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ANALYSIS OF SUBSOIL MODELING INFLUENCE ON DYNAMIC CHARACTERISTICS OF REINFORCED CONCRETE BUILDING

ANALIZA WPŁYWU MODELOWANIA PODŁOŻA GRUNTOWEGO NA CHARAKTERYSTYKI DYNAMICZNE BUDYNKU ŻELBETOWEGO

A b s t r a c t

The paper is devoted to issues related to creation of subsoil models. At the beginning of the paper, the model of the building chosen for the analysis was described. The procedures for calculation of different models of the subsoil were also described. The final part of this paper presents results of the analysis of natural frequencies of reinforced concrete building with regard to the different models of the interaction between subsoil and the structure, and the conclusions drawn from this analysis are also presented.

Keywords: model of the subsoil, dynamic characteristics, the dynamics of buildings, coefficient of elasticity, modal analysis

S t r e s z c z e n i e

Artykuł jest poświęcona zagadnieniom związanym z kształtowaniem modeli podłoża gruntowego. Na początku opisano model budynku wybranego do analizy. Opisane zostały również procedury obliczeniowe różnych modeli podłoża gruntowego. Końcowa część prezentowanej pracy zawiera wyniki analizy drgań własnych budynku żelbetowego z uwzględnieniem różnych modeli współpracy podłoża gruntowego z konstrukcją oraz wnioski, które z tej analizy wyciągnięto.

Słowa kluczowe: model podłoża gruntowego, charakterystyki dynamiczne, dynamika budowli, zastępczy współczynnik sprężystości K_Z, analiza modalna

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1. Denotations

K	–	substitute modulus of elasticity of soil [kN/m]
K_x, K_y, K_z	–	substitute modulus of elasticity of soil in x, y and z direction respectively [kN/m]
C_x C_y C_z	–	uniform deflection factor in x, y and z direction respectively [MN/m^3]
F	–	foundation area [m^2]
C_0	–	dynamic coefficient of the subsoil [MPa/m]
a, b	–	foundation dimensions [m]
Δ	–	correction factor [m^{-1}]
p	–	static foundation pressure on the soil from characteristic loads [MPa]
Δu	–	total settlement [m]

1. Introduction

Computational methods are now a widely used tool in the building design. Interaction between subsoil and the structure is frequently omitted and replaced by rigid supports. Numerical results (predicted displacements or deformations) derived from the model of the rigid connection between subsoil and the structure are different from those obtained as a result of in-situ measurements. Different models of the subsoil, which were created over the past years (ex. [1–5]), are helpful in this subject.

The subsoil parameters which could be delivered from [6] are used for modeling subsoil in commercial engineering programs. Engineer should be careful when they consider dynamic loads. The parameters of the subsoil used for dynamic modeling should be received from dynamic measurements (according to [7]) or from experience and knowledge of the investigator. In Poland for example this problem could be solved by using procedures included in [8].

In order to illustrate the problem of selection of a subsoil model, an example of reinforced concrete building was made, taking into account its cooperation with the substrate through the use of substitute soil elasticity modulus. Substitute modulus of elasticity of soil K was calculated in two ways: counting "by hand" in accordance with the recommendations contained in [8] and using the subsoil calculator contained in one of the commercial engineering programs. Then, modulus K calculated in this way was used for modal analysis of the building to determine the effect of K on the characteristics of the natural vibration, and in particular on the natural frequency of the structure.

2. The model of the chosen building

The four-storey framed, reinforced concrete building was chosen for analysis. Building dimensions in plan are 20.80 × 18.00 m and the height is equal to 19.70 m. The bearing structure are columns with dimensions of 35 × 45 cm (external columns) and 35 × 35 cm (internal), substrings 35 × 60 cm, ribs 25 × 40 cm, slab with a thickness of 10 cm, and spread footings with dimensions in plan 2.5 × 2.5 m and a height of 80 cm. A stock character of the building was assumed, that is why the estimated load of individual footings are as follows: 3000 kN for the internal feet, 1500 kN for the external feet, and 750 kN for the corner feet.

Three models of the ground were adopted to compare the effect of the method of subsoil modelling on the dynamic characteristics of the building. In the first model, the building is rigidly supported; in the second model, the building is founded on loamy sand (*IL* = 0.1), whereas in the third model: on gravel-clay (*IL* = 0.2). For the last two models, the coefficient *K* was calculated using the recommendations contained in [8] and using the subsoil calculator contained in Robot Structural Analysis. Then, a thus obtained coefficient *K* was used in FEM models of the building and calculations of natural frequency of the building were being made. This has led to five variants of computational model that has been compared to each other. Building model constructed in Robot Structural Analysis is shown in Fig. 1.

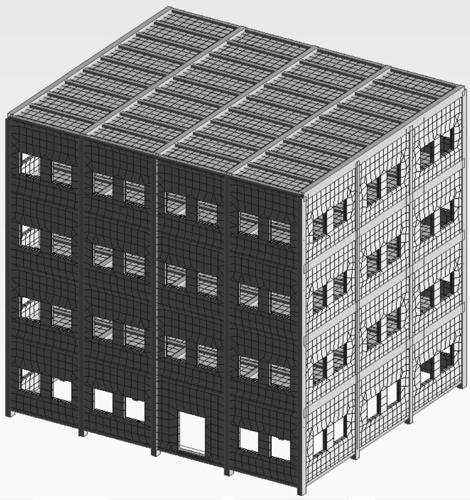

Fig. 1. FEM model of chosen building

3. The calculation of coefficient *K* in accordance with [8]

The procedure of calculation of the dynamic stiffness of the subsoil according to [8] is shown below. This procedure shows detailed calculations made for loamy sand but the algorithm is identical to the second soil.

