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ANALYSIS OF THE INFLUENCE OF REINFORCED CONCRETE BEAM-AND-SLAB FLOOR FORMING ON DYNAMIC CHARACTERISTICS OF A BUILDING

ANALIZA WPŁYWU KSZTAŁTOWANIA MODELU STROPU PŁYTOWO-ŻEBROWEGO NA CHARAKTERYSTYKI DYNAMICZNE BUDYNKU

A b s t r a c t

A dynamic response of structures determine its dynamic characteristics, i.e. the natural frequency, the corresponding figures of vibration and damping coefficient. Designing of a building in terms of dynamics lets us interfere in its stiffness and mass which allows the derivation of the structure of the resonance zone early in the design stage. It is known that the larger the value of the natural frequency the greater the stiffness of the whole structure. The article examined how the natural frequencies of the objectchange under the influence of adjustments in the development of the floor model. The main purpose of the analysis carried out in the article was to determine the relationship between stiffness and mass matrices and the results of the modal analysis of the chosen structure. The article hypothesized that the natural frequency is inversely proportional to the mass of the floor raised to a suitable exponent. A formula derived from this relationship has been verified on a number of variants of the building model made in the program for numerical calculation Dlubal.

Keywords: modal analysis, natural frequencies of the structure, dynamic, numerical model.

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

Odpowiedź dynamiczną budowli determinują jej charakterystyki dynamiczne tj.: częstotliwości drgań własnych, odpowiadające im postacie drgań i współczynnik określający tłumienie drgań. Projektując budowlę pod względem dynamicznym można ingerować w jej sztywność i masę co pozwala na wyprowadzenie konstrukcji ze strefy rezonansowej już na etapie projektu. Wiadomym jest, że im większe wartości częstotliwości drgań własnych tym większa sztywność całej konstrukcji. W artykule sprawdzono w jaki sposób zmieniają się właśnie częstotliwości drgań własnych obiektu pod wpływem zmian w kształtowaniu modelu stropu konstrukcji. Głównym celem przeprowadzonych w artykule analiz było ustalenie zależności pomiędzy macierzami sztywności i mas a wynikami analizy modalnej wybranej konstrukcji. W artykule wysunięto hipotezę, wg której częstotliwości drgań własnych są odwrotnie proporcjonalne do masy stropu podniesionej do odpowiedniej potęgi. Wyprowadzony z tej zależności wzór został zweryfikowany na wielu wariantach modelu budynku wykonanym w programie do obliczeń numerycznych Dlubal.

Słowa kluczowe: analiza modalna, częstotliwości drgań własnych konstrukcji, dynamika, model numeryczny

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1. Introduction

Nowadays a civilization progress causes a series of new problems in modern civil engineering. Among them, without any doubts, very relevant is a matter of building dynamics, connected with designing higher buildings (where the most important factor in design is the dynamic influence of the wind) or with occurring new sources of vibration, like underground, railways, mining activities and earthquakes.

One of the dynamic characteristic of the structure is natural frequency, which is also known as resonance frequency. In case of designing buildings subjected to dynamic influence we try to control natural frequencies of the building in a way where we can avoid resonances of a structure. Appropriate control of natural frequencies of the building is possible through the selection of proper values of stiffness and mass matrixes, because those two parameters have large influence on natural frequency of the structure (acc. [1]).

In these article the influence of beam-and-slab floor forming on the dynamic characteristic of a building is taken into consideration, which means finding dependence between forming stiffness or mass matrix on building resonance frequencies. Because of that frequencies which occur, in the real structure the resonance area can be avoided only by changing the forming of the floor.

2. Description of the structure and model variants

The structure analyzed is a reinforced concrete frame structure which has six floors without basement, designed as open-space office building. All reinforced concrete elements were made of concrete C30/37, reinforced with steel A-IIIN, RB-500W. The dimensions of the building in axes are 37.50 × 30.00 m. Beam-and-slab floor is composed of 5 five-span binders with span length 7.50 m, sixteen four-span ribs with span length 7.50 m and unidirectionally reinforced plates with dimensions in rib axes equal to 2.50 m. Floors are supported by internal columns with dimensions of cross section 350 × 350 mm and external columns with dimensions of cross section 350 × 450 mm. The whole structure is completed by internal and external walls, allowing the use of the internal open-space plan. These walls also stiffen the building in both horizontal directions.

