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Vibration monitoring of structures in the light of the Polish and international requirements

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Abstract: The paper concerns the wide range of strategies used to protect structures against man-made dynamic excitation. The most popular approaches applied worldwide are compared, and the main differences and similarities are summarized. The literature studies are supported by the results of the measurements performed on different types of real structures, which are sensitive and insensitive to the dynamic load. To make the conclusions more general, various types of excitation forces are examined (long-term and short-term excitations, traffic load, and loads resulting from geotechnical works). The main issue raised in the paper is the problem of unequivocal and accurate assessment of the potential structure damage, based on the different legislations. It can be seen that the application of different codes can even result in opposite conclusions about the safety of the structure.

Keywords: vibration monitoring; structure protection; seismic load.

1 Introduction

Human activities (operation of machines, road and railway traffic, or construction activities [1]) may cause dynamic loads that affect structures and people [2-7]. The problem was described and observed during vibration monitoring of different types of structure and a wide range of dynamic excitations, for example, caused by traffic excitations [8,9,10], hydrotechnical works [11], traditional [2] and innovative vinyl sheet pile driving [6] and Franki pile driving [2], and vibratory [7] and rapid impulse compaction [5]. Extended investigations of buildings subjected to long-term vibrations have been analyzed in [12].

This effect is usually more significant and dangerous in urban areas due to their close location to the vibration source. Geometrical and material damping causes rapid surface wave attenuation in soil medium for the point located close to the vibration source (~ $1/\sqrt{r}$, where r is the distance form the vibration source). The phenomenon of wave propagation and its attenuation in soil medium was described with details for linear [13, 14, 15] and nonlinear [13, 14] systems. Structural protection in dynamic source vicinity is recommended according to the wide range of Polish and international registrations [1, 8-11]. The Polish Construction Law (9 Article 5, point 1) undertakes to design and construct structures ensuring *inter alia* compliance with the basic requirements for protection against noise and vibrations (see point *e*). More requirements can be found in other Polish regulations, where vibrations and noise are defined as environmental pollution. According to The Environmental Protection Law (8, Article 3), pollution is understood as emission (directly or indirectly) to air, water, soil, or land, resulting from human activities, among others noise and vibration. This emission is hereinafter referred to as pollution, which may be harmful to human health, or the condition of the environment may cause damage of material goods, may deteriorate the esthetic values of the environment, or may conflict with other, justified ways of using the environment. The articles of The Environmental Protection Law, that is, articles 6, 7, 137, 139, 147a, refer to environmental liability, as well as financial liability for the removal of damage and legal liability [8]. There is also a provision to counteract pollution, which prevents or limits the release of substances or energy into the environment. Compliance with environmental protection requirements related to the operation of roads, railways, trams, airports, or structures at the working stage is ensured by the managers of these facilities (Article 139). In turn, in Article 147a, it

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is mentioned that the measurements of "pollutants," including vibrations, can only be made by authorized and accredited laboratories.

Vibration monitoring is helpful to ensure the dynamic safety of structure. However, defining the limit of the vibration amplitudes that can guarantee the structure and people's protection can be problematic. Two different approaches can be used to solve this problem – detailed numerical analysis and a simplified approach based on the wide range of codes and standards. The first one is more universal and exact; however, it is time-consuming and costly, so it is addressed rather to more complicated and problematic cases. The second one gives an estimation of the safety level rapidly; however, it is limited only to typical structures and ground conditions.

In the paper, different international standards and Polish approach are introduced with the example of the man-made vibrations (geotechnical works, traffic excitations). Complex guidelines for the protection of the adjacent structures and the surrounding environment against vibration are critical for structural protection, but assessments of the impact of vibrations on the environment are ambiguous and can bring different (even opposite) conclusions about the safety of the surrounding buildings. Some remarks on the methods used during vibration monitoring to ensure structural safety have been already formulated by the authors [8,11,15,20] and other researchers [1,13]. However, they usually focus only on polish standard [8, 13]. The studies [1,15, 20] include both Polish and selected international standards, but without comparison studies and conclusions. In this paper, polish and international approaches are presented more accurately (Circulaire 23/07/86 and Eurocode 3 are added to the theoretical studies) and all methods are compared to each other for two opposite cases – vibration-sensitive structures with long-tem excitations and vibration-resistant structures exposed to a dynamic load of short duration. Theoretical investigations are supported by the selected case studies. We chose the cases of vibration monitoring with large values of the soil response to underline the differences in the estimations of the structural safety given by the different codes. Conclusions based on the literature and legislation review and our own experience are formulated.

