DOI: 10.2478/v.10169-012-0014-z

ANALYSIS OF INFLUENCE OF VIBRATIONS ON HUMANS IN BUILDINGS IN STANDARDS APPROACH

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People living in buildings may be exposed to dynamic actions. In the diagnosis and design of buildings there is an increasing need of taking into account these activities and verification of compliance of the building requirements for vibration comfort of people residing in buildings. This study presents the results of analysis of such criteria in the following standards: Polish PN-88/B-02171 [1], British BS 6472-1 [2], German DIN 4150 [3], and ISO international standards [4,5]. Basing on the results of this analysis and on the review of selected items of literature, the application of standards recommendations in diagnosis and design of buildings, as well as areas for further research on this subject is indicated. This article is an extended version of the conference paper [6] presented on the conference Urban Transport 2011.

Key words: vibration, vibration influence on humans in buildings, vibration comfort.

1. Introduction

In the vicinity of the completed and designed buildings there occur different sources of vibration, which are called paraseismic action. They are transmitted through the subsoil to the foundations and basement walls of buildings and constitute their kinematic forcing. For this type of dynamic actions, vibrations induced by means of transport passages are included, and they are called transport vibration. During the vibration of buildings, inertia forces generate an additional (apart from the static one) load on the structure. In the diagnosis and design of buildings, these forces are taken into account by analysing the structure satisfaction of the requirements for stiffness and strength. Exceeding these requirements may lead to acceleration of wear and even structural damage.

In areas of buildings there may be people who are exposed to vibration, and having no direct influence on the source of vibration – perceive these vibrations in a passive way. Users of building space should be provided with necessary requirements for vibration comfort.

Methods of calculation and experimental studies are developed and they provide not only a reliable and objective evaluation of dynamic action on people in the

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buildings, but also prediction of these activities. An important element of such a procedure are the criteria used in the assessment. Basing on the results of many studies and developed verification, these criteria are introduced into the standards documents. These criteria are regarded as requirements of an objective and considered in dynamic diagnosis and building design.

This paper presents the results of the analysis stored in the standard procedures and criteria for assessing the influence of vibration on people in buildings. Provisions of the standards: Polish PN-88/B-02171 [1], British BS 6472-1 [2], German DIN 4150 [3] and ISO international standards [4,5] were taken into account. This article is an extended version of the conference paper [6] which was presented on the conference Urban Transport 2011.

2. RESEARCH OF THE INFLUENCE OF VIBRATIONS ON HUMANS

For many years, the research on influence of vibration on humans has been carried out. To make a comparison of the results of those tests, two possible body positions of the reception of vibration by people were determined by linking them with an orthogonal reference system.

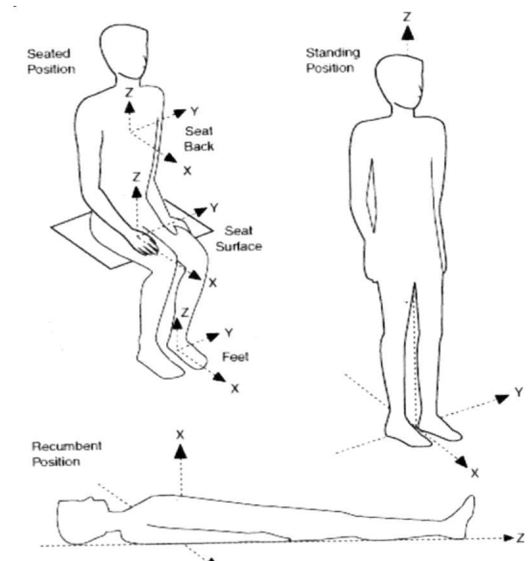

Fig. 1. Directions of vibration reception by a person.
Rys. 1. Kierunki odbioru drgań przez człowieka

A person in a sitting and standing position perceives vibration by feet or seat surface in such a way that the axis "z" which runs along the spine (axis line: foot –

head) is vertical, and the axes: “x” and “y” take horizontal direction. In the recumbent position of a person, the entire body surface perceives vibrations in such a way that the axis ”z” is horizontal. Axes in “x” and “y” directions are marked: back – chest (axis ”x”), and side to side (axis ”y”).

Research on the influence of vibrations on a person held in each of the two body positions was performed during many laboratory tests and is carried on (cf. the work of Tamura et al. [7] Blume [8], Benson et al. [9].) Verification of these results was carried out on real objects (cf. the work of Goto [10] , Jeary et al. [11], Hansen et al. [12], Reed et al. [13].). Efforts were undertaken to eliminate in this way the influence of individual perception of vibration. It follows from these and earlier studies that human response to vibration depends on many factors, of which the most significant influence are: frequency of vibration, amplitude of movement, direction and vibration conditions of acceptance.

