Designing of Buildings in the aspect of prediction of people from traffic included vibrations

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Abstract. Newly designed buildings must meet conditions regarding limit states of strength and serviceability. These conditions must be fulfilled in case of static load, dynamic load as well as both of them at the same time. Bearing in mind that currently sources of vibrations are located closer and closer neighborhood of inhabited buildings, particular attention should be paid to this issue. Mentioned problem of vibrations is even more important as it can concern loads (sources of vibrations) as well as buildings that are both existing and designed. It should therefore be considered - depending on the existence stage of the dynamic load and the building - four possible cases of analyzed problem. These are diagnosis, diagnosis with prognosis, designing and designing with diagnosis.

The study describes methods how to include in the design and protection of buildings impact of traffic induced vibrations on people staying at the facility. The criteria for assessing dynamic influences on people (as it is presented in codes) are specified. Particular attention was paid to the situation when we deal with existing road (vibration source) and designed building. In this case we are able to determine (by measuring in situ) parameters of kinematic excitation and then affect the FEM model of planned building to meet its dynamic parameters criteria's imposed during assessing of the impact of vibrations on people. The paper presents a calculation example of the building, which location is planned 12 m from the national road. Possible various technical conditions of the road surface including damaged surface and its permissible by national code unevenness that may occur in the surface course were considered. As a criterion for admission selected building to the operational state the provisions contained in the PN/B-02171:2017 Evaluation of vibration influence on people in buildings were used. Since the main factor determining the fulfillment of the code requirements were vertical accelerations during analysis author focused on choosing the appropriate thickness of slabs.

1. Introduction

Provisions included in the Act [1] (Environmental Protection Law) define conditions for implementation of the sustainable development program, which requires to ensure proper quality of human life at level allowed by the current civilization development and without harming future generations. Structure should be designed and constructed in accordance with the principles of technical knowledge, ensuring that many requirements are met, including protection against noise and vibrations, as well as appropriate health and safety conditions for environment.

Thus, among many different criteria for assessing proper quality of life of a human inside a building, there are also those that relate to protection against vibrations. Vibrations generated by operation of various devices can adversely affect the human environment. They can not only damage buildings but also violate the conditions of comfort required in rooms where people are staying.

Among many sources of vibrations occurring in the immediate vicinity of buildings, dynamic influences generated by communication related sources are considered in this work. Vehicles moving along the road generate noise and mechanical vibrations. Although both these impacts most often occur together their impact on the environment is analysed separately. They differ in the frequency range and propagation path. It also affects the applied measurement methods and criteria for diagnostic assessments pertaining to each of these activities [2].

Vibrations caused by wheeled vehicles propagating through the ground to the building, excite (as so-called kinematic excitation) vibrations of the structure, generate inertia forces that additionally load the structure and cause movement of the building influencing people staying inside.

In analyses related to the assessment of impact of vibrations on buildings and people, three basic elements are distinguished: vibration source, vibration propagation path and vibration receiver. In all situations presented in this work the source of vibrations will be wheeled transport on the ground surface; the receiver would be a human being staying in the building, receiving passively vibrations (i.e. having no direct influence on the source of vibrations)

Current procedures used during designing buildings increasingly include dynamic actions transmitted by the ground. It occurs when level of vibrations affected the building generates inertia forces, which value could not be neglected. Impact of these dynamic actions is taken into account during checking bearing capacity of structural elements. However, there are situations in which the influence of vibrations on people staying in the building is worth considering already in the design phase. Requirements in this area are often more restrict than those resulting from impact of these vibrations on the building structure itself.

2. Diagnostic and designing situation

In Table 1 (see [4]) main diagnostic and design cases were presented referring to person receiving the vibrations depending on the state of the source of vibrations and the building itself receiving vibrations in which the human being is located during the development of the diagnosis and design process.