2 Literature review

2.1 International approach concerning the impact of vibrations on buildings

In most of the legislations, the threshold values of the peak particle velocity (PPV) are presented in the frequency domain for different types of structures. The limit values cannot be exceeded during the exposition of structure to dynamic excitation. Four definitions of PPV are used for vibration monitoring, while the most common concerns the maximum observed component of the velocity vector for the measurements carried out in three orthogonal directions (e.g., BS 5228-4, BS 7385-2, DIN 4150-3 – for the measurements made on the foundation level) [21-23]. Other definitions are addressed to a maximum of two measured horizontal components (e.g., DIN 4150-3 measurements of the structure dynamical response in the upper ceiling level), vertical component (DIN 4150-3 measurements of the structure dynamical response in the middle of ceiling), square root of the sum of the squares of the maximum values observed in all three orthogonal directions (SRSS), or the true vector sum of the three-velocity vector components (TVS) (used in SN640312 [24]). Each definition leads to a different estimation of the structure damage risk. According to [1], PPV based on the maximum value of the three components of the velocity vector gives a value up to 25% smaller than TVS. On the other side, the application of SRSS can lead to even 50% greater values than TVS.

According to the majority of the standards analyzed in the paper, points located near the ground surface or foundation should be observed during vibration monitoring. Measurements should be carried out on the structural wall next to the vibration source in three orthogonal directions. Moreover, the whole structure should be observed during monitoring to avoid the resonance effect of the whole structure or its selected elements, especially in the case of long-term vibrations (BS 7385-2, DIN 4150-3, Circulaire 23/07/86). The critical points for structure, where the largest dynamical response is predicted, are located on the highest floor:

- in the middle concerning the vertical component and
- in the corner of the structural walls concerning the horizontal components.

The observed value of PPV is compared to the threshold value given by the appropriate standard, which depends usually on the type of the examined structure and

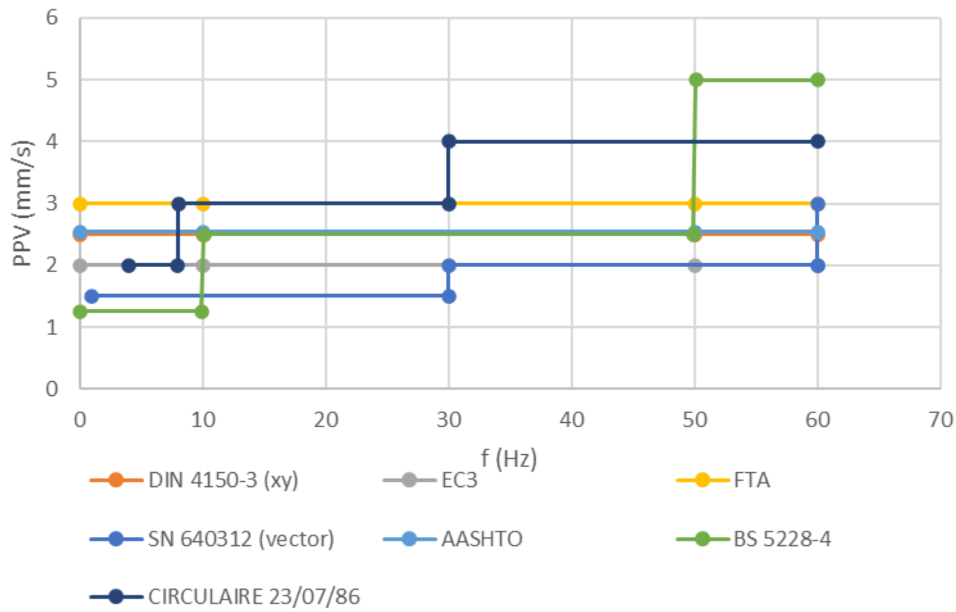


Figure 1: Threshold values of PPV at the foundation level given by the different codes addressed to structures sensitive to the dynamic load and long-time vibrations.

characteristics of the excitation force (frequency, long- or short-term vibrations).

In Figs 1 and 2, the threshold values of PPV are compared in the light of different international standards [21-29]. Two opposite cases (the most and the least conservative ones) are presented:

– structures sensitive to the dynamical excitations subjected to long-time vibrations (Fig. 1) and
– industrial, heavy commercial buildings subjected to short-time dynamical excitations (Fig. 2).

