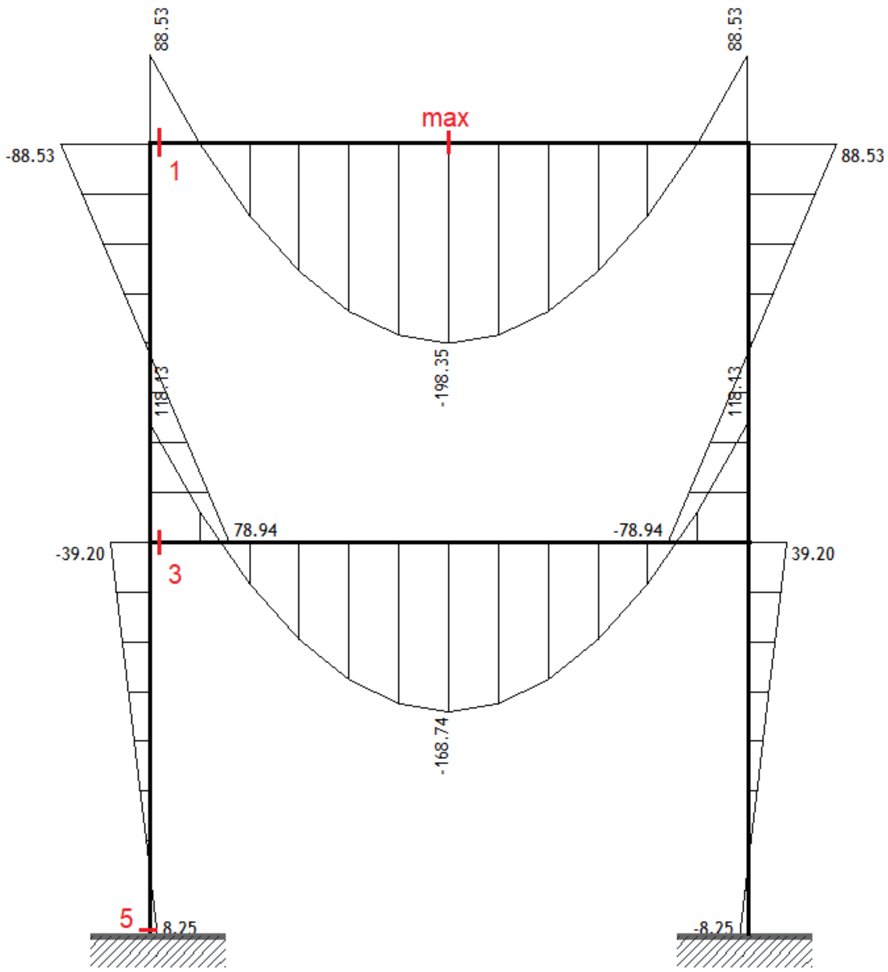

Figure 3. Two-story reinforced concrete planar frame - moment diagram

4.2 The value of moments at characteristic points for the values of the subgrade reaction coefficient obtained by other authors

Due to space limitations, only one diagram of moments on the structure is shown, and other values will be monitored in table form.

Table 4. Comparison of values on the foundation with dimensions 1.00 m × 1.00 m × 0.60 m

Author	Node 1	Node 3	**Node 5**	Maximum	Deviation
	kNm	kNm	**kNm**	kNm	%
Vesić	88.60	117.75	**6.83**	198.27	-17.21
Biot	88.49	118.37	**9.12**	198.39	+10.55
Meyerhof & Baike	88.54	118.05	**7.95**	198.33	-3.64
Kloppe & Glock	88.42	118.72	**10.49**	198.46	+27.15
Selvadurai	88.65	117.48	**5.87**	198.22	-28.85
Average	88.53	118.13	**8.25**	198.35	0.0

Table 5. Comparison of values on the foundation with dimensions 1.20 m × 1.20 m × 0.60 m

