Influence of Different Structural Solutions for Dynamic Response of the Modernized Building

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Abstract. During modernization of the building where comfort threshold of people staying inside is exceeded we should solve the problem comprehensively. Implemented solution which fulfilled expectations of the designer is not always correct in the other (apparently similar) conditions. This paper describes an attempt to interference with the stiffness of the floors of a residential building in order to achieve comfort of people staying inside. It is disturbed by car passing the way located 20 meters from building. Investigated object is a two-storey apartment building with basement, typical for the '70s. It is characterized by compact design (block in the form of a cuboid) and low vertical stiffness of floors, where horizontal partitions (walls) are supported by identical system of walls. In the study it is discussed the desirability of interference with the construction of the building and 5 variants of floor structure were carried out. Those variants constituted reinforced concrete slabs with thicknesses of 10, 12, 14 and 16 cm as well as existing reinforced concrete slab supported by steel beams made of IPE 180 spaced every 2 m. This procedure was applied on every residential storey. Criterion to rank applied solution was comfort of the people staying inside the building according standard PN88 / B-02171 - Evaluation of vibrations influence on people in buildings. As follows from the analysis interference in floors stiffness in the present case does not bring the required results. The reason for this is that an essential component of the vibration of the building is its movement as a solid. Change in time of the configuration of internal components constitutes little impact on the comfort of the people staying inside. In addition, based on analysis of the responses floors of the building on two floors, it is concluded that even in the same building in the application of the solution (which in terms of static should be the same) construction does not always result in similar effects. The reason of different floor responses at different levels is that they are separated by elastic damped medium, which change boundary conditions seemingly similar structural components. An additional aspect is the path length of wave propagation affecting the amplitude-frequency characteristics of extortion of selected floor slabs. Therefore, repeating selected structure solution should only occur after completing the calculation.

1. Introduction

Vicinity of the thoroughfare often causes vibrations transmitted by ground and caused by passing wheeled vehicles. Vibrations of the building foundation constitute its kinematic extortion, generate
inertia forces loading additionally the structure and cause the movement of the building, which affects vibration comfort in rooms where people reside.

In the presented paper, among many factors affecting level of vibrations transmitted to people in the building, influence of floor stiffness, which provides necessary comfort in term of vibration is analyzed. Due to the fact that analyzed building has two levels where there are people, both have the same structural solution of partition walls. This made it possible to compare among themselves the effect of vibrations on people on both floors.

Evaluation criterion of vibrations transmitted to people staying inside building (e.g. passive reception of vibrations) was adopted according Polish standard [1], which content refers to the ISO standard [2]. RMS of accelerations in 1/3 - octave bands were analyzed, comparing them with threshold values of vibrations perceptibly by the people as well as comfort thresholds. This coefficient is called WODBO in the amendment Polish PN-88 / B 0271 code.

2. Measuring procedure

In analyzed building, which was located 23 m from the road, there were chosen measuring points in such a way that in the rigid node of structure the measuring point P1 was established (according to Polish code [1] on the foundation or on a basement wall at ground level) in order to obtain vibrations describing kinematic extortion of building (here acceleration). Two subsequent measurement points were located on the first - point P2 and second - point P3 floor (at the center of its spans), where vibrations transmitted to inhabitants were recorded. Notation of measurement points are shown in Figure 1.

![Figure 1. Location of measuring posts](image)

Obtained during measurements accelerations were used to assess the effects of traffic induced vibrations on people as well as to verify the computational model of analyzed building. During dynamic investigations 36 measurements associated with moving vans, trucks and buses was carried out. A part of the measurement protocol is visualized in the Table 1.

During measurements types of vehicle causing vibrations were identified, as well as its distance (road side) from the vibration receiver. Because of the application of appointed model in assessing the impact of vibrations on people in buildings following criterion for acceptance of building model was adopted. It was result of the compliance assessment of the vibration effects on people obtained on the lower and upper floor of the building on the basis of measured vibrations and calculations of building model subject registered during measurements kinematic extortions. Gaining - in the frequency bands corresponding to the highest values of RMS - accelerations, which do not differ by more than 30% of the values obtained from direct measurement is considered to be condition of acceptability of the computational model (see. [3], [7]).
Table 1. A part of the measurement protocol

| Test event | P1       | P2               | P3               |
|------------|----------|------------------|------------------|
|            | x        | y                | z                |
|            | cm/s²    | cm/s²            | cm/s²            |
| ground level |          |                  |                  |
| M 1 - truck TIR side B | 1.04   | 0.78             | 2.34             |
| M 2 - truck TIR side B | 1.32   | 1.04             | 2.63             |
| M 3 - truck TIR side A | 0.32   | 0.34             | 0.65             |
| M 4 - 2 trucks TIR side A | 1.24   | 1.21             | 2.29             |
| M 35 - truck side. A | 0.41   | 1.21             | 0.91             |
| M 36 - truck TIR side A | 1.17   | 1.25             | 2.03             |

Subsequent analysis concerned different models of the building, in which type of ceiling by mean of its height was changed (reinforced concrete slab of varying thickness and alternatively reinforced concrete floor supported by steel beams). Assuming previously measured kinematic extortion, vibrations at points located on floors were analyzed in order to evaluate effect of vibrations on people. In this way, information about the impact of the floor structure type to vibrations transmitted to the people in the building were obtained.