Generally, the acceptable vibration level is lower in the first analyzed case. Long-lasting continuous vibrations may cause material fatigue and initiate the resonance effect of the whole structure or its elements. As the natural frequency of typical structures is relatively small (less then few Hertz), the threshold values of PPV are smaller for the excitation frequencies close to the range of frequencies typically observed for buildings. For large values of excitation frequencies, the vulnerability of the structure to damage caused by the resonance effect is smaller. Therefore, larger values of the acceptable velocity components can be observed for both continuous (Fig. 1) and transient (Fig. 2) vibrations. In the case of impulse type of excitation (like blast), the permissible vibration level is much bigger than in the case of long-time excitations, as the possibility of the resonance effect and structure or material fatigue decreases (Figs 1 and 2).

Generally, for long-time vibrations and dynamically sensitive structures, the vibration PPV limits are very small values (1.25 mm/s) for low frequencies (<10 Hz) and more significant (4–5 mm/s) for the frequencies apart from the natural frequencies of structures (>30 Hz). The most conservative estimation of the damage possibility is presented in Swiss code (SN640312) (Fig. 1).

The limit value if velocity is 1.5 mm/s in the wide frequency range covering the natural frequencies of structures (<30 Hz). It has to be emphasized that not only the threshold values given by SN640312 are lower compared to other codes, but also they are related to the sum of the velocity vector components, not the maximal values of three orthogonal components, like in the vast majority of the codes analyzed (DIN 4150-3, BS 7385, BS 5228-2, Circulaire 23/07/86, and others). On the other hand, French code (Circulaire 23/07/86) requires the largest values of velocity vector components; however, the threshold values are given for measurements carried out not only on the foundation level, but also on the floors [25]. In other codes, the threshold values defined for ceilings are usually bigger compared to the ones given for monitoring made on the foundation level (compare DIN 4150-3 and BS 5228-2).

In the case of transient vibrations of the dynamically insensitive structures (Fig. 2), the acceptable limit of vibrations is less conservative compared to the case described above (Fig. 1). Moreover, the wider range of the

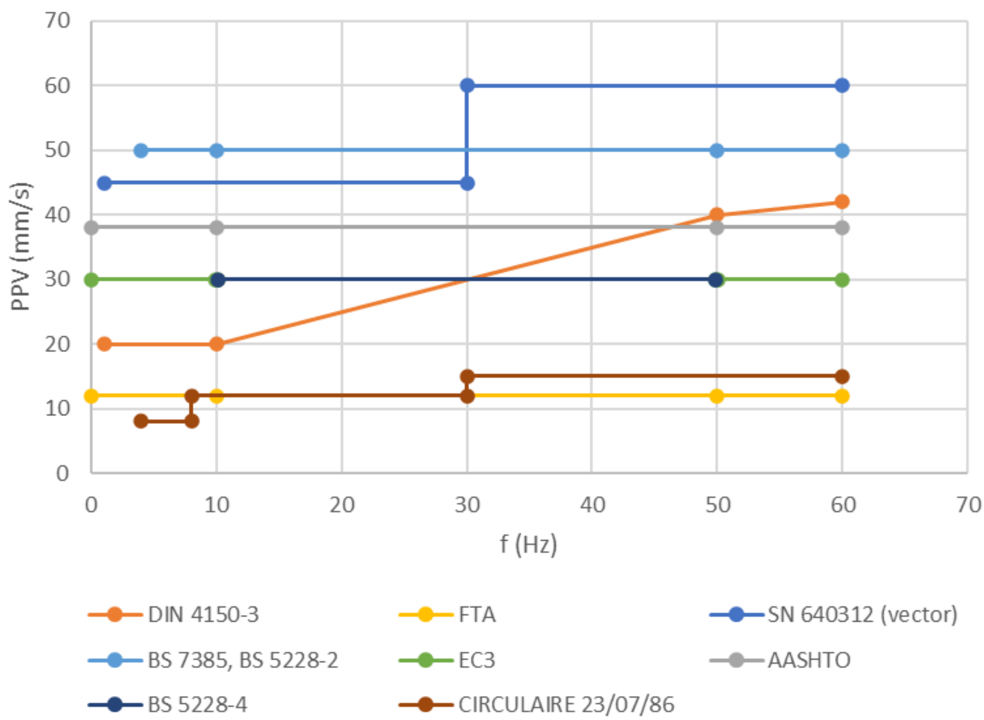


Figure 2: Threshold values of PPV at the foundation level given by the different codes addressed to industrial and heavy commercial buildings insensitive to the dynamic load and short-time vibrations.