Author	Node 1	Node 3	**Node 5**	Maximum	Deviation
	kNm	kNm	**kNm**	kNm	%
Vesić	88.47	118.43	**9.59**	198.40	-14.06
Biot	88.35	119.09	**12.07**	198.52	+8.15
Meyerhof & Baike	88.41	118.76	**10.84**	198.46	-2.87
Kloppe & Glock	88.29	119.43	**13.42**	198.59	+20.25
Selvadurai	88.53	118.13	**8.46**	198.34	-24.19
Average	88.40	118.85	**11.16**	198.48	0.0

Table 6. Comparison of values on the foundation with dimensions 1.50 m × 1.50 m × 0.60 m

Author	Node 1	Node 3	**Node 5**	Maximum	Deviation
	kNm	kNm	**kNm**	kNm	%
Vesić	88.31	119.28	**13.04**	198.56	-10.07
Biot	88.20	119.88	**15.29**	198.67	+5.45
Meyerhof & Baike	88.26	119.59	**14.21**	198.62	-2.00
Kloppe & Glock	88.15	120.16	**16.40**	198.73	+13.10
Selvadurai	88.37	118.98	**11.90**	198.50	-17.93
Average	88.24	119.67	**14.50**	198.63	0.0

4.3 Distribution of stresses and settlements under the foundation

For granular soil and shallow foundations, it is usual to assume a uniform distribution of stresses under the foundation. The linear distribution of stresses is based on the assumption that the cross-sectional geometry is constant (infinite stiffness) [1], [14], [15]. For the needs of a large number of common engineering structures, and for practical reasons, the fact of deformation of the shape of the foundation, soil and their interaction is ignored [15], [16]. That is how it was approached in this example as well. The stress diagram under the foundation (Figure 4) and the settlement diagram (Figure 5) for the example in Figure 3, with a finite element mesh 0.20 m × 0.20 m, is presented as an example.

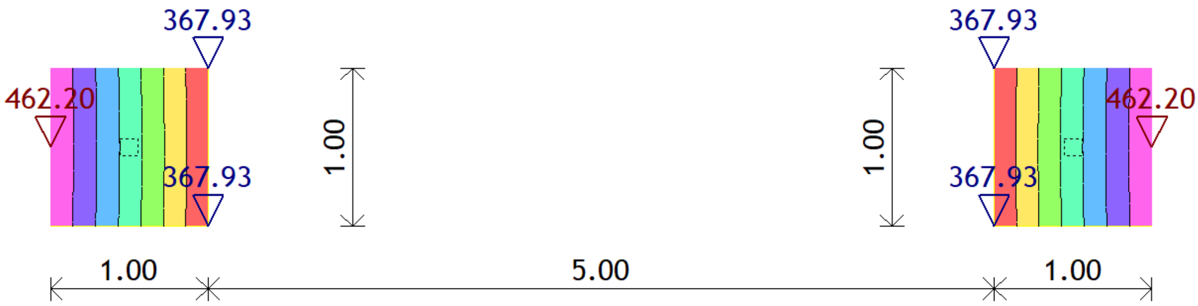

Figure 4. Distribution of stresses (kPa) under the foundation 1.00 m × 1.00 m × 0.60 m - TOWER

