The influence of construction change in concrete reinforced building on vibration change perceptible by humans

The genesis of undertaking the research

Dynamic analysis is an important element of design process especially in buildings located next to transportation zones. Vibrations caused by vehicle and train motion can influence buildings’ construction as well as human comfort in those buildings. Many standards determine thresholds for vibrations values, which depend on building’s response on kinematic excitation. Standard requirements [1, 2] should be taken into account by the designer in order to ensure construction safety and vibration comfort for building’s occupants.

In this work a real object in Warsaw is being analyzed. There have been made in-situ acceleration measurements. For building analyses some measured acceleration values exceed humans vibration perceptibility threshold. Measurement results indicate that the building’s construction is sensitive to vibrations. In this work there is made an attempt to determine design changes which would fulfill standard requirements. It is important especially in design process to predict vibrations which can influence humans. It is known that changes in building’s design can reduce vibrations – even a small change in slab thickness can reduce vibrations below the threshold [3, 4].

The change of design can also be unfavorable for dynamic response. In this work there is shown the influence of design changes on building’s response on the example of very common building, consisting of concrete slabs and frames, built in a traditional precast technology.

Standard requirements

There are many standards which deal with dynamic analysis of buildings. Polish Code PN-88/B-02171 Evaluation of vibrations influence on people in buildings describes conditions which should be fulfilled in order to provide comfort for humans. There are two main methods of evaluating vibrations. This work provides a method assuming measurement of accelerations in 1/3 octave bands. The Polish code gives maximum threshold values of acceleration in each direction. In order to evaluate the building there should be RMS values computed by the following expression:

\[ a_{RMS} = \sqrt{\frac{1}{T} \int_0^T a^2(t)dt} \] (1)

It is very important to apply the correct time of excitation in order to determine RMS values properly. Polish Code recommends to analyze time of vibration in which amplitudes exceed 20% of maximum acceleration.

The Code gives formula for maximum acceptable acceleration:

\[ a_{dop} = a \times n \] (2)

where \( n \) is a coefficient dependent of the type of building’s function. The values for vibrations during the day are listed below:

\( n = 1 \) for hospitals

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Although the building’s function should be analyzed, it should be taken into account that all the vibrations that exceed the threshold for $n=1$ are felt by humans and influence occupants’ comfort. In this work threshold for $n=1$ [2] is analyzed.

**Building description**

The analysis object is a concrete reinforced two-storey building, located 6.5 m from a roadway edge. The object is a service and merchant building, constructed in 1970. It has a prefabricated frame construction with columns of 35 x 35 cm dimension. The frame spacing is 6 m, each frame segment is 360 cm high. The construction is joined by ceiling concrete slabs. Construction plan and cross-section are shown in figure 1.

**Numerical analysis description**

The analyzed object has been modeled in Abaqus computational environment. In order to keep relation to real design situation there were applied some simplifications to the model. Non-structural elements’ influence on mass distribution was omitted, as well as material nonlinearity due to concrete cracking. Due to small displacements and accelerations which do not exceed 10 cm/s$^2$, a linear analysis was used. The model bases on Finite Element Method. Frames were modeled as beam elements 6 degrees of freedom in each node. Concrete slabs were modeled as plate quad elements, connected with beam frames. Material and live load characteristics were assumed basing on [5, 6]. A simplification assumption of encastré boundary condition in supports was made.

In the design process there are many possibilities to change the dynamic characteristics of the structure. In this work there has been analyzed the influence of slab thickness and modulus of elasticity change on structure’s dynamic response. Dimensions and modulus of elasticity values in all cases are shown in table 1.

Using measured excitation Time History Analysis has been performed. The kinematic load was applied to foundations as acceleration-time function. Pulse frequency for numerical analysis was 300 Hz. Accelerations were obtained in the same point on the construction for different simulations. Then the signal was a subject of band filtering and RMS calculations. ESAM program was used in order to calculate accelerations in frequency bands [7]. Finally a comparison was made of the results obtained for all the bands.
The dynamic model uses excitation measured in-situ at the level of building foundations. Measurements have been made for many passes of different vehicles: cars, articulated and normal buses and heavy trucks. The acceleration sensors were situated on the construction foundation, right at the ground level. To ensure that the sensors indicate construction vibrations, plasters were removed. The measurement pulse frequency was 1024 Hz.