values given by the different guidelines can be observed (Fig. 2), compared to the case of continuous vibrations (Fig. 1). The most conservative approach is presented in French code (Circulaire 23/07/86), where acceptable velocity components differ from 8 mm/s for lower frequencies (<8 Hz) to 15 mm/s for the frequencies away from the natural frequencies of structures (>30 Hz), when the resonance effect is less possible. The highest values of vibration limits are presented by British and Swiss codes, where the threshold vales for the velocities are greater than 45 mm/s. However, it must be emphasized that the threshold value given by Swiss code is related to the velocity vector and not to its component, so the relative estimation is more conservative.

2.2 Polish approach concerning the impact of vibrations on buildings

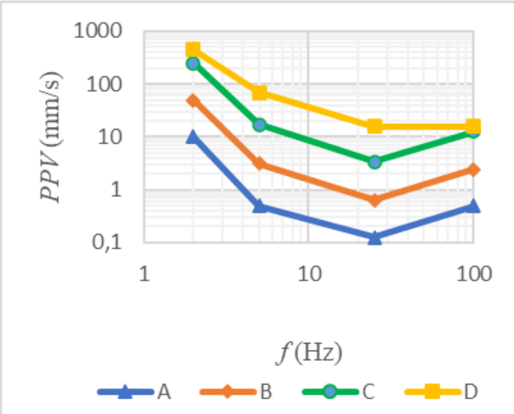
The criterion for assessing the impacts on structures is not yet widely disseminated and used in civil engineering. Substantially, there is also no provision in the legal regulations related to the obligation to perform an assessment of dynamic impacts. There are, however, certain legal regulations in Poland that relate to the analyzed issue.

Specific legal regulations can be found in the PN-B-02170: 2016-12 standard [30], based on which the impact of vibrations on buildings is tested. The second standard item is PN-B-02171: 2017-06 [31], based on which the impact of vibrations on the people in buildings is determined.

The measurement methodology can be divided into four cases, depending on the existence (or not) of a building object and the source of vibrations [30] as follows:

- the building is designed, the source of vibrations is designed;
- the building is designed, the source of vibrations is exploited;
- the building is existing, the source of vibrations is planned; and
- the building exists, the source of vibrations is in use.

The most common case is when both the building is in operation and the source of the vibration is known. In this case, the focus should be on determining the influence of vibrations by making actual field measurements. In the case of actual measurements and their analysis, the diagnosis is based on vibrograms recorded with the use of specialized equipment, that is, vibration charts showing the dependence of displacement, velocity, or acceleration on time.



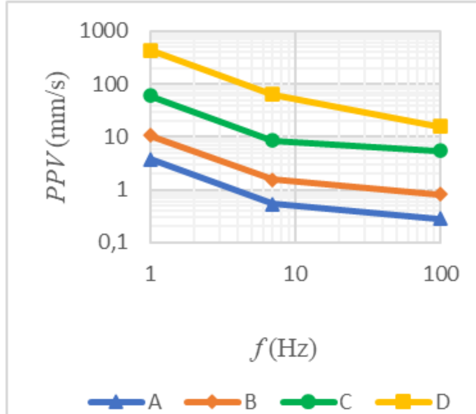


Figure 3: Dynamic Influence Scale (DIS I on the left, DIS II on the right) [21].

However, according to [30], the influence of vibrations transmitted to the ground may be neglected if the building is located

- 25 m from the axis of the railway line,
- 15 m from the axis of the tram line or the axis of the first category road,
- 20 m from the source of vibrations caused by construction works (sticking in piles, sheet piling, vibratory hammers), or
- 60 m from the path of road rollers.

