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IMPACT OF THE SELECTION OF DIFFERENT COMPUTATIONAL MODELS OF PARTITION WALLS FOR STRUCTURE RESPONSE DUE TO VIBRATIONS CAUSED BY CAR TRAFFIC

WPŁYW WYBORU MODELU OBLICZENIOWEGO ŚCIAN DZIAŁOWYCH NA ODPOWIEDŹ BUDYNKU NA DRGANIA SPOWODOWANE RUCHEM SAMOCHODÓW

A b s t r a c t

Creating a computational model of the existing building, in which there are non-structural components, taking into account a variety of operating factors, possible reassignment of objects and the accompanying load changes cause doubt about which scheme of work of the partition wall should be applied. This paper presents an analysis of the effect of vibration caused by the use of cars for people staying in the building, depending on the different computational models of heavy type partition walls. The selection of work schemes of elements in the structure is not always clear from its purpose and should be adapted to the purpose it serves. The study shows four alternative models of work and analysis of the partition walls in the building, which use the kinematic loading resulting from car traffic as an ordering criterion adopted for the analysis of computational models, the influence of vibration on people in the buildings in accordance with the PN-88/B-02171 standard. As proved by the calculations performed for the chosen residential building, the differences between the responses applied to the excitation reach several percent. In order to estimate the safely comfort of the inhabitants, the computational model should take into account any possibility of changing the work schemes of elements, which would appear to have no effect on the estimated parameter.

Keywords: traffic induced vibrations, non-structural components, impact of vibrations on people

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

Budując model obliczeniowy budynku istniejącego, w którym elementy niekonstrukcyjne ze względu na różnorodne czynniki eksploatacyjne, ewentualne zmiany przeznaczenia obiektów i towarzyszące temu zmiany obciążeń, nasuwają się wątpliwości co do przyjmowania schematów ich pracy. W opracowaniu przedstawione są analizy wpływów drgań spowodowanych ruchem samochodów na ludzi przebywających w budynku w zależności od alternatywnych modeli obliczeniowych ścian działowych typu ciężkiego. Dobór schematu pracy elementu w konstrukcji nie zawsze wynika z jego przeznaczenia i powinien być dopasowany do celu, któremu służy. W opracowaniu dobrano cztery alternatywne modele (pracy i analizy) ścian działowych w budynku, który poddano obciążeniu kinematycznemu pochodzącemu od ruchu samochodów. Jako kryterium szeregując przyjęte do analizy modele obliczeniowe zastosowano wpływy drgań na ludzi w budynkach zgodnie z normą PN-88/B-02171. Jak wynika z obliczeń dla przyjętego budynku mieszkalnego różnice pomiędzy odpowiedziami konstrukcji na zadane wymuszenie wynoszą kilkanaście procent. Dążąc do bezpiecznego oszacowania komfortu przebywania ludzi w budynku należy w modelach obliczeniowych uwzględnić ewentualne możliwości zmian schematów pracy elementów, które wydawałoby się, że nie mają wpływu na szacowany parametr.

Słowa kluczowe: drgania komunikacyjne, drgania drogowe, elementy niekonstrukcyjne, wpływy drgań na ludzi

1. Introduction

When analysing the response of a structure subjected to vibrations caused by communication influences, one is often faced with the dilemma of how to take into account the response of the secondary structure elements when analysing the object. These so-called "non-structural" elements affect the dynamic characteristics of the structure. By increasing the mass of the structure, they change frequencies, mode shapes and damping of the object. In many cases (especially in case of inappropriate construction), they may change the stiffness of the whole structure.

According to the standard provision [1] regarding the mass of the object beyond its constant part Q'_k, one must add a part of the long-term variable load Q''_k according to the relationship:

$$m_k = \frac{Q'_k + \lambda \cdot Q''_k}{g} \tag{1}$$

wherein the value of participation factor λ depends on the purpose of the building and is equal to:
$\lambda = 0.4$ for residential buildings and public utility buildings,
$\lambda = 0.6$ for other types of buildings.