The basic level of reference in assessing the influence of vibration on humans is called the limit vibration sensation. The results in this regard were taken as the basis for formulation of criteria for assessing the influence of vibration on humans. If the vibrations at the place of receipt by a person are characterized by values below sensation threshold of vibration, they can be considered as undetectable by man. In clinical and verification tests, there is also an information about the parameters characterizing the vibrations obtained, which still provide appropriate vibrational comfort for !people. Vibration of parameters higher than described above are considered as infringing the conditions of necessary comfort for humans to perform tasks the premises are destined for (eg office, residential, hospital, etc.).

3. Methodology and criteria of assessment

The criteria used in assessing the influence of vibration on humans in buildings depend on the evaluation method. There are three basic methods of assessment , in which the following parameters are considered:

a) acceleration (velocity) of vibration corrected in the whole frequency range
b) spectrum (frequency structure) of the effective value (RMS) of acceleration (velocity) of vibration in 1/3 octave band,
c) vibration dose.

Corrected value (present in standards [1, 3]) is determined by measuring the vibration at the place of receipt by a person using correction by means of a correction filter. Characteristics of the correction filter is described by the values of correction factors assigned to the center frequencies of 1/3 octave bands. The measurement information is obtained, expressed by one number, which is compared with the corresponding value of providing the necessary vibrational comfort to people in the building. Application of the corrected value of acceleration of vibration in the evaluation of their influence on people is relatively simple, but simultaneously deficient in information. In the case of infringement of requirements in the concerning provision of necessary comfort to people in buildings no information is obtained from such studies about the frequency band in which the violation occurred. One can not, therefore, determine on this basis at what frequency and at what degree the reduction of vibration should be introduced in order to ensure people the necessary vibration comfort. For these reasons, later in this study this evaluation parameter will not be analysed.

More relevant information useful in assessing the influence of vibration on humans is obtained on the basis of presentation in form of the frequency curve spectrum RMS acceleration in 1/3 octave bands. This evaluation parameter is adopted in standards [1, 4, 5]. By comparing the frequency structure of the measured frequency curve with the corresponding frequency providing the necessary comfort of vibration to humans in the building, not only information about a possible breach of the requirements is obtained, but also the frequency band in which the violation occurred.

Evaluation using the spectrum of effective acceleration in 1/3 octave bands requires definition of time T_r, which determines the RMS value of acceleration a(t). Extension of this time and including low level of vibration leads to an unjustified reduction in RMS. In [1] the duration time of vibration T_r is clearly defined as corresponding to vibration, during which the local maximum values exceed 20% of the maximum value throughout the time of registration. This is illustrated in Figure 2.

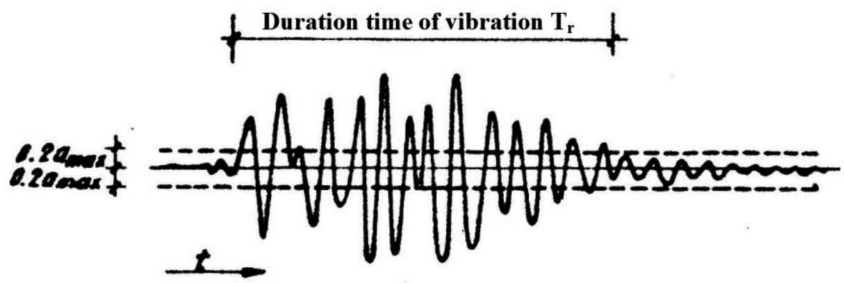

Fig. 2. Presentation of duration time of vibration acc.[1].
Rys. 2. Ilustracja czasu trwania drgań za [1]

The third of the applied parameters of the characteristics of vibration allows analysing of the effect of vibration on humans in buildings by reference to the full-time assessment of the impact of vibration. Introduction of a value defined as the vibrations dose for assessment of influence of vibration on people, allows the assessment of vibrations of varying duration and repetition (continuous, intermittent, impulse). Their action is considered during the entire period of human exposure to vibration. The vibration dose was introduced in order to assess the vibration in the standards [2, 3, 5]. In the standard [2] vibration dose denote as VDV and expressed in [$m/s^{1,75}$] is given by formula:

(3.1) $$VDV = \left(\int_0^T a^4(t)dt \right)^{0.25}$$

where: a (t) – acceleration [m/s^2] as a function of time with the weightings Wb or Wd introduced depending on the vibration frequency and direction of its transmission to humans, T – total time of vibration [s].

Depending on the type of vibration procedures for determining the vibration dose for the entire period of vibration effects (day – 16 hours, night – 8 hours) are also given in the said standards. For example, at vibration of a continuous character the dose of vibrations per a considered period of the day is determined by the formula:

(3.2) $$VDV_{DAY} = \left(\frac{t_{day}}{t_\tau} \right)^{0.25} VDV_\tau$$

where: VDV_τ – vibration dose determined in the representative time τ, [m/s^{1,75}],

t_{day} – duration time of the interval of the day in question (day, night), [s],

t_τ – total duration of vibration corresponding to the vibrations of the analyzed representative time τ [s].