If the building is located closer to the vibration source, it is recommended to check the influence of dynamic effects on structure. According to the Polish code, measurement sensors (accelerometers) should be installed at least in three places on the site from the vibration source [32]. The measuring points should be located on the foundation or on the wall at the ground level. The sensors should not be placed in places with a dilated sense from the building and in places with high vibration amplitude, for example, on a wall under the landing of the stairs. The sensors should also not be placed on the ceiling above the basement because it may have overstated values [33]. The measurement should be performed for the horizontal vibration components on the foundation or load-bearing walls at the ground level, separately for the longitudinal and transverse directions. It is assumed that the reliable vibration duration is the time during which the amplitude values are greater than 0.2 of the extreme value. Measurement results should be filtered in the frequency range 1–100 Hz. The analysis is performed in one third octave bands for the center frequencies. A separate detailed standard analysis is performed for each building. It is, therefore, necessary to determine the extreme amplitudes for 21 different center frequencies and plot them on the Dynamic Influence Scale (DIS) graph (see Fig. 3), and then read the zone in which the object is classified. The standard [30] applies to residential, brick buildings, constructed in traditional technology, which are divided into two groups as follows:

1) compact buildings with small external dimensions of the horizontal projection (maximum length 15 m), with one or two storeys; the height of the building should not exceed the dimensions of the horizontal projection and
2) buildings up to five storeys; the height of the building should not exceed twice the shortest width.

DIS I has been created for residential buildings belonging to the first group and DIS II for buildings meeting the assumptions of the second group (Fig. 3).

Influence zones are defined as follows [30]:

- zone I (below A line in Fig. 3): no impact of vibrations on the building;
- zone II (between A and B lines): vibrations are noticeable, but do not pose a threat to the structure;
- zone III (between B and C lines): the overall load-bearing capacity of the building may be weakened;
- zone IV (between C and D lines): vibrations have a major influence on the building, the amplitudes are high enough to cause various objects in the apartments to tremble, and there is a risk for the health of inhabitants; and
- zone V (line D): the load-bearing capacity is dysfunctional as a result of large amplitudes of vibrations, which may lead to a major malfunction or even total collapse of the structure.

3 Results of the field measurements

The examples of vibration monitoring presented in the paper are related to man-made vibrations (geotechnical works and traffic excitations). They cover two types of dynamic excitations (long term and short term). For these opposite cases, the results of the vibration monitoring made during geotechnical works are related to the international standards (Sections 3.1 and 3.2). To make the presented research more complex, traffic-induced vibrations related to the Polish standards are also presented (Section 3.4).

The first presented example (Section 3.1) concerns the influence of long-term vibrations on the structure sensitive to the dynamical excitation during diaphragm wall realization. The technology is described in detail in [34].

The second example (Section 3.2) concerns plunging the steel profiles of the soldier pile wall. The technology is described in [35]. In this case, the structure is insensitive to the dynamic influences and is subjected to short-term vibrations. Both study sites were in Wrocław (Poland). The measurements were performed in the years 2000–2022. The city is situated on The Silesian Lowland, which is the southernmost part of the Middle-Polish Lowlands. There is a vast plain with little diversity of relief. It spreads from the southeast to the northwest, along the glacial valleys of the Oder River, which is filled with alluvial sediments of Pleistocene and Holocene, mostly sand and gravel [37]. The last example concerns traffic-induced vibrations in the light of Polish legislations (Section 3.3). The measurements were performed in Słupsk, located in *northern Poland, on the Baltic coast*.

3.1 Long-term vibrations and vibration-sensitive structure (geotechnical works)

The presented example concerns the influence of vibrations on the structure located close to the vibration source during diaphragm wall realization (Fig. 4). The dipper (~20 T) suspended on ropes was lowered freely to finally hit the ground. In this way, dynamic impulse with rather low velocity amplitudes and low frequencies occurs. After the bucket is closed, the soil is removed. In this way, the trench is gradually deepened. The process of one-segment realization takes ~30–60 min, so it causes long-term or permanent vibrations according to the definitions given in the different standards [21-30]. The monitored facility is a school building with a traditional brick structure, built in the years 1890–1892. The building does not have concrete lintel beams, ring beams, or other modern bracing ensuring spatial stiffness. The catastrophic flood in 1997 in Wrocław, Poland did not cause structural damage directly, but had an adverse effect on the building. Moreover, the development on the adjacent property resulted in further adverse impacts on the building. The location of the building in the city center, the impact of other sources of vibration from road and rail traffic, as well as its existing damage allow to classify the structure as an object sensitive to dynamic influences. Vibrations were measured ~0.5 m above the ground level in three orthogonal directions (Fig. 5), using the three-channel geophone (Digital IR filter) Profound's VIBRA+ device. With Profound's VIBRA+, vibrations are measured reliably in accordance with the national and international standards (like DIN 4150-2 and -3, BS 5228-2, BS 7385-2). VIBRA+ also determines the dominant frequency in accordance with the advanced FFT (*Fast Fourier Transform*) method. Velocity range 0–100 mm/s with the resolution display 0.01 mm/s.