Additionally, when designing a building, it is recommended to consider its work in three stages of construction:

- building subjected to constant load, excluding loadings due to finishing works (taking into account only the weight of structural elements),

- completed building (including the loads resulting from finishing works), but without the variable loadings,
- completed building, loaded with a constant load with reduced, according to the formula (1) long-term part of the variable load.

The study shows the influence of traffic induced vibrations on people residing in buildings, depending on the approach to taking into account the partition walls in the facility, which are treated as a constant load. The value of the operating load was assumed as 2.0 kN/m^2.

As defined in [2, 7], a partition wall is a vertical partition that separates an inner space inside the object. Its removal should not affect the behaviour of the structure as a whole. Due to the additional features, which the partition wall can perform, it reaches different weights, and therefore appears in a heavy variant (made of bricks or breezeblocks) and light variant (made of gypsum boards fixed to wood or steel frame, etc.).

During the designing process, a partition wall can be treated as a linear load located in a specific place or as a surface load, which is equivalent to the weight of the partition wall. In order to assume the partition wall as a linear load, it should not be fixed to the adjacent walls and its transverse rigidity should be zero. There is no material that satisfies such requirements; therefore, partition walls have an effect on the structure response to load of dynamic character.

The paper presents an example, which includes four ways of taking into account partition walls in the building.

- Fig. 1. Model 1 – partition wall treated as a linear load located at the line dividing space of the room. It is a typical example of a partition wall that satisfies the definition
- Fig. 2 Model 2 is an equivalent of the partition wall in the form of a surface load often used in “open-space” areas.

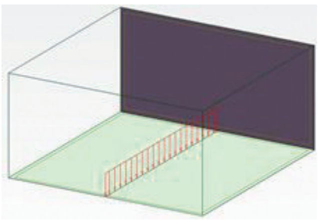


Fig. 1. Model 1 partition wall regarded as a linear load

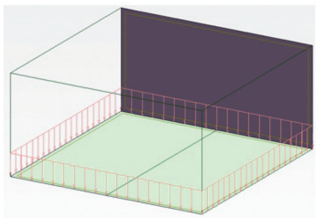


Fig. 2. Model 2 partition wall regarded as a substitute surface load

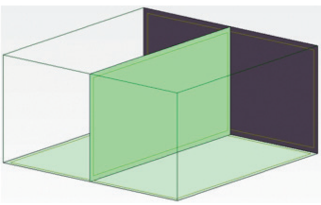


Fig. 3. Model 3 partition wall fixed peripherally to the structure

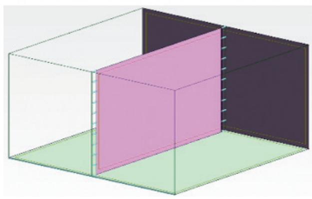


Fig. 4. Model 4 partition wall connected with the structure on vertical sides

- Fig. 3. Model 3 – damaged partition wall where the ceilings are placed on it, and in addition, the partition wall is connected to the side walls.
- Fig. 4. Model 4 – damaged partition wall where the ceilings are placed on it and the partition wall is not connected to the side walls

In the analysed example, it is assumed that the partition wall is a heavy type – the volumetric density exceeds the value of 10 kN/m^3. In the case of static-strength analysis, it is often assumed as a surface replacement of the partition walls, which depends on the dimensions of the obtained surfaces. Its value changes from 0.25 kN/m^2 to 1.25 kN/m^2. In the analysed example, partition walls have a thickness of 14 cm and are made of a material with a volumetric density of 15 kN/m^3, which, taking into account walls in the analysed object, can be replaced with an equivalent surface load of the 1 kN/m^2.