The building chosen was modeled in Dlubal RFEM, in thirty-six variants of beam-and-slab floors formation. The cross section of chosen three elements (binder, rib and slab) was modified between each variant. Firstly the limits for the height of binder h_b and rib h_r depending on the elements length were determined (acc. [2]).

$$h_r = l_r \cdot \left(\frac{1}{18} \div \frac{1}{12}\right) = 7.50\,\text{m} \cdot \left(\frac{1}{18} \div \frac{1}{12}\right) = \left(420\,\text{mm} \div 625\,\text{mm}\right) \quad (1)$$

$$h_{db} = l_{db} \cdot \left(\frac{1}{18} \div \frac{1}{12}\right) = 7.50\,\text{m} \cdot \left(\frac{1}{15} \div \frac{1}{10}\right) = \left(500\,\text{mm} \div 750\,\text{mm}\right) \quad (2)$$

In the next step several heights of the elements were determined, all of them had to be included inside determined intervals earlier. The width of each rib and binder were determined according to the formula (acc. [2]):

$$b_{db,r} = h_{db,r} \cdot \left(\frac{1}{2,5} \div \frac{1}{2} \right) \quad (3)$$

Using the above described method, six cross sections of binders were determined numbered from 1 to 6 and four cross sections of ribs were also named from A to D. Determined cross sections were combined into pairs: binder – rib, assuming, that each next two variants have only different cross section of a binder or of a rib. All 9 variants were tested with four versions of slab thickness: 120, 160, 200, 240 mm as presented in Table 1.

Table 1

Different variants of the floor

Rib	Binder						
Symbol:	Number:	**1**	**2**	**3**	**4**	**5**	**6**
	Cross sections [mm]	250 × 500	250 × 550	300 × 600	300 × 650	350 × 700	350 × 750
A	200 × 450	1A	2A				
B	250 × 550		2B	3B	4B		
C	250 × 550				4C	5C	
D	300 × 600					5D	6D

3. Description of foundation, dynamic soil coefficient and computer modeling

Three soil layers were taken:
- humus soil, layer thickness 0.30 m,
- loamy sand with $I_L < 0$, layer thickness 2.20 m,
- half-compact loam with $I_L = 0$, as the deeppest layer.

Building foundations were divided into groups, due to their dimensions. For each group the dynamic soil coefficient was calculated, according to [3] and [4]. It was proven, that the dynamic soil coefficient calculated from relations created by Sawinow for multilayer ground are directly proportional to the square root of the tension on the border of soil – the foundation. This assumption allowed to calculate precisely dynamic soil coefficient for each variant.

The mash consists of 3D square elements with side dimension equal to 0.5 m. Binders were modeled as reinforced concrete beams, cooperated with reinforced concrete slab on width equal to L/6.

4. Analysis of the results

Analyses of calculation results show that with increasing mass of floors, values of natural frequencies are decreasing (com. Fig. 1.)

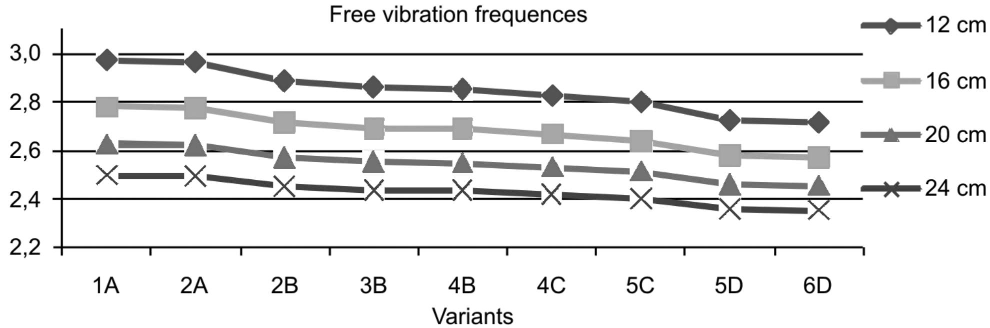

Fig. 1. Changes of the values of first natural frequency depending on the model variant

Inversely proportional character of the dependence between natural frequencies and the mass of the floor was a base to make a hypothesis, according to which natural frequency is inversely proportional to floor mass, raised to the μ power (com.eq. 4).

$$f \cdot M_s^{\mu} = k \tag{4}$$

where:

f – natural frequency of the structure,
M_s – floor mass,
μ – power of floor mass,
k – proportionality constant.

