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ANALYSIS OF THE INFLUENCE OF SHAPING STEEL HALL PILLARS OF ITS DYNAMIC CHARACTERISTICS

ANALIZA WPŁYWU KSZTAŁTOWANIA SŁUPÓW HALI STALOWEJ NA JEJ CHARAKTERYSTYKI DYNAMICZNE

A b s t r a c t

In this paper, the analysis of the influence of the changes in shaping steel hall pillars of its dynamic characteristics, in particular of the value of the natural frequency, has been subjected. The moment of inertia about the axis of the transverse profile of a typical arrangement of the pile and its mass influence on the dynamic characteristics of the steel pillars hall. These factors are different for different types of steel poles profile. The article presents the results of the analysis of the influence of the shape of the three selected types of profiles on the dynamic characteristics of the steel hall. Steel hall selected for the analysis is a workshop, a single nave hall with a frame structure covered with a gable roof. Profile sections of load bearing pillars used for the analysis are: IPE 450, 280 HEB, HEM 220. These profiles were selected due to similarities between stress levels. The evaluation shall assess the influence of such dimensional manipulation on change of the construction costs of the steel hall selected for analysis. Static design and modal analysis was made in Robot Structural Analysis which is FEM engineering program.

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

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

W artykule analizie poddano wpływ zmiany kształtowania słupów hali stalowej na jej charakterystyki dynamiczne, a w szczególności na wartości częstotliwości drgań własnych. Na charakterystyki dynamiczne słupów hali stalowej mają wpływ moment bezwładności względem osi poprzecznej profilu przy typowym układzie słupa oraz jego masa. Czynniki te są różne dla różnych typów profili słupów stalowych. W artykule przedstawiono wyniki analizy wpływu kształtu trzech wybranych typów profili na charakterystyki dynamiczne hali stalowej. Wybrana do analizy hala stalowa to hala warsztatowa, jednonawowa o ramowej konstrukcji przykryta dwuspadowym dachem. Profile kształtowników słupów nośnych użyte do analizy to: IPE 450, HEB 280, HEM 220. Profile te zostały wybrane ze względu na podobny stopień wytężenia. Ocenie podlegał także wpływ takiej manipulacji wymiarowej na zmianę kosztów budowy wybranej do analizy hali stalowej. Wymiarowanie statyczne oraz analizę modalną konstrukcji hali stalowej wykonano w inżynierskim programie Robot Structural Analysis.

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

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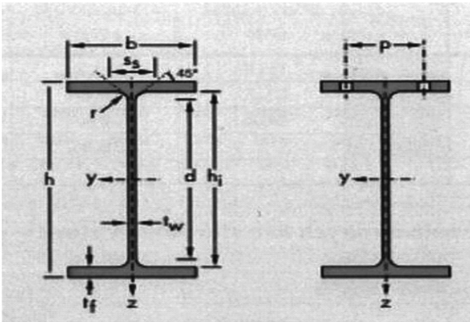
1. Introduction

Dynamic forces and dynamic characteristics of a building determine the dynamic response of structures [1]. It is widely known a relationship between the natural frequency and stiffness of the building – the higher is value of the frequency *f*, the greater is stiffness of the structure. The influence of parameters such as the height or width of the hall on the value of natural frequency is the subject of many studies include [2]. Also under consideration is sometimes influence of static scheme on the dynamic characteristics of halls for example [2].