It was assumed that during construction of the partition wall, between the top edge and the roof, a gap of 1 cm was left, which is filled with a material with a Young modulus E = 10 MPa. The response analysis of the structure due to the load caused by the movement of the car around the equilibrium position resulting from the static analysis of the structure, established after applying loads resulting from constant and variable loads, was considered. If the deflection value of the floor at the location of the partition wall is aligned with the dimension of the space between the upper edge of the partition wall and the bottom of the ceiling, then the calling rests on the partition wall, causing it to cooperate in the transfer of loads.

However, it should be noted that for the 3rd and 4th variant, partition walls are involved in the load transfer, but in elastically – the amount of loads gathered from the floor slabs depends on the stiffness of the supports and the bearing walls.

When analysing the response of the structure due to the dynamic load, it is good to know its dynamic characteristics, particularly natural frequencies. As is apparent from the literature [3–4], including non-structural elements has little effect on the change in basic frequency vibration. However, the response of the building (especially in the case of effect on people inside) to the dynamic forces particularly affects “local” vibrations. These are vibration components for which the share of modal mass in the form of natural vibrations is similar to the share of the mass of the structural element extracted from the structure. Table 1 shows the analysis of the natural problem in case of the local structure segment for the solutions adopted in partition walls modelling.

Table 1

Natural frequencies of the calling slabs for different models of partition walls

Nb	Model 1	Model 2	Model 3	Model 4
[–]	[Hz]	[Hz]	[Hz]	[Hz]
1	4.78	4.19	24.41	12.22
2	27.63	19.65	32.95	38.49
3	37.98	27.42	47.47	43.39

As shown in Table 1 the initial local frequencies of the structure in which the walls are treated as linear load (model variant 1) achieve the lowest value and are close (in the case of the first natural frequency) to the frequency vibration in case of model 2. For model variant 3 and 4, the initial frequencies are significantly higher, which is understandable, as the partition wall acts as a support, the stiffness increases with the amount of fastening the wall itself, but also with the amount of deflection of the floor slab. Therefore, during the analysis of the structure response, the ratio variable loads influence λ is quite an important parameter.

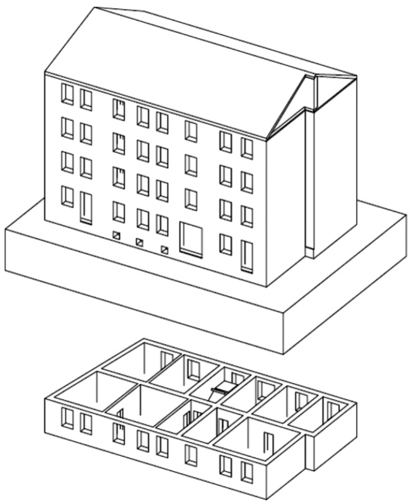
2. Analysed problem description

Computational analysis was carried out on four-storey building with a basement, constructed with traditional technology. All walls were made with full bricks. Thickness of the walls amounted, respectively: the outer walls 51 cm, internal longitudinal walls 38 cm. The ceilings were made with reinforced concrete with a thickness of 12 cm, the roof was made as a wooden rafter framing. The building was built on the brick continuous footing with a width of 60 cm at a depth of 2.9 m below ground level. The numerical model was created using the following materials:

- Concrete (floors and staircases) – Young modulus E = 20.0–26.00 GPa; Poisson's ratio $\nu = 0.2$, mass density $\rho = 2450$ kg/m^3,
- Brick (bearing walls and foundations) – Young modulus E = 2.0 GPa, Poisson's ratio $\nu = 0.25$, mass density $\rho = 1600$ kg/m^3,
- Filling material above partition walls – Young modulus E = 10 [MPa], Poisson's ratio $\nu = 0.4$,
- Wood – Young modulus E = 9.0 GPa, mass density $\rho = 650$ kg/m^3.