In the standard [3], in turn, – denoting frequency curve KB(t) – values similar to those described in [2] are used in the assessment of vibration exposure. The nature of vibrations is also taken into account through introduction of the correction resulting from the relation of timing of the vibration (exposure to vibration) to the total time of the considered time of the day (day/night). The parameters of assessment of the influence of vibration on people in buildings are related to the assessment criteria.

In [2] (section C.4) the simplified procedure for determining the estimated value eVDV is given. It applies to cases where the registered vibrogram is not standardized by weight functions W_b (vibration in the vertical direction) and W_g (vibration in the horizontal direction). The estimated vibration dose value can then be determined from the formula:

(3.3) $$eVDV = 1.4 \cdot a(t)_{RMS} \cdot t^{0.25}$$

where: $a(t)_{RMS}$ – the root-mean-squared value weighted according to the direction using W_b or W_g,

t – the total duration time of vibrations.

The standards, whose requirements are compared here to the requirements of the vibration assessment criteria, are given in the frequency range vibration from 1 to 80Hz. The reference level is the sensation threshold of vibration, taking into account the different human sensitivity to vibration, depending on the direction of transmission (z, xy).

Figure 3 (acc. [1, 4, 5]) shows the lines corresponding to the sensation threshold of vibration transmitted to humans in the direction z and directions xy.

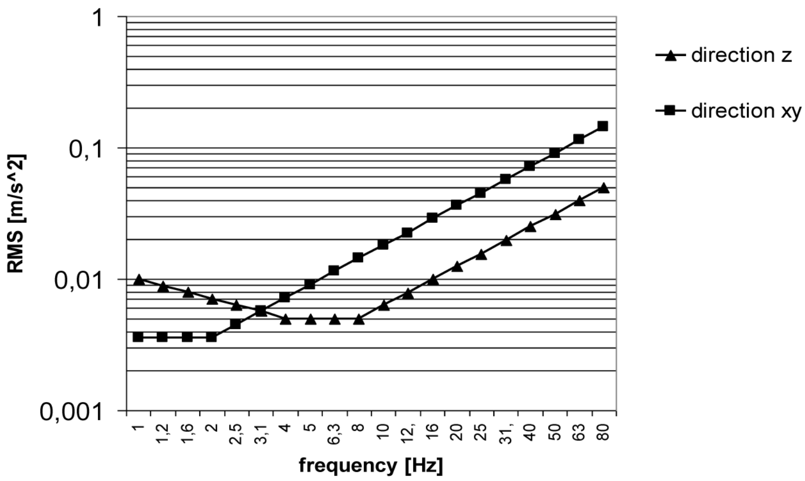

Fig. 3. Lines corresponding to the sensation threshold of vibration.
Rys. 3. Linie odpowiadające progowi odczuwalności drgań

Table 1

Value of the factor "n" (see [1]).
Wartości współczynnika "n" (za [1])

Designation of the room	Time of occurring vibration	The value factor "n" in the occurrence of vibration	
		steady state (continuous or intermittent) for more than 10 times a day	sporadic, with less than 10 times a day
Hospitals (operating-theatres)	Day Night	1	1
Hospitals (rooms of patients)	Day	2	8
	Night	1	4
Residential	Day	4	32
	Night	1,4	4
Offices	Day Night	4	64
Workshops	Day Night	8	128

The other factors determining the level of vibration ensuring a man in the building the necessary comfort of vibration (time of vibration occurrence, vibration character, designation of the room) are included in the assessment criterion by adoption of an increasing coefficient "n". The coefficient "n" increases the coordinates describing the limit of vibration sensation. The result is situation of new lines, parallel to the line of limit of vibration sensation. Vibration with parameter values below this line does not violate the conditions of necessary vibration comfort. Example of characteristics of standards concerning adoption of the coefficient "n" is given [1] in Table 1.

A similar approach, but specifying many additional details, according to [5], is given in Table 2.

Table 2

Value of the factor "n" (see [5]).
Wartości współczynnika "n" (za [5])

Place	Time	Continuous of intermittent vibration	Transient vibration excitation with several occurences per day
Critical working areas (hospital, operating – theatres, precision laboratories)	Day Night	1	1
Residential	Day	2÷4	30÷90
	Night	1,4	1,4÷20
Office	Day Night	4	60÷128
Workshop	Day Night	8	90÷128
The values given in ranges (from – to) are further described in the standard, which enables them to clarify, depending on the nature and terms of vibration reception.			

Basing on the above information, the criteria for the assessment assigned to a particular diagnostic situation can be determined in detail.

An example of formulation of specific criteria for vertical vibration of the floor (Z) of a continuous character, taking into account the possibility of occurrence of these vibrations in the daytime (man in the upright position, i.e. with axes Z and z overlap) and night (man lying down, i.e. axes Z and xy overlap) are given in Figure 4. The criteria summarized in this diagram relate to people in the residential areas.

In a similar way, the criteria for assessing the influence of vibration on man are formed, if the vibration dose (standards [2, 3, 5]) is used in evaluation of vibrations. Table 3 (after [5]) includes the respective quantities constituting the assessment criteria of the influence of vibration on people in buildings, staying in residential areas.