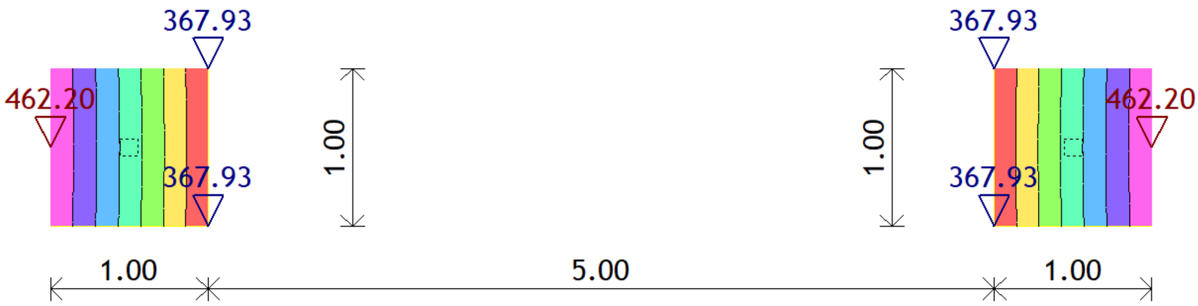

Figure 5. Distribution of settlements (mm) for the foundation 1.00 m × 1.00 m × 0.60 m - TOWER

Due to space limitations and clarity, the extreme stress and settlement values are presented in the following tables for all three characteristic foundations.

Table 7. Comparison of values on the foundation with dimensions 1.00 m × 1.00 m × 0.60 m

Author	σ (max)	σ (min)t	s (max)	s (min)
	kN/m^2	kN/m^2	mm	mm
Vesić	454.16	376.18	-3.61	-4.36
Biot	467.14	362.84	-2.23	-2.87
Meyerhof & Baike	460.50	369.68	-2.84	-3.54
Kloppe & Glock	474.86	354.84	-1.70	-2.28
Selvadurai	448.72	381.74	-4.51	-5.30
Average	462.20	367.93	-2.67	-3.35

Table 8. Comparison of values on the foundation with dimensions 1.20 m × 1.20 m × 0.60 m

Author	σ (max)	σ (min)t	s (max)	s (min)
	kN/m^2	kN/m^2	mm	mm
Vesić	324.51	260.96	-3.01	-3.74
Biot	332.56	252.47	-1.86	-2.46
Meyerhof & Baike	328.56	256.71	-2.37	-3.03
Kloppe & Glock	336.91	247.78	-1.43	-1.94
Selvadurai	320.83	264.78	-3.75	-4.55
Average	329.61	255.60	-2.22	-2.87

Table 9. Comparison of values on the foundation with dimensions 1.50 m × 1.50 m × 0.60 m

Author	σ (max)	σ (min)t	s (max)	s (min)
	kN/m^2	kN/m^2	mm	mm
Vesić	215.26	169.76	-2.45	-3.10
Biot	219.03	165.44	-1.53	-2.02
Meyerhof & Baike	217.23	167.55	-1.93	-2.50
Kloppe & Glock	220.84	163.21	-1.18	-1.59
Selvadurai	213.34	171.86	-3.05	-3.78
Average	217.72	166.99	-1.82	-2.37

5. CONCLUSION

When modeling any structure, we strive for the adopted numerical model to describe as accurately as possible the behavior of the actual structure under the action of different loads. For this modeling, it is necessary to know the characteristics of the soil, which is usually simulated by the Winkler spring model in numerical models for the case of shallow foundations. The characteristics of the spring are set by the subgrade reaction coefficient.

The problem of determining the value of the subgrade reaction coefficient was treated by different authors, and each one of them has given his own solution. The paper does not elaborate the issue of validity of a particular approach. On the contrary, it investigates the structural response of a two-story reinforced concrete frame for different numerical values of the subgrade reaction coefficient.

The value of moments at characteristic nodes, as well as the stress and settlement under the foundation, were monitored by numerical modeling of different combinations (different coefficient values due to different authors and different foundation dimensions).

The calculation results have shown that a higher value of the subgrade reaction coefficient gives less extreme values of the moments at the connection of the column and the last beam. However, on the other hand, it gives greater moments in the field and greater values at the column-foundation connection. As the dimensions of the foundation increase, this phenomenon becomes even more pronounced. Looking at the stresses under the foundation, it can be observed that a higher value of the subgrade reaction coefficient gives higher stress values, while the situation is opposite with settlement, which was to be expected. The effects of asymmetry of load and structure, as well as spatial effects, are not analyzed and are left in the domain of further research.

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