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

Krzysztof Kozioł

1Cracow University of Technology, Warszawska 24 St., 31-155 Cracow, Poland

kkodziol@pk.edu.pl

Abstract. Newly designed buildings must meet conditions regarding the 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 the current sources of vibrations are located closer and closer to the neighborhood of inhabited buildings, particular attention should be paid to this issue. The 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 of how to include in the design and protection of buildings the 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 dealt with an existing road (vibration source) and designed a 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 the vibration influence on people in buildings were used. Since the main factors determining the fulfillment of the code requirements were the vertical accelerations during the 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. The 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 the environment.

Thus, among many different criteria for assessing the proper quality of life of a human inside a building, there are also those that relate to protection against vibrations. Vibrations generated by the
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, the dynamic influences generated by the 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 analyzed 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 the 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 the 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 [3].

2. Diagnostic and designing situation

In Table 1 main diagnostic and design cases were presented referring to the 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.

| 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 the 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.

Figure 1 show lines determined by RMS values of vibration acceleration corresponding to the threshold of vibrations perceptibility by a 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.

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

Values of vibration parameters transmitted to human can be determined on the basis of measurements carried out at the 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 the 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,
- the direction of vibrations and position of the 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. The direction of vibrations in relation to the position of the human body during vibration reception affects the selection of the line relating acceleration values with vibration frequencies (Figure 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 | 1 | 1 |
|                      | Night | 1 | 1 |
| Hospitals (patients' rooms) | Day | 2 | 8 |
|                      | Night | 1 | 4 |
| Apartments | Day | 4 | 32 |
|                      | Night | 1,4 | 4 |
| Offices, schools | Day | 4 | 64 |
|                      | Night | 1 | 4 |
| Workshops | Day | 8 | 128 |
|                      | Night | 1 | 4 |

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 analyzed direction of vibration (along the spine, perpendicular to the spine) should meet the condition:

\[
  a_k \leq a_{k1} \cdot n
\]  

(1)

where:

\( a_{k1} \) - the 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 the effect of room purpose, time of occurrence of vibrations and nature of vibrations as well as its repeatability.

During assessing the impact of vibrations on people, which is based on the 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 the analyzed direction of vibration should meet the condition:

\[
  a(f_i) \leq a_1(f_i) \cdot n
\]  

(2)

where:

\( a_1(f_i) \) - value of acceleration corresponding to the threshold of vibrations perception by a 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 the purpose of the room, vibrations occurrence time, nature of vibrations and their repeatability.

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

Application of the assessment criteria requires information about parameters describing the 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 a 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 perceived
  by a 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”), the
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 the 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 the
considered building was prepared and is shown in Figure 2.
The mentioned model was subjected to a kinematic excitation in the form of a vibrograms developed on the basis of records from the described measurement database [2]. An exemplary calculation results in the form adopted in the assessment criterion shown in [4] is given in Figure 3. During the calculations of the building model, at the initial design stage, a reinforced concrete ceiling with a height of 14 cm was assumed. Obtained results (Figure 3) 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 \((n = 1.4)\). Ceiling thickness was increased by 2 cm first and then by 4 cm in relation to the initial dimension. The applied change reduced vibrations levels, bringing them clearly below the upper boundary line of the area, which provides necessary comfort to the people staying on this ceiling. In the case of the 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 a human.
The above example clearly proves that it is worth carrying out the relevant analyses during the design phase of the building.

6. Conclusions
Buildings must meet conditions regarding the 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. The 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. Depending on the existence stage of the dynamic load and the building should be considered four possible cases of analyzed problem. These are diagnosis, diagnosis with prognosis, designing and designing with diagnosis. The criteria for assessing dynamic influences on people (presented in PN-B/02171:2017) are specified. Particular attention was paid to the situation when we dealt with an existing road (vibration source) and designed a building. 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. It was shown in presented example.

References
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