In the standard [3] three levels of demarcation are also introduced and were denoted: Au – vibration sensation threshold, Ar – medium comfort conditions and Ao – upper limit to ensure the necessary comfort vibration.

4. APPLICATION OF EVALUATION CRITERIA

Criteria for assessing the influence of vibration on people in buildings can be used in the diagnosis and taken into account in the designing of buildings. Diagnostic assessment

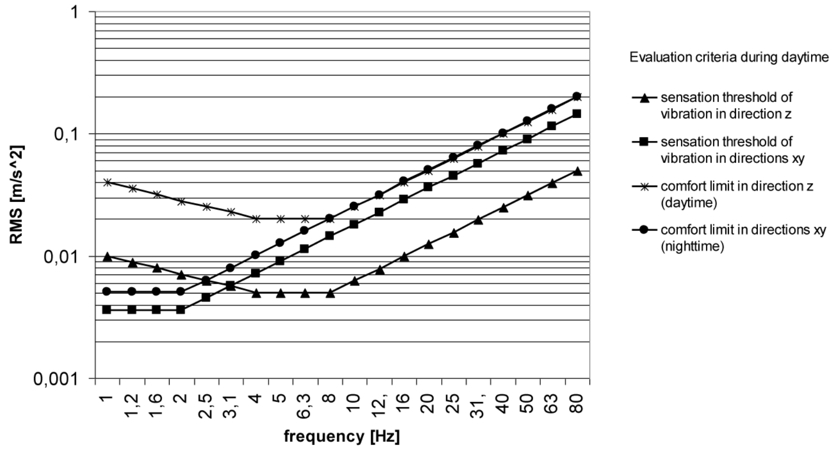

Fig. 4. Example of defining of a specific criterion for assessing the influence on humans in the residential area of floor vertical vibration in the daytime and nighttime.
Rys. 4. Przykład wyznaczenia szczegółowego kryterium oceny wpływu na ludzi w pomieszczeniu mieszkalnym drgań pionowych stropu w porze dziennej i nocnej

Table 3

Criteria for assessing the influence of vibrations depending on the value VDV [m/s^{1,75}].
Kryteria oceny wpływu drgań w zależności od wartości VDV[m/s^{1,75}]

Place	Low probability of adverse comments	Adverse comments possible	Adverse comments probable
Residential buildings 16h day	0,2÷0,4	0,4÷0,8	0,8÷1,6
Residential buildings 8h night	0,13	0,26	0,51

occurs when it is possible to carry on measurements of vibration directly at the site of their reception by man. Then, the record of vibrations in the building measured at the place of receipt by man is presented in a form with corresponding application of assessment criteria applied. The frequency structure of these vibrations in the 1/3 octave bands can therefore be given, or a vibration dose can be appointed. For such presentation of measurement results, the evaluation criteria are used, and on this basis a diagnosis is formulated.

In the case of the design of the building, a computational model (e.g. FEM model) is elaborated first, and the predicted kinematic forcing vibration of the building is determined. In the next stage, vibrations of the building in areas of receipt by people (individual floors) are calculated and the vibrograms are analysed similarly, as described above. The procedure for determining an appropriate building computational model is presented e.g. in [14].

It is worth noting that from the two methods of assessing the influence of vibration on people in buildings included in the standards, more information useful in diagnosis and design is achieved by using the frequency structure of the vibration in 1/3 octave bands as a parameter of assessment. However, in order to make the estimation more precise, using this criterion , a more precise determination of the value of factor ”n” becomes necessary. This procedure has already been introduced in the ISO standards (see [4, 5]).

In the case of impulse vibration, the range of the factor ”n” is relatively wide (see Table 2). For example, with regard to residential areas and occasional vibrations, the factor ”n” is recommended to be taken in the range from 30 to 90. However, the additional information provided in the standards [4, 5] permit to define precisely the value “n” as a function of: social and cultural conditioning, location of the building (urban or suburban area), frequency, duration, etc.

5. New directions in research on precising the assessment

The vibration frequency range in which the assessment is carried out is given in the standards. The analysis concerns vibration in the range from 1 to 80Hz. Erection of high and very high buildings causes a situation that this range should be extended towards low frequencies (less than 1Hz). Already the Japanese standard [15] considers the effect of vibration frequency range from 0.1 to 6 Hz. The ISO [16] also includes vibration of frequencies from 0.1 to 1Hz. In the assessment, Figure 5 summarizes the information about the proposed criteria for assessing the impact of vibration on humans in the buildings, listed in the standards [15, 16] in relation to records in the standard [5]. The criterion concerns vibrations transmitted to humans along the z-axis (feet - the head) in the residential area during daytime. This statement already shows that it is necessary to conduct further research into precising of information characterizing the effect of vibrations in the low frequency range.