3. Analyzed building and source of vibration

For exemplary analyzes a single-family building, located at a distance of 23 m from the road with damaged surface was selected. Poor technical condition of the road affected generation by vehicles significant vibration of the building. Analyzed single-family building is a rectangular facility, in a plan has a rectangular shape 10.5x10m, height of the building is 9.0m. Foundations of the building were made of concrete class C12.5/15, walls - below the ceiling of the first floor walls were made of concrete class C15/20 (20 cm) whereas above of brick K1 bonded with cement-lime mortar (28cm thick). Floors were made as reinforced concrete slabs alternatively, reinforced concrete slabs on steel beams. Measuring points were located in the middle of the floor span ceilings, more specifically on floors with the largest spans. Most unfavorable (intense) vibrations were recorded during truck passages (TIR). Figure 2-4 shows exemplary vertical components of acceleration recorded during one of these rides. Since change in slab thickness does not significantly affect dynamic load of analyzed building as well as its rigidity, it was assumed that the extortion for each of the analyzed FEM model will be accelerations registered in the point P1, an example of which is given in Figure 2.

Figure 2. Vertical vibrations registered in the fixed structure during truck passage on the road with damaged surface
Figure 3. Vertical vibrations registered on the lower floor during truck passage on the road with damaged surface

Figure 4. Vertical vibrations registered on the top floor during truck passage on the road with damaged surface

Analysing accelerations showed in Figure 3 and 4 in accordance with procedure described in [1], author obtained RMS values of floors vibration acceleration for particular 1/3 - octave bands. Analysis results are shown in Figure 5.

Figure 5. Result analysis of vibration presented on Figs 3 and 4 in order to evaluate effect of vibrations on people staying on first and second floor of the building
This figure also shows lines - included in Polish standard - matching the threshold of perceptibility vibration by people [7] in a direction parallel (the lowest solid line) and perpendicular to the axis of the spine (the lowest dotted line). Vertical vibrations transmitted from floor, inhabitants could receive being seated or standing (in the day) as vibration parallel to the axis of the spine. In this case level of comfort will be restricted from the top by third continues line (Polish standard coefficient \( n = 4 \)). If that same vibration will occur at night, it will affect people in a direction perpendicular to the axis of the spine and then line restricting the area of required comfort of the people in the living room would be the middle dotted line shown in Figure 5 (coefficient \( n = 1.4 \)). It is clearly visible that requirements to provide the necessary comfort of people have been affected in the bands with center frequencies of 10Hz and 12.5Hz for the first floor and in the band 10Hz for the second floor.

Computational model of the building was prepared using FEM. After its validation according to the procedure described in [3]; [7] obtaining sufficient compatibility of assessment results of effects of vibrations on humans from measurement as well as carried out calculations, model shown in Figure 6 was applied. It should be noted that this building was built on an elastic soil. The coefficient of substrate elasticity is in the range 24-50 MN/m and reflects the fact of deposition below building medium sands and the width of wall footing from 0.5 to 0.7 m.

![Figure 6. FEM model of the analyzed building](image)

4. Calculation results obtained using different types of floors

Different types of floors were analysed. Typical floors (existing in the building) constructed as a reinforced concrete slab with a thickness of 10 cm (RCS-10). Additionally, it was taken into account reinforced concrete slabs with greater height: 12cm (RCS-12), 14 cm (RCS-14) and 16 cm (RCS-16) and alternatively a plate 10 cm supported by steel beams spaced every 2 m (arranged perpendicularly to the road) made of IPE180 profile (RCS-10 + IPE180).

Exemplary calculation results for lower floor are visualized in Figure 7.

As it follows from calculations (Figure 7, Table 2) change in the thickness and structure solution of floors has small impact on improvement of comfort in the occupied rooms on the ground floor. WODB
coefficient, which for the slab with thickness of 10 cm (RCS-10) reached value 6.79, was reduced in the best case to 2.07 for a slab with thickness of 16 cm.

![Figure 7. Results analysis of the lower floor impact on the reception of vibrations by people](image)

**Table 2.** Comparison of the WODB coefficients for analyzed building

| Floor | WODB | Type of Ceiling | RCS-10 | RCS-12 | RCS-14 | RCS-16 | RCS-10 +IPE180 |
|-------|------|-----------------|--------|--------|--------|--------|----------------|
| I     | WODB | 1,46            | 0,76   | 0,43   | 0,10   | 1,32   |
|       | f [Hz]| 12,5            | 12,5   | 12,5   | 12,5   | 12,5   |
| II    | WODB | 6,79            | 3,05   | 2,31   | 2,07   | 2,55   |
|       | f [Hz]| 12,5            | 12,5   | 12,5   | 12,5   | 12,5   |

The reason for such a low effectiveness of proposed solutions can be a fact, that large part in response of ceilings on each floor of the building constitute vibrations of the analyzed building as a solid structure. Analysing the differences in response of the building floors for both levels (Figure 6) author defined dimensionless coefficient $R$ that is ratio of the structure response (RMS value) on level 2 to response on level 1. This coefficient depends on the frequency component of vibrations and its value for investigated floors is 7.87. It turns out that the duplication of protection against vibrations, even in the same building, with the same seemingly exertions does not always give similar effects.

![Figure 8. Dimensionless coefficient $R$](image)
References

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