In the analysis, the following values of live load were applied:

- in residential areas 2.0 kN/m^2,
- on staircases an corridors 2.50 kN/m^2,

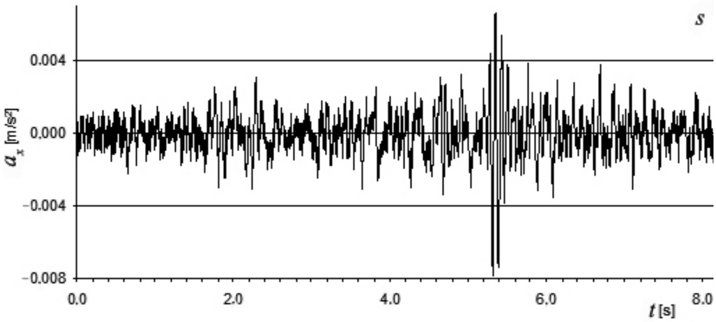


Rys. 5. FEM model of the analysed building

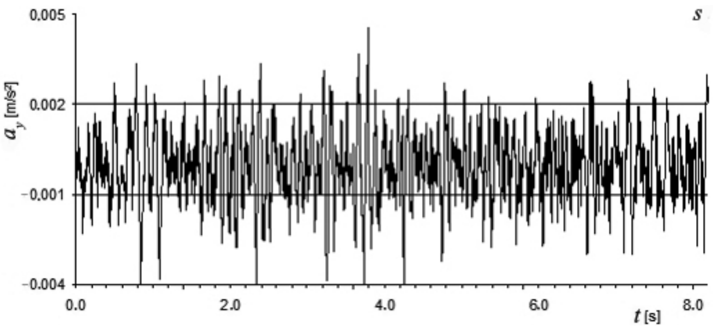
In the building, there were only surface elements – ceilings and walls; therefore, they were modelled as shell elements. Due to the minor importance of the roof structure, it was modelled as a surface element with characteristics corresponding to the isotropic wooden shell with static rigidity corresponding to the real roof structure.

The calculations were performed using direct integration of equations of motion assuming the integration step as $\Delta t = 0.001$ s. The dynamic load of the object constituted kinematic excitations described in the time domain by accelerations, which have been measured on the analysed object. Those accelerations were taken from the vibration database created at the Institute of Structural Mechanics, Cracow University of Technology. Those excitations were applied in model supports – interface of the building with the ground. Exemplary excitations in the form of acceleration waveforms are presented on Fig. 6–8. As a result of structure loading using the analysed vibrograms, the highest values of WODL during the measurements performed on the real object were obtained.

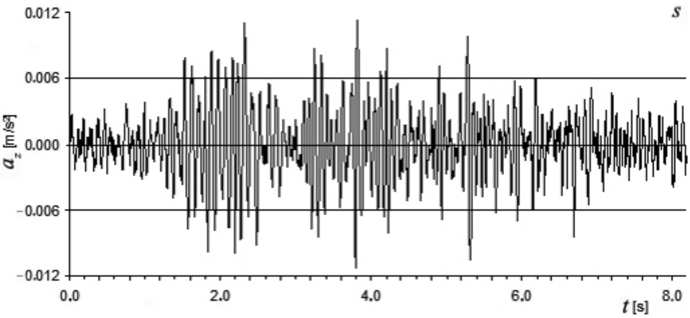
Due to the fact that in all of the analysed floor model reactions on the ground caused by static loads are similar and differences in the global (in the object as a whole structure) dynamic characteristics of the object are similar; therefore, any load difference originating from passing cars can be neglected. Results of the influence on people (prepare according [5–6]) staying inside on floor 4 for each of the floor models are visualised in Figures 9–12.