With known values of coefficient μ and *k*, we are able to control floors masses in a way which allows us to obtain desirable natural frequencies of the building. To prove the hypothesis, a series of calculations were made, which proved that for each vibration mode a constant coefficient μ exists, for whose proportional coefficient *k*, for each variant, is also constant.

Masses of each floor are shown in Table 2 and first natural frequencies for each variant were shown in Table 3. Values of coefficient k were calculated using formula (4) with control of value of coefficient μ in such a way to get the smallest differences between all variants. Finally after transforming formula (4), new values of first natural frequencies for different variants of the model were determined, based on M_s, μ and average value of *k* coefficient. Results of this analysis are shown in Table 5.

Table 2

Floor mass for each variant of the model (in tons)

Slab thickness	Variant								
	1A	2A	2B	3B	4B	4C	5C	5D	6D
12 cm	485.39	491.57	527.72	545.77	553.19	568.77	590.53	636.03	644.68
16 cm	589.18	595.36	629.01	646.08	653.50	669.08	689.85	732.86	741.51
20 cm	692.97	699.15	730.31	746.39	753.81	769.39	789.17	829.68	838.34
24 cm	796.76	802.94	831.61	846.70	854.12	869.70	888.49	926.51	935.17

Table 3

First natural frequency of each model variants

Slab thickness	Variant								
	1A	2A	2B	3B	4B	4C	5C	5D	6D
12 cm	2.969	2.962	2.886	2.860	2.852	2.827	2.799	2.723	2.716
16 cm	2.780	2.775	2.714	2.691	2.687	2.668	2.641	2.577	2.570
20 cm	2.626	2.622	2.571	2.552	2.549	2.532	2.514	2.460	2.455
24 cm	2.497	2.495	2.451	2.435	2.433	2.418	2.401	2.356	2.352

Table 4

Value of coefficient *k* for each model variant

Slab thickness	Variant								
	1A	2A	2B	3B	4B	4C	5C	5D	6D
12 cm	27.86	27.92	27.91	28.00	28.06	28.09	28.20	28.18	28.24
16 cm	27.98	28.04	27.97	28.01	28.08	28.12	28.14	28.07	28.11
20 cm	28.03	28.08	27.97	27.98	28.05	28.07	28.13	28.03	28.08
24 cm	28.03	28.09	27.95	27.95	28.01	28.02	28.04	27.94	27.98

Table 5

New values of first natural frequency

Slab thickness	Variant								
	1A	2A	2B	3B	4B	4C	5C	5D	6D
12 cm	2.988	2.975	2.899	2.864	2.850	2.822	2.783	2.710	2.696
16 cm	2.786	2.775	2.721	2.694	2.683	2.660	2.631	2.574	2.563
20 cm	2.627	2.618	2.577	2.557	2.548	2.529	2.506	2.461	2.452
24 cm	2.497	2.490	2.459	2.443	2.435	2.419	2.401	2.365	2.357

Calculation is made for first three natural frequencies of the structure, results are shown in Table 6.

Table 6

Results of natural frequency calculation

Free vibration shape	μ	average *k* value	Average standard deviation of *k* value	Average value of error of *f* value
First mode (longitudinal)	0.362	28.04	0.08	0.23%
Second mode (transverse)	0.345	26.08	0.07	0.20%
Third mode (torsion)	0.330	34.19	0.10	0.21%

5. Summary

The purpose of this paper was to analyze the influence of beam-and-slab floor model on natural frequencies of the building which are the part of dynamic characteristic (ex. [5]). It has been shown that the change in slab forming causes changes in mentioned frequencies and it was shown that these dependences can be presented as exponential equation. This opens new possibilities in designing of the structure subjected to dynamic influence. This gives the possibility of controlling resonance zone only by proper design of the structure instead of installing expensive and difficult to design devices (such as dampers ex.[6–8]) that reduce the influence of vibration on the structure.

In the next step of calculation there are predicted calculation of k and μ for any case. The influence of floor stiffness on natural frequencies of the building will also be considered in future.

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