Out of many measurements this analysis uses a measurement with the biggest acceleration values in 1/3 octave bands. Excitation was caused by a heavy truck pass. Figures 2–4 present excitation diagrams. The maximum acceleration values are: in $x$ direction – 1,43 m/s$^2$, in $y$ direction – 0,53 m/s$^2$, in $z$ direction – 1,37 m/s$^2$. There has been performed a FFT analysis of the measured signal, a sample graph for vertical vibrations is shown in fig. 5. This excitation was chosen for analysis due to the fact that it causes vibrations which exceed the threshold of humans’ perceptibility.
Fig. 2. Excitations in x direction.

Fig. 3. Excitations in y direction.

Fig. 4. Excitations in z direction

Fig. 5. Frequency spectra of vibrations in z direction.
Calculation results

As a result of simulations many maps of structure accelerations were obtained. Figure 6 shows a sample map of resultant acceleration of third second of analysis.

Fig. 6. A sample map of accelerations.

In excitation from transportation vertical accelerations usually have the biggest influence on humans. Usually maximum vertical acceleration RMS values are present in the middle of the slabs. These points should be checked in order to make sure, that code requirements are fulfilled.

The vibrations obtained for different building constructions were calculated in 1/3 octave bands. Figures 7–13 show obtained RMS values for analyzed point. For all cases $WODL$ coefficient was calculated, defined as:

$$WODL = \frac{a_{RMS}}{a_{maximum}}$$ (3)

Maximum acceleration values and $WODL$ coefficient values computed in different construction situations are listed in table 1.

Table 1. Reduction of acceleration depending on construction changes.

<table>
<thead>
<tr>
<th>Slab thickness</th>
<th>Modulus of elasticity $E$</th>
<th>WODL</th>
<th>Frequency of max $WODL$</th>
<th>Figure number</th>
</tr>
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<tr>
<td>[cm]</td>
<td>[GPa]</td>
<td>[−]</td>
<td>[Hz]</td>
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<tr>
<td>30</td>
<td>34 GPa</td>
<td>0.46</td>
<td>25 Hz</td>
<td>13</td>
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</table>
Fig. 7. Vertical vibration influence on humans in analyzed point for 22 cm thick slab and $E = 25$ GPa.

Fig. 8. Vertical vibration influence on humans in analyzed point for 30 cm thick slab and $E = 25$ GPa.

Fig. 9. Vertical vibration influence on humans in analyzed point for 32 cm thick slab and $E = 25$ GPa.
Fig. 10. Vertical vibration influence on humans in analyzed point for 34 cm thick slab and $E = 25 \text{ GPa}$.

Fig. 11. Vertical vibration influence on humans in analyzed point for 38 cm thick slab and $E = 25 \text{ GPa}$.

Fig. 12. Vertical vibration influence on humans in analyzed point for 30 cm thick slab and $E = 31 \text{ GPa}$. 
Conclusions

The above described analysis can lead to the following conclusions:

- the influence of a small change in slab thickness can have a big influence on vertical vibrations; change of 25% slab’s thickness can cause the WODL coefficient grow over 50%,
- in some cases increase as well as decrease in a slab thickness may unfavorably influence perception of vibrations by humans,
- increase of element stiffness without the increase of mass can influence vibration band diagrams causing vibration reduction, especially for excitations with maximum amplitudes at low frequencies.

There may be many ways to increase element stiffness. If the construction is at the stage of design process, the class of concrete as well reinforcement degree can be increased. For existing structures stiffness reduction may result from concrete cracking. In those cases repair procedures can be provided, including crack injection with a material having correct damping and rheology parameters [8].

This work will be continued by a more detailed numerical dynamic modeling of concrete buildings. After further numerical simulations more certain conclusions should be gained, useful in the design process helping in vibration reduction due to vehicle and train transportation.

Abstract

The article presents a dynamic numerical analysis of a concrete reinforced building. There is used a kinematic excitation measured at the building in-situ, during heavy vehicles passes. The building consists of concrete columns and slabs. Dynamic response of the building was determined in dependence on building structure. There was made an analysis in the points of the structure where vibrations exceed threshold values on humans determined in Polish Standard PN-88/B-02171. There is shown the influence of change in building’s construction and material parameters on vibration perceptibility by humans.

Keywords: concrete structure, humans, traffic, vibrations.
Streszczenie


Słowa kluczowe: konstrukcje betonowe, ludzie, ruch uliczny, wibracje.

References