Table 1. Diagnostic and design cases depending on the situation of the source of vibrations and building itself

Case designation	Vibration source	Object receiving vibrations, human inside the building	Identification of the case
A	Existing	Finished	Diagnosis
B	Designed	Finished	Diagnosis with prognosis
C	Existing	Designed	Designing
D	Designed	Designed	Designing with prognosis

Most often, the dynamic diagnosis concerns case *"A"*. In this case, diagnostic evaluation uses results obtained during direct vibration measurements at the place of their receiving by a human and applies appropriate assessment criteria. The *"B"* case is also included in the diagnosis, but in the assessment of dynamic influences, the forecasted vibration parameters generated by the designed source are taken into account. Determining predicted vibrations requires a set of many reliable results of measurements carried out in conditions similar to those included in the diagnosis. Such a set is a database of measurement data. Reliability of the diagnosis depends largely on the extensiveness of this database and the precision during identifying the relevant parameters.

The *"C"* and *"D"* cases are included in the design tasks, but the procedures for determining the parameters characterizing the source of vibrations are similar to those used in the case *"B"*. In the same way one could use a database.

3. Evaluation criteria for dynamic influences on people

Criteria used in assessing the impact of vibrations on people in buildings are included in the standard [4]. This standard defines the permissible values of mechanical vibration parameters ensuring the required comfort in various conditions of human presence in accommodation spaces, offices, workshops and in special purpose rooms (e.g. hospitals, precision laboratories, etc.). Vibrations are evaluated in the band from 1 to 80 Hz.

Assessment of the impact of vibrations on humans is carried out on the basis of parameters values specified in the standard [4] depending on used evaluation method. An assessment may be made on the basis of measurement of adjusted acceleration (or velocity) of the vibrations in the whole frequency band or on the basis of the RMS measurement of the acceleration (or velocity) of vibrations in 1/3 octave bands.

Figs 1 show lines determined by RMS values of vibration acceleration corresponding to the threshold of vibrations perceptibility by human. The line “xy - Human perception threshold for vertical vibrations” corresponds to the situation in which a person receives vibrations in the "z" direction, i.e. along the axis of the spine, and “xy - Human perception threshold for horizontal vibrations” a situation in which a person receives vibrations in the "x, y" direction, i.e. perpendicular to the spine axis.

Fig. 1. Line indicating vibration perception threshold in the direction of spinal axis

Values of vibration parameters transmitted to human can be determined on the basis of measurements carried out at vibration reception site. Those values can also be determined on the basis of calculations of the building FEM model subjected to predicted kinematic excitation.

Parameter values obtained from measurements or calculations are compared with the values ensuring the required comfort. During determination of these values, the influence of many factors is taken into account. The most important of them were considered in the norm [4]:

- purpose of the room in the building,
- time of occurrence of vibration,
- nature of vibrations and their repeatability,
- direction of vibrations and position of human body during receiving vibrations.

Purpose of the room, time of occurrence and the nature of vibrations and their repeatability affect the value of the coefficient *"n"* specified in table 2. Direction of vibrations in relation to the position of the human body during vibration reception, affects selection of the line relating acceleration values with vibration frequencies (Fig.1).

Table 2. Values of the "n" coefficient according to PN-B-02171:2017 [4]

Purpose of the room	Time of the day	Value of the coefficient during vibrations:	
		Fixed (continuous or intermittent) with a multiplicity greater than 10 per day	Occasional
Hospitals (operating rooms), precise laboratories	Day Night	1	1
Hospitals (patients' rooms)	Day	2	8
	Night	1	4
Apartments	Day	4	32
	Night	1,4	4
Offices, schools	Day Night	4	64
Workshops	Day Night	8	128

When performing the assessment on the basis of the adjusted value, the fulfilment of the condition described below is checked, in which the adjusted value of vibration acceleration (a_k) corresponding to the analysed direction of vibration (along the spine, perpendicular to the spine) should meet the condition::

$$a_k \leq a_{k1} \bullet n \quad (1)$$

where:

a_{k1} – adjusted value of acceleration corresponding to the threshold of perceptibility vibrations by human adopted from Table 2 given in the Standard [4],

n – coefficient taking into account effect of room purpose, time of occurrence of vibrations and nature of vibrations as well as its repeatability.