Increasingly, the research is undertaken on the effects of duration of vibrations on reception by man (i.e. exposure to vibration). Mostly this factor is taken into account in assessment carried out by use of the vibration dose. Relatively rarely the frequency spectrum in 1/3 octave band is applied in assessment of the influence of vibration.

Investigations are also undertaken on the influence of the shape of motion forms on human perception of vibration. In [7] the results of such a research were described. During the experiment, the horizontal vibrations of the base in various shapes were induced. They were thus generated as vibrations: clearly unidirectional (X or Y), circular and elliptical, all of different – very low frequencies. The participants of the experiment aimed at identification of the shapes of realized vibrations. The results of the identification are given on Figure 6. It can be seen that the participants identified almost univocally vibration of evidently one direction, and vibration moving on a

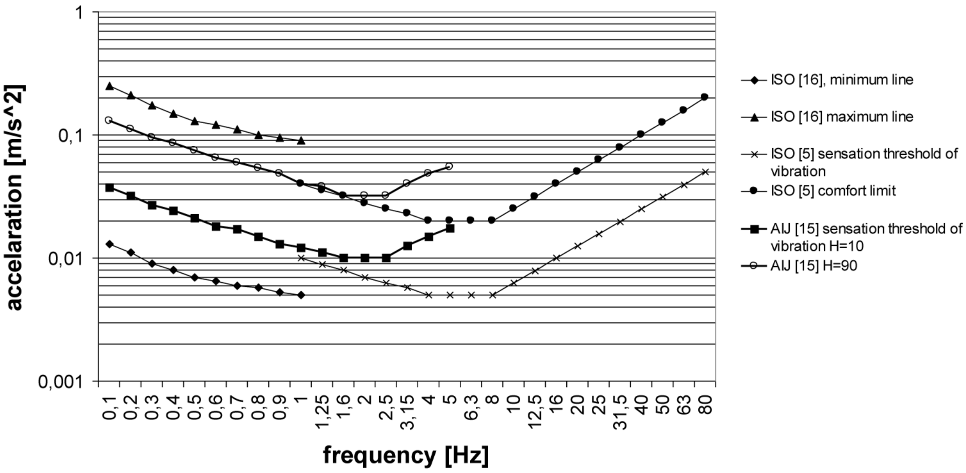

Fig. 5. Comparison of criteria for assessing the influence of vibration transmitted to people in the direction feet – hand according to the standards [5, 15, 16] taking into account very low-frequency.
Rys. 5. Porównanie kryteriów oceny wpływu drgań przekazywanych na człowieka w kierunku: stopy – głowa wg norm [5, 15, 16] z uwzględnieniem bardzo niskich częstotliwości

circular line. In the case of vibration of elliptical motion, this identification was not so univocal.

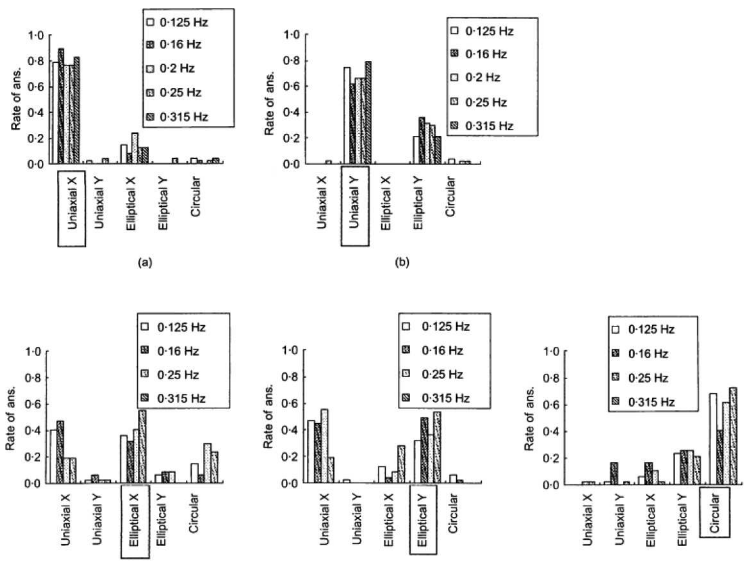

Fig. 6. Results of an experiment on identification of shapes of horizontal vibration by humans (see [7]).
Rys. 6. Wyniki eksperymentu dotyczącego identyfikacji formy drgań poziomych przez ludzi (za [7])

Equally interesting were the results of experiments in which perception by man of harmonic vibration and vibration of a random character was checked. The results of these tests are given in Figure 7.

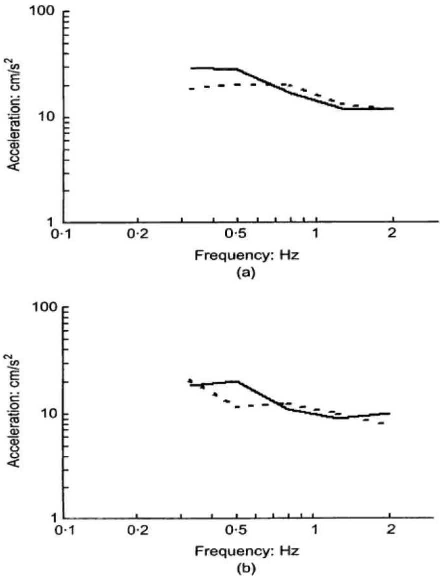

Fig. 7. Perception by humans of random vibration (continuous) and harmonic vibration (dashed line) – as [7].