Rys. 6. Acceleration of the building foundation in the direction of its longer axis due to moving truck



Rys. 7. Acceleration of the building foundation in the direction of its shorter axis due to moving truck



Rys. 8. Acceleration of the building foundation in the vertical direction due to moving truck

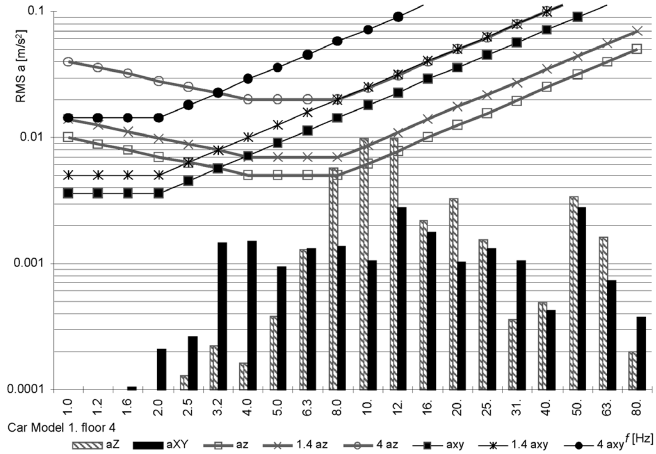


Fig. 9. Impact of vibrations on people staying on floor 4 for model variant No. 1

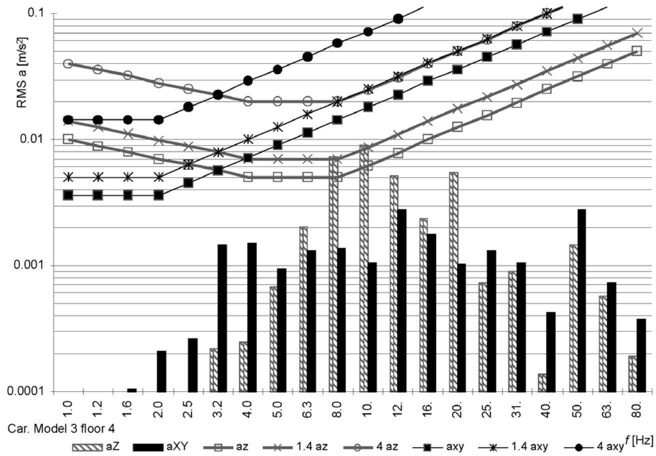


Fig. 10. Impact of vibrations on people staying on floor 4 for model variant No. 2

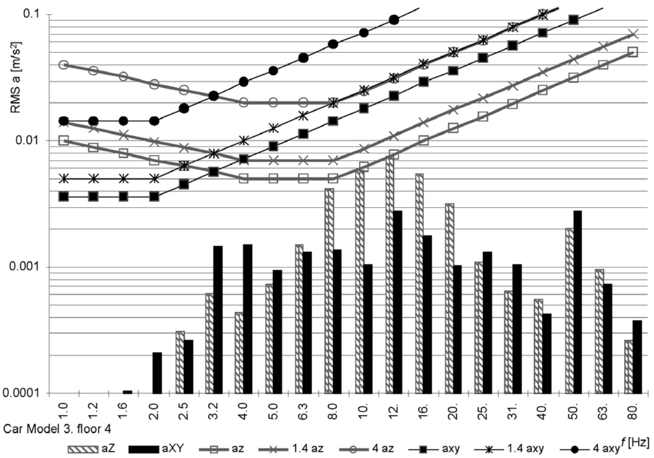


Fig. 11. Impact of vibrations on people staying on floor 4 for model variant No. 3

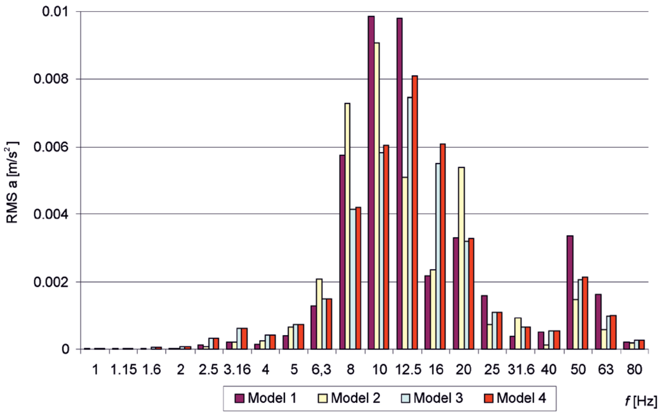


Fig. 12. Impact of vibrations on people staying on floor 4 for model variant No. 4