During assessing impact of vibrations on people, which is based on spectrum of effective vibration acceleration in 1/3 octave bands, it is required that the effective value of acceleration $a(f_i)$ in each 1/3 octave band with the center frequency f_i corresponding to analysed direction of vibration should meet the condition:

$$a\,(f_i) \leq a_1(f_i) \bullet n \quad (2)$$

where:

$a_1(f_i)$ - value of acceleration corresponding to the threshold of vibrations perception by human, taken from Table 3 given in the Standard [4], in a given 1/3 octave band with the center frequency f_i,

n - value of the coefficient taking into account purpose of the room, vibrations occurrence time, nature of vibrations and their repeatability.

4. Procedure regarding influence of traffic included vibrations during building designing

Application of the assessment criteria requires information about parameters describing operation of the designed source of vibration. It can be obtained on the basis of in situ measurements (*A* type of diagnosis described in Table 1). Research teams carrying out dynamic measurements while performing diagnostic tasks acquire a lot of information about propagation of vibrations in the ground, transferring them from the ground to the foundation of the building and the structure in places where these vibrations are receiving by humans. Thus a set of investigations results is created, which, if properly developed, can be a database of measurements data corresponding to different situations. Such information's contained in the results database can be successfully used to determine the predicted vibration parameters in situations where the source of vibrations is not yet present and is in the design phase (cases "*B*" and

"*D"* included in Table 1). Disposer of a comprehensive measurement database can successfully characterize the vibrations that will be transmitted to the building in the future during the occurrence of the predicted source of vibrations. In case "*C"* listed in Table 1 part of information concerning vibrations transmitted to the building can be obtained during measurements proceed at the location of the designed building. However, to determine the vibrations affected the designed building, important information can also be obtained from a suitably developed measurement database.
This work – as indicated in the introduction – refers to buildings being designed (cases "*C"* and "*D"* included in Table 1). Description of vibrations constituting the kinematic excitation of the FEM models of these buildings can be obtained from direct measurements supplemented with analysis of information collected in the measurement database (case "*C"*) or only from the measurement database (case *"D"*).
Taking the above into account, it is possible to present the procedure of including during designing buildings the influence of vibrations on people staying in it as given below.
Vibration source is existing (case *"C"*):

- ground vibrations are measured at the place of future location of the building;
- parameters of the building's kinematic excitation (vibrograms) are determined using information on the results of measurements contained in the measurement database, corresponding to similar situations;
- after completing the computational model, a description of building movement at the points of vibration perception by human is determined;
- in relation to analytically determined vibrograms, appropriate criteria for assessing the impact of vibrations on people in the building are used;
- if the requirements are not met, changes are made to the design in such a way to meet the requirements providing required comfort to people in the building.

Vibration source is being designed (case *"D"*):

- basing on analysis of the set contained in the measurement database, the most probable description of kinematic excitation of the building is determined and this excitation is applied to the model of the designed building,
- vibrations in the building are determined in places where these vibrations are being percepted by human;
- determined vibration parameters are used in assessing their impact on humans according to the adopted assessment criterion;
- if required requirements are not met, changes are made to the design and calculations are repeated until the goal is achieved, which is to meet the requirements of the designed building regarding the impact of vibrations on people staying in it.

With regard to designing process (case *"C"*) as well as designing with prognosis (case *"D"*), action consists of designing the building to meet the requirements for providing necessary comfort to people in the building.
Ensuring meeting the requirements still in the designing phase of the building is easier and cheaper than introducing appropriate changes in the construction of the already completed object.

5. Example

As an example, the results of calculations made in the designing phase of a brick building with two floors located 15 meters from the road were presented. Using the FEM computational model of considered building was prepared and is shown in Fig. 3.