Rys. 7. Odczuwanie przez ludzi drgań o charakterze losowym (linia ciągła) i harmonicznym (linia przerywana) – za [7]

It turns out that in the frequency range from 0.3 to 0.6 Hz, harmonic vibration is felt at a lower vibration amplitude than vibration of a random character. This means that the actual line of the vibration sensation threshold of harmonic vibrations in the considered frequency range lies lower than that of the corresponding line of random vibration.

6. COMPARISON OF ASSESSMENT OF VIBRATION ACCORDING TO VARIOUS CRITERIA

The results of assessment of vertical floor vibration influencing people in a residential building are presented. Vibrations were caused by buses and tram passages. Vibration measurements were performed at the reception of vibrations by people in the building (fourth floor, center of the floor, vertical vibrations in direction Z).

a) Truck passage.

Vibrogram corresponding to vertical floor vibration is given in Figure 8.

Analysis of the vibrogram in the 1/3 octave bands was made. RMS values corresponding to consequent frequency bands were determined. Figure 9 gives the results of

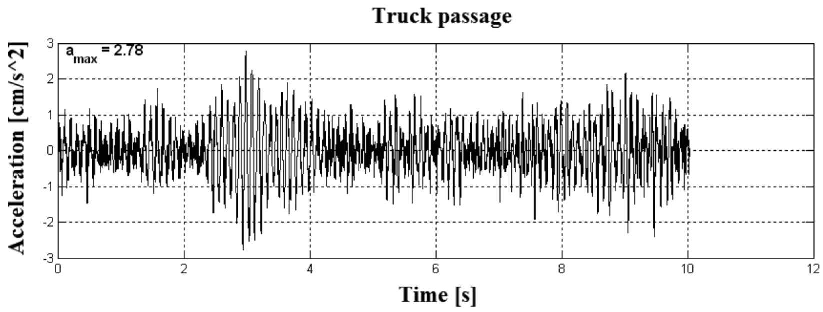

Fig. 8. Vibrogram recorded during truck passage.
Rys. 8. Wibrogram zarejestrowany podczas przejazdu samochodu ciężarowego

the analysis in frequency bands. There are also plotted lines corresponding to the sensation threshold of vibration by human as well as lines (located above) corresponding to the upper limit of vibrational comfort.

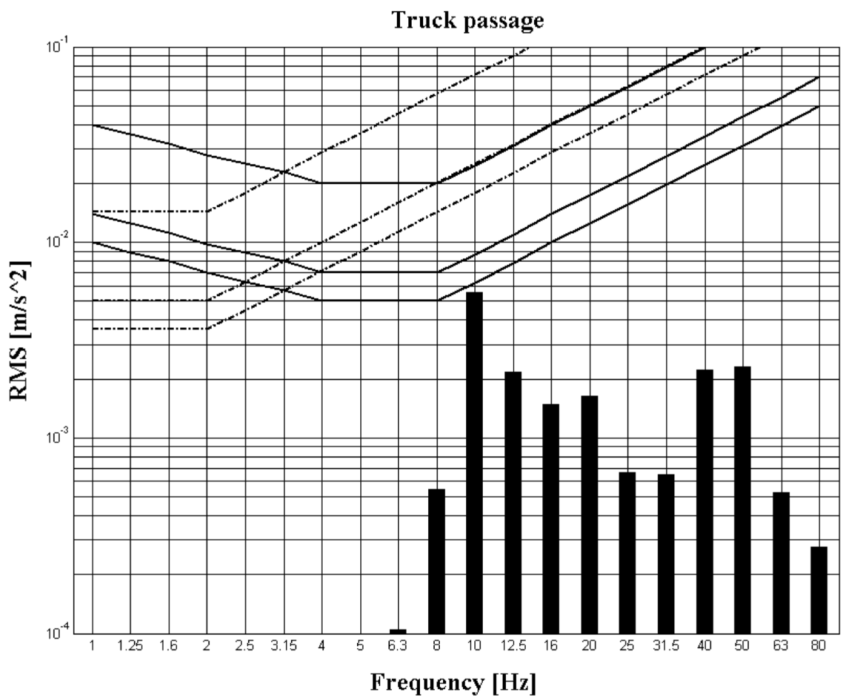

Fig. 9. Assessment of influence of vibration on humans based on RMS values in 1/3 octave bands.
Rys. 9. Ocena wpływu drgań na ludzi na podstawie wartości RMS w pasmach 1/3 oktawowych

The VDV value was also calculated according to equation (1) considering W_b (vertical vibration). VDV = 0,195 was obtained.