Oznaczenie Designation Označení	Wymiary Dimensions Rozměry							Wymiary do projektowania Dimensions for detailing Konstrukční rozměry				
	G kg/m	h mm	b mm	t_w mm	t_f mm	r mm	A mm² x10²	h_i mm	d mm	Ø	p_{min} mm	p_{max} mm
IPE 450	77,6	450	190	9,4	14,6	21,0	98,8	420,8	378,8	M 24	100	102

Oznaczenie Designation Označení	Własności statyczne / Section properties / Statické vlastnosti												
		oś y-y strong axis y-y silná osa y-y					oś z-z weak axis z-z slabá osa z-z						
	G kg/m	I_y mm⁴ x10⁴	$W_{el,y}$ mm³ x10³	$W_{pl,y}$♦ mm³ x10³	i_y mm x10	A_{vz} mm² x10²	I_z mm⁴ x10⁴	$W_{el,z}$ mm³ x10³	$W_{pl,z}$♦ mm³ x10³	i_z mm x10	s_s mm	I_t mm⁴ x10⁴	I_w mm⁶ x10⁹
IPE 450	77,6	33740	1500	1702	18,5	50,9	1676	176	276	4,12	63,2	66,9	791

Oznaczenie Designation Označení	Wymiary Dimensions Rozměry							Wymiary do projektowania Dimensions for detailing Konstrukční rozměry				
	G kg/m	h mm	b mm	t_w mm	t_f mm	r mm	A mm² x10²	h_i mm	d mm	Ø	p_{min} mm	p_{max} mm
HE 280 B	103	280	280	10,5	18	24	131,4	244	196	M 27	114	178

Oznaczenie Designation Označení	Własności statyczne / Section properties / Statické vlastnosti												
		oś y-y strong axis y-y silná osa y-y					oś z-z weak axis z-z slabá osa z-z						
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HE 280 B	103	19270	1376	1534	12,11	41,09	6595	471,0	717,6	7,09	74,62	143,7	1130

Fig. 1. adopted steel profiles

The aim of the study is to analyze the influence of the selection of steel profiles of hall pillars on its dynamic characteristics. The scope of work includes: developing a model of the hall using the Robot Structural Analysis, checking the structure under static loads, calculation of the dynamic characteristics of the chosen steel hall for three variants of pillars profiles: IPE 450, 280 HEB, HEM 220 - chosen due to the similar similarities between stress levels as well as analysis of the cost of each profiles. The characteristics of the profiles shown in Fig. 1 by [3]. The scope of work includes analysis of the cost of individual profiles.

The concept of dynamic characteristics are defined as: natural frequencies, mode shapes and damping coefficients. In this study, because of numerical calculation, it was possible to achieve natural frequencies and mode shapes of chosen steel hall. Values of damping ratio of such a structure are possible to obtain only during *in-situ* measurements [4].

2. Description of chosen steel hall

Chosen steel hall is a workshop, a single nave hall with a frame structure covered with a gable roof. Height of the hall is equal 6,06 m in the roof ridge and the cross-section is 18.3 × 54 m in the axes of pillars.

Elements of the steel hall are as fallows:

- bidding rafters – I-section profile IPE 180,
- roof transom – I-section profile IPE 400,
- frame pillars – I-section profile IPE 450 (in the begining),
- steel bracing – cilcular bar ϕ 10 mm,
- roof encaseing – laminar panels 140/100 mm.

Steel used for the structure is S 355.

Connection between the structure of steel hall with the foundation is fixed. Foundation are reinforced concrete feet with the dimensions as fallows: B/L/h: 1,5m/2m/0,56m Length of the span of frame structures is equal 54m, and the frame spacing is 6m. Bidding rafters are placed on roof transoms in spacing equal 3,05m.

3. Numerical model

Chosen steel hall was examined as 2d frame. Numerical model was carried out in FEM program named Robot Structural Analysis [5]. The model assumes the following material coefficients:

- for concrete C20/25 acc. [6]:
  - f_{ck} = 20 MPa – characteristic strength of cylindrical concrete compressive strength after 28 days
  - f_{cm} = 28 MPa – the average value of the strength of cylindrical concrete compressive,
  - f_{ctm} = 2.2 MPa – the average value of the concrete tensile axial,
  - E = 30 GPa –Young modulus,
  - ν = 0.2 –Poissons ratio.