As it is evident from the analyses in case of omissions impact rigidity of partition walls (Fig. 9–10), we obtain the most unfavourable RMS value in the vertical direction. The limit perceptibility of vibrations by people is reached, whereas for the floor model variant No. 1, exceeding of the border of perceiving vibrations is higher. Taking into account the stiffness of the partition walls (Fig. 11–12), it lowers the threshold of perceptibility of vertical vibration.

3. Conclusions

Comparative analysis of the vibration perceptibility originating from car traffic (Figure 13) shows that the method of constructing partition walls (which followed proper computational model assumption) has an impact on the results obtained for the comfort of inhabitants. For the analysed building (Table 3), these differences reach 50% in the range of dominant frequencies of vibrations. Distribution of extreme values of influence of vibrations on people suggests that if the vibrations are caused by the use of cars, the magnitude of the effects of vibrations on humans increases with the level of the building.

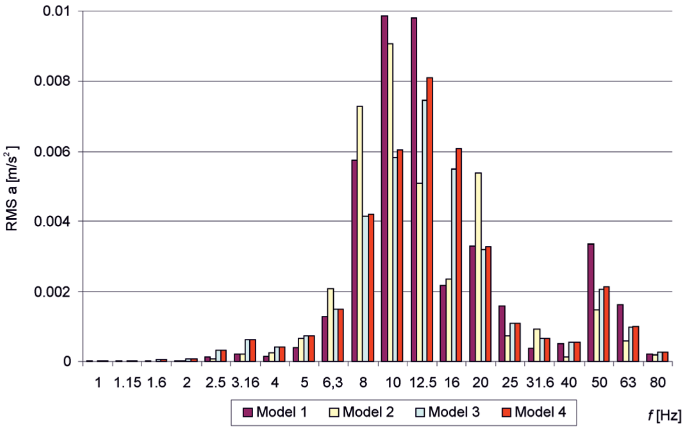


Fig. 13. Influence of vertical vibration on people in building for floor model variant No. 1–4

In the analysed structure, assumption of linear nature of this growth is a good fitting of trend line as evidenced by the determination coefficient (R2 > 0.9). The extreme values of the vibrations' influence on humans listed in Table 3 suggest that the responses of the structure are similar for FEM model 1 and 2 as well as for model 3 and 4. However, analysis of the response in the full frequency range (Fig. 13) shows that it is not. Along with the change of the model, the dominant frequency of the structure response is also changing. During construction of partition walls, the type of its support must be therefore chosen to "move away" from the dominant frequency excitations.

Table 2

Extreme values of vibrations' influence on people (WODL) – the ratio of the RMS value to the threshold of perceptibility of vibrations

FLOOR		1	2	3	4	Trend line	R^2
Model 1	WODL	0.42	0.77	1.16	1.59	0.3912x + 0.0085	0.9980
	f	10.0	10.0	10.0	10.0		
Model 2	WODL	0.39	0.71	1.07	1.46	0.3598x + 0.0078	0.9980
	f	10.0	10.0	10.9	10.0		
Model 3	WODL	0.25	0.45	0.68	0.96	0.2586x + 0.0274	0.9890
	f	10.0	10.0	10.0	10.0		
Model 4	WODL	0.26	0.47	0.71	1.04	0.2364x + 0.0053	0.9960
	f	10.0	10.0	10.0	12.5		

As is apparent from the obtained results, a replacement of the partition walls with equivalent load – Model 1 and Model 2 (which appears to be less labour-intensive during FEM modelling), is safer in terms of its impact on people (vibrations generated by traffic load) than the introduction of additional FEM elements in the form of partition walls (Model 3–4), which significantly increase the size of the computational task.

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