The eVDV was then calculated according to formula (3) and taking into account W_b values related to the RMS value in each frequency band. eVDV = 0,18 was obtained.

According to the assessment carried out by use of RMS in frequency bands (Fig.9) recorded vibrations are eligible for not perceptible by humans(people) (below the sensation threshold of vibrations). The result of the assessment by use of value of VDV is similar. This results from a comparison of determined value of VDV with those given in Table 3.

$$0{,}195<0{,}2$$

b) Two tram passages.

Vibrogram corresponding to vertical floor vibration is given in Figure 10.

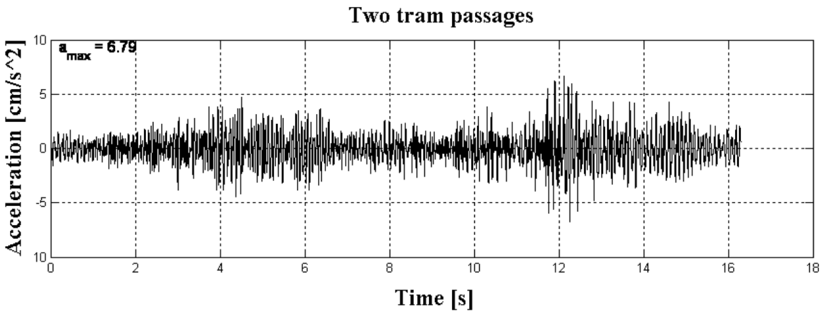

Fig. 10. Vibrogram registered during two tram passages.
Rys. 10. Wibrogram zarejestrowany podczas przejazdu dwóch tramwajów

Analysis of the vibrogram in the 1/3 octave bands was made. RMS values corresponding to consequent bands were determined and marked on illustration in the coordinate system: frequency – RMS of vibration acceleration. The result is given in Fig. 11, line of sensation threshold of vibration of vertical vibration was exceeded at 10 Hz frequency band.

The VDV value was calculated according to equation (1) considering W_b (vertical vibration). VDV = 0,42 was obtained.

The eVDV was then calculated according to formula (3) and eVDV = 0,39 was received. A comparison with the values compiled in Table 3 indicates that the probability of residents complaints is on the border between low and possible.

If it is assumed that trams can pass several times a day, then the assessment should be made according to formula (2).

It was taken into account (basing on the tram timetable) that the situation recorded during the measurement can occur 60 times a day. Then VDV_{day} = 1,18. this value corresponds to already great probability of handing in complaints by residents.

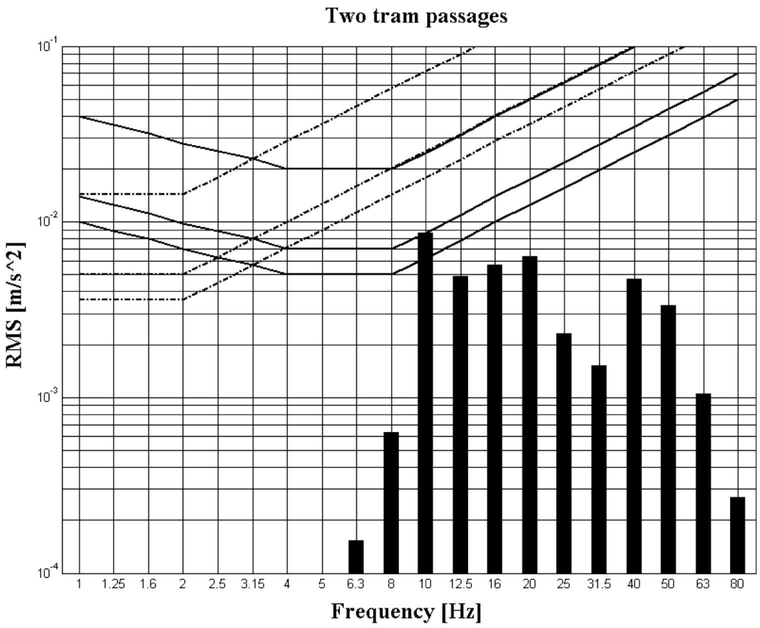

Fig. 11. Assessment of influence of vibration on humans basing on RMS values in 1/3 octave bands.
Rys. 11. Ocena wpływu drgań na ludzi na podstawie wartości RMS w pasmach 1/3 oktawowych

7. Conclusions

Problems of assessing the impact of vibration on humans in buildings are more and more frequently the subject of dynamical diagnoses. Hence, it became necessary to define assessing criteria. By introducing these criteria into the standards, their unification becomes possible. Increasingly, the imposed requirements consider the protection of human environment and evokes the interest in such evaluation, also concerning the influence of vibration. In particular, it is a question of vibration generated by vehicles passages, i.e. transport vibrations. The intensity of these vibrations is growing.