Loamy sand (IL = 0.1) corresponds to III category of soil (soil medium stiffness: loamy sands, dusts, clay and loam hard plastic, *IL* = 0–0.25). The value of the dynamic coefficient of the substrate C_0 for this type of soil is 16 to 20 MPa/m. For the calculations a value of 16 MPa/m was chosen. The coefficient K_z (substitute modulus of elasticity of soil *K* in *z* direction) in accordance with [8] is calculated from the following formula:

$$K_z = C_z \cdot F. \tag{1}$$

Coefficient C_z contained in the formula (1) is determined using the relationship:

$$C_z = C_0\left[1+\frac{2(a+b)}{\Delta\cdot F}\right]\sqrt{\frac{p}{0.02}} \quad (2)$$

where:

C_0 – was adopted 16 [MPa/m],

$\Delta = 1$ [m^{-1}].

Obtained from the above formulas values of coefficient K_z are listed in table 1.

Table 1

The values of Kz obtained in accordance with [8]

Soil Foundation type	Loamy sands	Gravel-clay
	K_z [kN/m]	
Internal footing	1274000	2069818
External footing	900700	1463582
Corner footing	636900	1034909

It was also necessary to adopt values of the coefficients K_x and K_y, because the elastic foundation in the model takes into account not only the vertical elasticity, but also horizontal elasticity. The coefficients K_x and K_y were determined using the simple relationship:

$$K_x = K_y = 0.7K_z \quad (3)$$

resulting directly from equation (4):

$$C_x = C_y = 0.7C_z \quad (4)$$

4. The calculation of coefficient *K* using subsoil calculator

Using available computer programs is the easiest way to take into account the interaction between soil and the building. The Robot Structural Analysis Professional holds a subsoil calculator, so the building designer can easily determine the modulus of elasticity of the subsoil K_z. The type of foundation (slab, continuous footing, footing), the dimensions of the foundation, and the estimated load must be defined to obtain the coefficient K_z from this calculator. A detailed procedure for calculating the coefficient *K* is contained in [9]. Soil under the foundation is split into bands with a thickness of 0.2 m. The average tension delivered from the formula Boussnesqu'a is determined in the middle of each band. Then, the average subsoil settlement in each band is determined from the relationship between tension and compression modulus. Total settlement is the sum of settlements in successive bands. Total settlement is associated with coefficient *K* by the formula:

$$K_z = {}^{1}\!/_{\Delta u} \quad (5)$$

In Table 2 the values of coefficient K_z obtained from subsoil calculator are summarised.

Table 2

The values of Kz obtained from subsoil calculator of Robot program

Soil Foundation type	Loamy sands	Gravel-clay
	K_z [kN/m]	
Internal footing	202896	163420
External footing	216503	173087
Corner footing	237853	190156

When comparing Table 1 and 2, huge differences can be observed between the values of the coefficient K_z obtained according to standard [8] and values of the coefficient obtained using subsoil calculator. Subsoil Calculator is based on the standard [6], which is used to determine the so-called static modulus of soil elasticity, while the procedure included in [8] is used to determine the dynamic modulus of soil elasticity. Static coefficient K_z is not suitable for dynamic calculations. For this type of calculations, it is necessary to use the dynamic coefficient K_z calculated according to [8].

5. Modal analysis taking into account the different models of interaction between soil and the structure

Differences in the coefficient K_z, although very large, may not lead to significant differences in the dynamic calculations. In order to analyse the influence of the coefficient K_z on quality of analysis, calculations of natural frequency of the building were performed. The three variants of the model were considered: rigid supports and the elastic foundation with to two types of soil using the static and dynamic K_z coefficient. The following table shows the results (first 10 natural frequencies) for all model variants.

Table 3

The values of the natural frequency for all variants of the model

No.	Rigid support	Loamy sand		Clay-gravel	
	Frequency f [Hz]	Frequency f [Hz]		Frequency f [Hz]	
		K_z stat.	K_z dyn.	K_z stat.	K_z dyn.
1	3.16	**2.36**	2.73	2.28	2.83
2	4.07	2.41	2.91	2.32	3.09
3	6.29	4.01	4.72	3.90	4.97

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4	9.15	7.40	8.62	6.98	8.77
5	10.93	7.69	10.00	7.40	10.35
6	11.76	8.55	10.59	8.18	10.96
7	12.20	8.96	10.95	8.63	11.25
8	12.31	9.22	11.33	8.83	11.70
9	12.44	9.33	11.82	9.07	12.19
10	12.87	10.73	12.52	10.32	12.60

The calculation results obtained from the model of the subsoil with the use of dynamic coefficient K_z mostly correspond to real behaviour of the structure (ex. [10]). The results from a rigid support overstates the value of the natural frequency, which can lead to an incorrect assessment of the stiffness of the structure (the higher the frequency, the greater its rigidity). The results obtained from the use of static coefficient K_z underestimate the value of the natural frequency, which are on the safe side.

6. Conclusions

The main purpose of this article is to sensitize designers who use modern FEM programs on calculation results which they obtain. First of all, it is important to verify the algorithm, which is used by the program in the calculations and check if the chosen algorithm is suitable for calculations that we should do. Errors in numerical calculations are not the fault of the program, but the user who did not check their contents.

It is shown in only one aspect of coefficient K_z that, in the case of non-standardcalculations (e.g. such as in this case – the dynamic calculation), the designer should pay particular attention to the quality of the numerical results. In such cases it is always worth to perform even a simple manual check of the results using the recommendations specified by the standards.

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