– For steel S355, acc [7]:
  - f_y = 355 MPa – yield strength
  - f_u = 510 MPa – tensile strength,
  - E_s = 200 GPa –Young modulus,
  - G = 80 GPa – Kirchoff modulus,
  - ν = 0,27 – Poissons ratio

Soil – structure interaction was taken into account with using elastic foundation (Fig. 2). Elastic foundation takes into account possibility of settlement occuring and makes model of foundation more realible. After including soil conditions (types of soil in different stratum) the Robot soil-calculator gives as a result value of substitute modulus of elasticity of soil in z-direction called Kz. Values of substitute modulus of elasticity of soil in x and y-direction were calculated according to rules enclosed in [8].

Fig. 2. The definition of the elastic support in Robot

Modal analysis was chosen to obtain natural frequencies and mode shapes of the selected structure [9]. Calculations of these dynamic characteristics of the chosen steel hall were made for three variants of pillars profiles: IPE 450, 280 HEB, HEM 220 as mentioned previously. Mode shapes for all three variants of the structure look almost the same, they differ insignificantly in amplitudes. The two first mode shapes of variant I (profile IPE 450) are presented on Fig. 3 and 4.

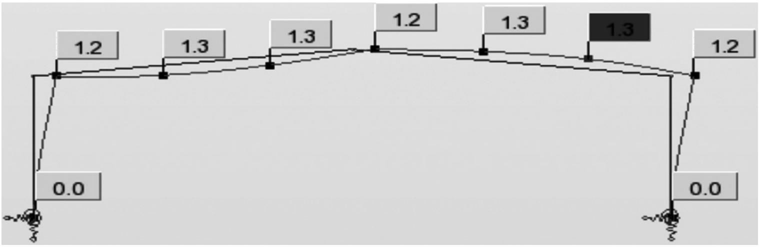

Fig. 3. First mode shape of variant I

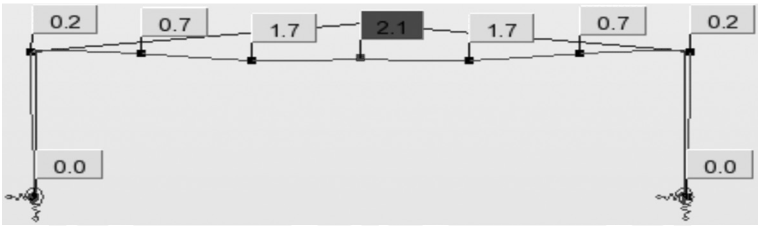

Fig. 4. Second mode shape of variant I

4. Results of modal analysis

Pillar profiles were selected due to similarities between stress levels from I-section type profiles such as IPE, HEB and HEM. The results of analysis shows that changing in pillar profiles influence on dynamic characteristic of whole structure. Values of natural frequencies of selected variants of numerical model are listed in Table 1.

Table 1

Values of natural frequencies for 3 variants

No variant	Section	Degree of effort	Natural frequencies				
			1	2	3	4	5
type of mode shape		–	antisym.	sym.	antisym.	sym.	antisym.
V 1	IPE 450	0,62	4,16	4,19	11,27	17,76	28,14
V 2	HEB 280	0,66	3,46	3,86	10,55	17,15	27,52
V 3	HEM 220	0,69	3,15	3,67	10,17	16,85	27,19

The highest values of frequencies were obtained for basic variant: IPE 450, and the lowest values were obtained for third variant: HEM 220. This results from the fact that factors which determine the values of frequencies are the moment of inertia Iy (according to the axis of local systems as shown in Figure 3) and mass section according to the following formula (ex. [10]):

$$\sqrt{\frac{EI}{m}}$$

where:
E – Young's modulus,
I – moment of inertia with respect to the corresponding axis,
m – mass.