A comparison of evaluation criteria introduced into the international and national standards shows similarity of records. Currently there are two groups of evaluation criteria used and being improved. In one of these, the criteria are stored by using the frequency structure in 1/3 octave bands, while in the other one - by the so called vibration dose. As shown above, the first of these methods contains more information which may be helpful in diagnosis and in designing of new buildings and their effective vibration insulation (comp. [17]). At present, the research is carried out on in order to increase the precision of the guidelines related to the two groups of criteria. In particular, it concerns a range of vibration frequencies below 1 Hz and a more precise determination of the value of the factor "n", in relation to impulse and occasional vibrations.

ACKNOWLEDGEMENTS

Scientific research has been carried out as a part of the Project *"Innovative recourses and effective methods of safety improvement and durability of buildings and transport infrastructure in the sustainable development"* financed by the European Union from the European Fund of Regional Development based on the Operational Program of the Innovative Economy.

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ANALIZA WPŁYWU DRGAŃ NA LUDZI W BUDYNKACH W UJĘCIU NORMOWYM

Streszczenie

Coraz częściej w diagnozach dynamicznych i projektowaniu budynków zlokalizowanych w sąsiedztwie źródeł drgań konieczne staje się uwzględnienie wymagań odnośnie do zapewnienia ludziom przebywającym w budynkach niezbędnego komfortu wibracyjnego. Metody i kryteria oceny wpływu drgań na ludzi w budynkach podawane są odpowiednich normach. W niniejszym opracowaniu przedstawiono wyniki analizy kryteriów zapisanych w normach: polskiej PN-88/B-02171 [1], brytyjskiej BS 6472-1 [2], niemieckiej DIN 4150 [3] oraz w normach międzynarodowych ISO [4,5]. Na podstawie analizy przeglądu wybranych pozycji literatury wykazano kierunki wykorzystania zapisów normowych w diagnostyce i projektowaniu budynków oraz obszary dalszych prac badawczych poświęconych temu tematowi.

Rozważano kryteria oceny wyrażone za pomocą następujących wielkości:

a) skorygowana w całym paśmie częstotliwości wartość przyspieszenia (prędkości) drgań,
b) widmo (struktura częstotliwościowa) wartości skutecznej (RMS) przyspieszenia (prędkości) drgań w pasmach $^{1}/_{3}$ oktawowych,
c) dawka wibracji.

Wykazano, że najwięcej informacji przydatnych w ocenie wpływu drgań na ludzi w budynkach uzyskuje się na podstawie przedstawienia wibrogramu w postaci widma wartości skutecznej przyspieszenia drgań w pasmach $^{1}/_{3}$ oktawowych. Przez porównanie tak wyznaczonej struktury częstotliwościowej pomierzonych drgań z poziomem odpowiadającym zapewnieniu ludziom w budynku niezbędnego komfortu wibracyjnego uzyskuje się nie tylko informacje o ewentualnym naruszeniu wymagań, ale również o paśmie częstotliwości, w którym to naruszenie wystąpiło. Zastosowanie w kryteriach oceny dawki wibracji uwzględnia z kolei odniesienie wpływu drgań na ludzi w budynkach do pełnego czasu oddziaływania wibracyjnego.

Kryteria dotyczą drgań z przedziału od 1 do 80Hz. Wznoszenie wysokich i bardzo wysokich budynków powoduje, iż przedział ten powinno się rozszerzyć w kierunku niskich częstotliwości (mniejszych od 1Hz). Już obecnie w normie japońskiej [15] uwzględnia się wpływ drgań o częstotliwościach z przedziału od 0,1 do 6Hz. W normie ISO [16] również uwzględniono w ocenie drgania o częstotliwościach mniejszych od 1Hz. W opracowaniu wykazano, iż konieczne jest prowadzenie dalszych badań w zakresie uściślania informacji charakteryzujących wpływ na ludzi w budynkach drgań z przedziału niskich częstotliwości oraz bardziej precyzyjnego określenia zasad wyznaczania wartości współczynnika „n" (umożliwia on podanie górnego poziomu zapewnienia ludziom w budynkach niezbędnego komfortu wibracyjnego) i uwzględniania czasu ekspozycji człowieka na drgania. W podsumowaniu stwierdzono, że kryteria oceny wpływu drgań na ludzi w budynkach zapisane w analizowanych normach międzynarodowych i krajowych są podobne. Obecnie stosowane i doskonalone są dwie główne grupy kryteriów oceny. Jedne z nich odnoszą się do struktury częstotliwościowej drgań w pasmach $^{1}/_{3}$ oktawowych, drugie zaś – do tzw.

dawki wibracji. Prace badawcze są współcześnie prowadzone nad uściśleniem zapisów odnoszących się do obydwu wymienionych grup kryteriów. W artykule przedstawiono także kierunki rozwoju metod oceny wpływu drgań na ludzi przebywających w budynkach zawarte w literaturze w tym także wprowadzane w innych przepisach normowych. Niniejszy artykuł jest poszerzoną wersją prezentacji [6] na konferencji Urban Transport 2011.

Remarks on the paper should be
sent to the Editorial Office
not later than September 30, 2012

Received March 1, 2012
revised version
June 5, 2012