Mentioned model was subjected to a kinematic excitation in the form of a vibrograms developed on the basis of records from described measurement database. An exemplary calculation results in the form adopted in the assessment criterion shown in [4] is given in Figure 4. During calculations of the building model, at the initial design stage, a reinforced concrete ceiling with a height of 14 cm was assumed. Obtained results [Fig. 4] showed that the predicted vertical vibrations of a 12 cm thick reinforced concrete ceiling in 8, 10 and 12.5 Hz bands may not fulfil the necessary comfort conditions in a living room (n = 1.4)

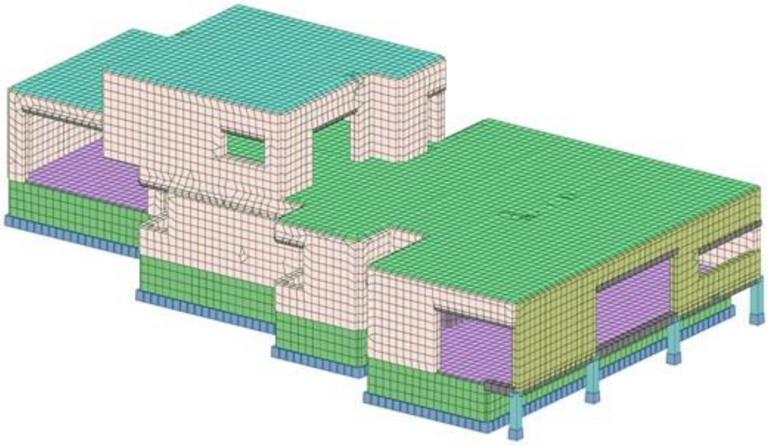

Fig. 3. FEM model of considered building

Ceiling thickness was increased by 2 cm first and then by 4 cm in relation to the initial dimension. Applied change reduced vibrations levels, bringing them clearly below the upper boundary line of the area, which provides necessary comfort to people staying on this ceiling. In case of fourth variant, it was possible to obtain such a significant reduction of vibrations transmitted to a person staying in the room under consideration, that it will be below the threshold of perceiving vibrations by human.

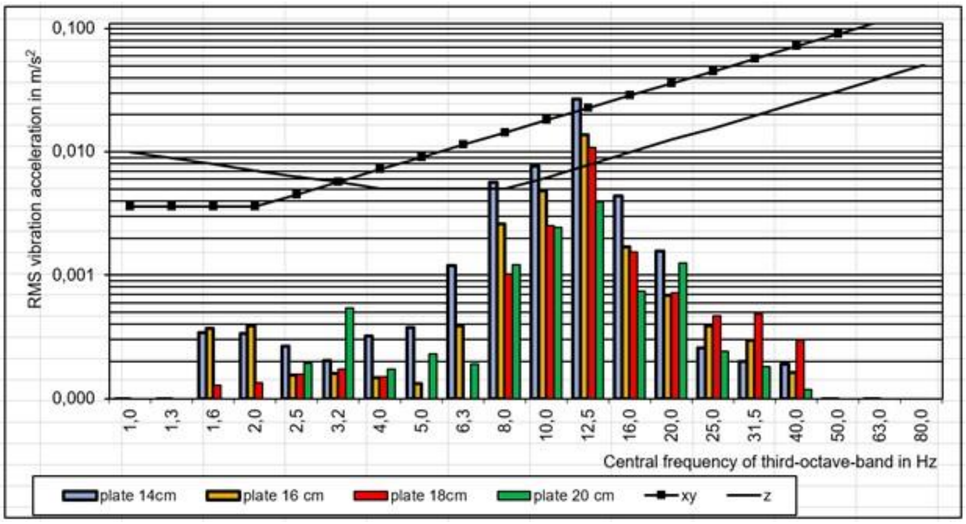

Fig. 4. Analysis results of predicted vibrations at the place of their reception by a human staying inside the building

The above example clearly proves that it is worth carrying out the relevant analyses during the design phase of the building.

References

[1] Act of April 13, 2018 Environmental Protection Law (Dz.U. 2018 poz. 799).

[2] Kozioł K . The influence of vibration propagation from trams on building vibration caused by ground shaking, Civil-Comp Press, 2015

[3] Kawecki J. Stypuła K, Ensuring vibratory comfort for people in buildings exposed to communication activities, 2013. PK, 2013.

[4] PN-B-02171:2017, Evaluation of vibrations influence on people in buildings, (2017) Polish Standard (in Polish)

[5] ISO/CD 10137.2: Table for design of structures – Serviceability of buildings and walkways against vibration; 2005