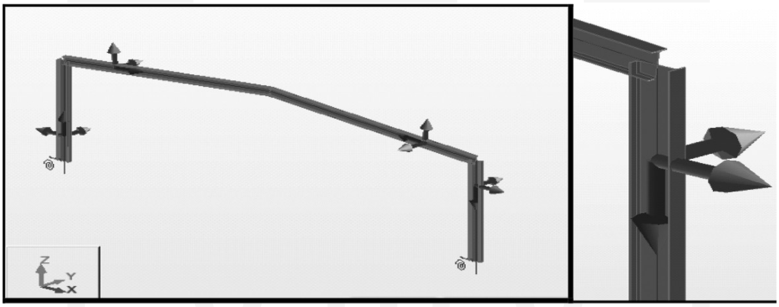

Fig. 5. The local systems of bearing frame elements

Table 2 shows the percent differences in values of natural frequency for three different variants.

T a b l e 2

Differences in values of natural frequencies for the first mode shape

	Variant I	Variant II	Variant III
Frequency for the first mode shape	4,16	3,46	3,15
Difference to the variant I		16,8 %	24,3 %

The difference in natural frequencies of over 24% between I and III variant demonstrates the significant influence of shaping steel pillars on dynamic characteristics of steel hall.

Changing the sections of pillars also effects on costs of the whole building. Prices per kg for each section (acc. [11]) are close to each other for all three variants but when we consider the mass of each section, differences in cost between I and III is almost equal 120 zlotys per section (see Tab. 3).

Table 3

Costs per section

section	Price per kg [zl]	Mass [kg/m]	Price per meter of section [zl]
IPE 450	2,7	77,6	209,52
HEB 280	2,6	103	267,80
HEM 220	2,8	117	327,60

5. Conclusion

This paper was intended to analyze the influence of shaping steel hall pillars on its dynamic characteristics. Selected steel hall has been designed and verified in Robot FEM program in terms of statics. Soil Structure interaction was taken into account through the use of elastic support using for this purpose soil calculator included in Robot and the rules specified by standards.

In order to test the influence of shaping steel hall pillars in its dynamic characteristics, the three variants of the cross section steel pillars were taken for analysis: IPE 450, 280 HEB, HEM 220.

Based on the analysis of the three model variants it can be concluded that the various shaping steel hall pillars has a significant influence on the natural frequency. The differences in results reach approx. 24%. Variant I- section profile IPE 450 showed the highest frequency in the longitudinal direction of the profile (direction of z, cf. Fig. 3). Variants II and III - H sections, which due to a much larger mass and a much lower moment of inertia "Iy" show a lower stiffness in the longitudinal direction z.

The article also performed a cost analysis of individual profiles and found that the profile IPE 450 is the cheapest, or the most optimal for the pillars for this steel hall.

References

[1] Brooks N.B., Newmark N.M. *The response of simple structures to dynamic loads*, Technical Report to Office of Naval Research, University of Illinois, April 1953.

[2] Kwiatkowski T. *Trójwymiarowa analiza dynamiczna ramy nośnej hali stalowej*, Budownictwo 17,119–128.

[3] Bogucki W., Żyburtowicz M., *Tablice do projektowania konstrukcji metalowych*, wyd. 7, Arkady, Warszawa 2007.

[4] Flaga A., Szulej J., Wielgos P., *Comparison of determination methods of vibration's damping coefficients for complex structures*, Budownictwo i Architektura 3, 2008, 53–61

[5] Autodesk Robot Structural Analysis Professional. Verification Manual for American Codes, March 2014.

[6] Eurokod 2, PN-EN 1992-1-1:2008 Projektowanie konstrukcji z betonu.

[7] Eurokod 3, PN-EN 1993-1-1:2006 Projektowanie konstrukcji stalowych.
[8] PN-80/B-03040 Foundations and supporting structures for the machine. Calculation and Design (Polish Standard).
[9] H e J., F u Z. F., *Modal Analysis*, Elsevier 2001.
[10] Osiński Z., *Teoria drgań*. PWN Warszawa 1978.
[11] http://www.a20.pl/10010 (14.01.15 r.).