The results are presented in Fig. 5, where PPV exceeding according to the most and the least restrictive codes are presented. It can be seen that application of different codes can result in different conclusions.

For FTA (Federal Transit Administration) starndards, only few potentially unsafe exceedings appear. This is opposite to the analyses base on BS 5228-4, where the situaltion looks more dengerous. According to BS, geotechnical works should be stopped, **whereas in the light of** FTA, the situation is safe. During trench excavation, some additional dangerous effects may appear due to the variations in the level of the groundwater table, the pore pressure, or due to the soil collapse, weak soil lenses, suction forces, etc. [37]. Distinction of the cause of failure between the vibrations themselves and the above-mentioned factors can be difficult because the mentioned defects usually appear simultaneously [38].

3.2 Short-term vibrations and vibration-resistant structure (geotechnical works)

The case of short-term dynamic interactions characterized by high velocity amplitudes and high frequencies is presented using the example of plunging the steel profiles of the soldier pile wall (Fig. 6).

According to the technical specification of the ABI vibration hammer used, it works in the frequency range ~29–35 Hz and generates a centrifugal force ~237–324 kN on the profile IPE 300 profiles being deepened.

A monitored residential building with a reinforced concrete structure, still in the construction phase, without finishing elements, is resistant to dynamic effects (Fig. 6). Vibration monitoring was conducted using the device Profound's VIBRA+. Measurements were performed on the structural walls at the ground level in three orthogonal directions, consistent with the direction of the structural elements. The effect of the short-term dynamic excitation on the structure is presented in Fig. 7 and Table 1. Large vibration amplitudes and frequencies can be observed in the presented case. However, only few transgressions can be seen considering BS 7385-2, unlike the FTA where the situation looks much more dangerous.

Figure 4: The examined case: structure sensitive to dynamic excitation located in the vicinity of diaphragm wall installation (a); vibration monitoring made on structure (b).

3.3 Long-lerm vibrations and vibration-insensitive structure (traffic load)

In the presented case, long-term vibrations are analyzed in the light of Polish legislations [30], wherein the obligation to conduct tests applies only to cases where the building is located 15 m from the axis of the first category road (see Section 2.2). In the presented example, it is a local road; so, there is no legal obligation to carry out surveys. However, the research has been carried out because owners reported vibration discomfort when vehicles passed in front of the house. The examined building is a single-family house made of concrete blocks, with reinforced concrete foundations, is newly built, and its dimensions exceed 15 m. It is located on a road made of

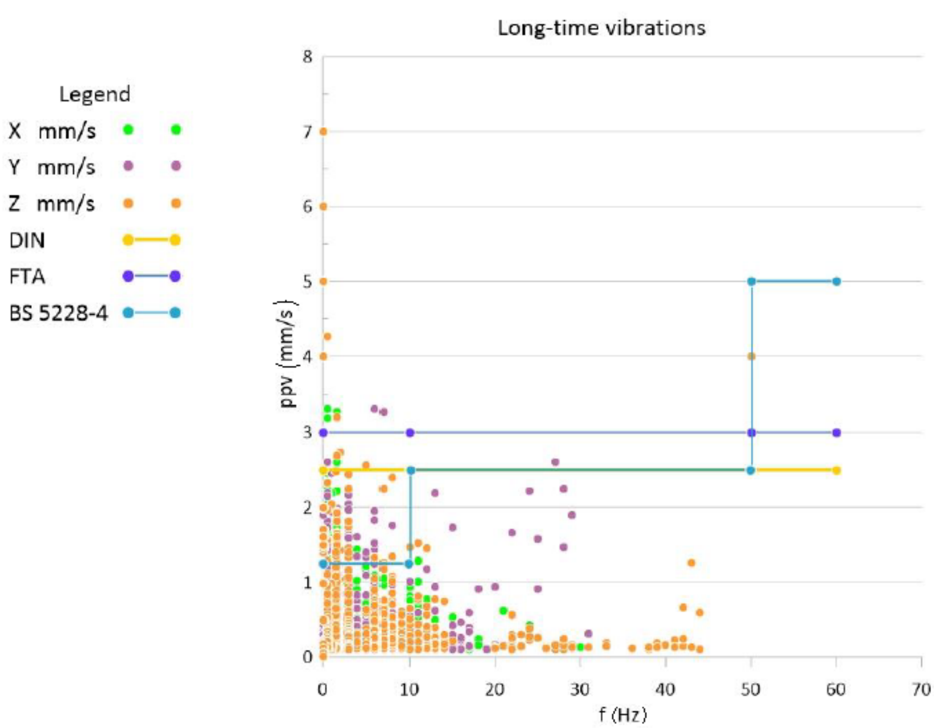


Figure 5: PPV values on the foundation level compared to the vibration limits given for the vibration-sensitive structures and long-time vibrations.

Figure 6: The examined case: vibration-resistant structure located near the soldier pile wall realization.

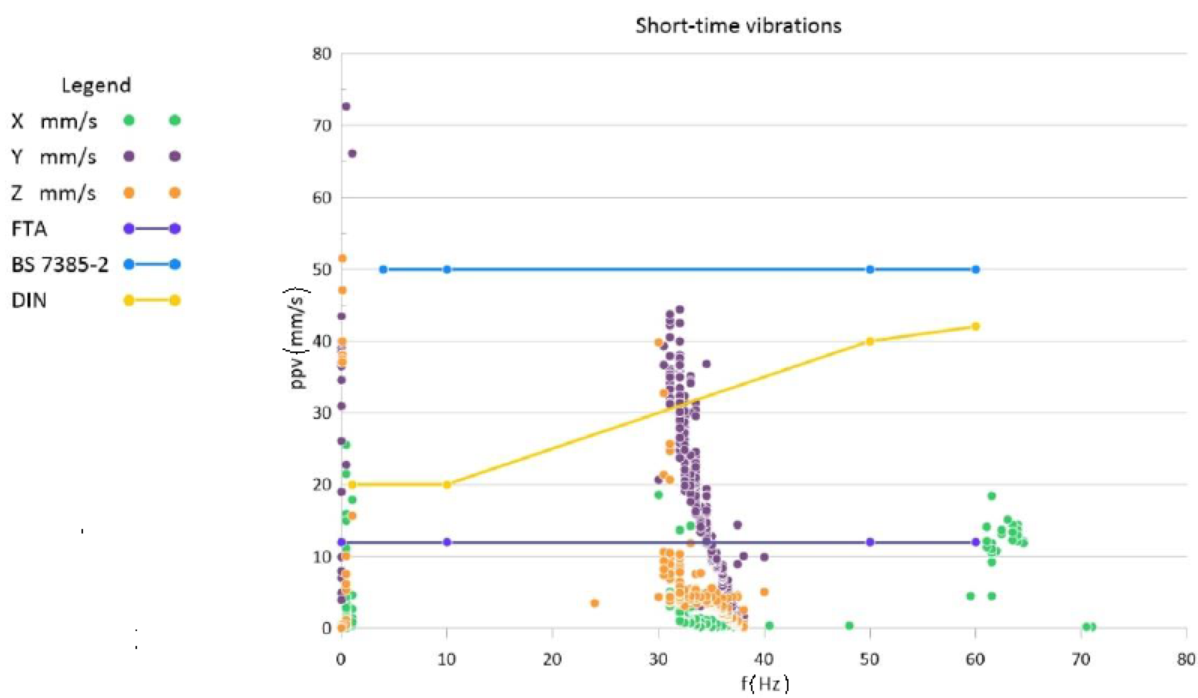


Figure 7: PPV values at the foundation level, compared to the vibration limits given for the vibration-insensitive structures and short-time vibrations.

Table 1: Number of occurrences of PPV transgressions according to the most and the least restrictive codes and the average (vibration-insensitive structures and short-time vibrations).

Standard used	*Number of PPV exceedings*
BS 7385	*2*
DIN	*71*
FTA	*280*

reinforced concrete slabs, which is in a very bad condition (Fig. 8a). Piezoelectric acceleration sensors have been connected to the measuring apparatus, which had been properly configured. The tests have used six sensors mounted on the foundation wall of the building parallel to the street, just above the ground level. After connecting the sensors and setting up the apparatus, calibration has been carried out. On a computer connected to the

(a)

(b)

Figure 8: The examined case (a) and specialized measuring equipment with a computer and sensors connected to the foundation (b).

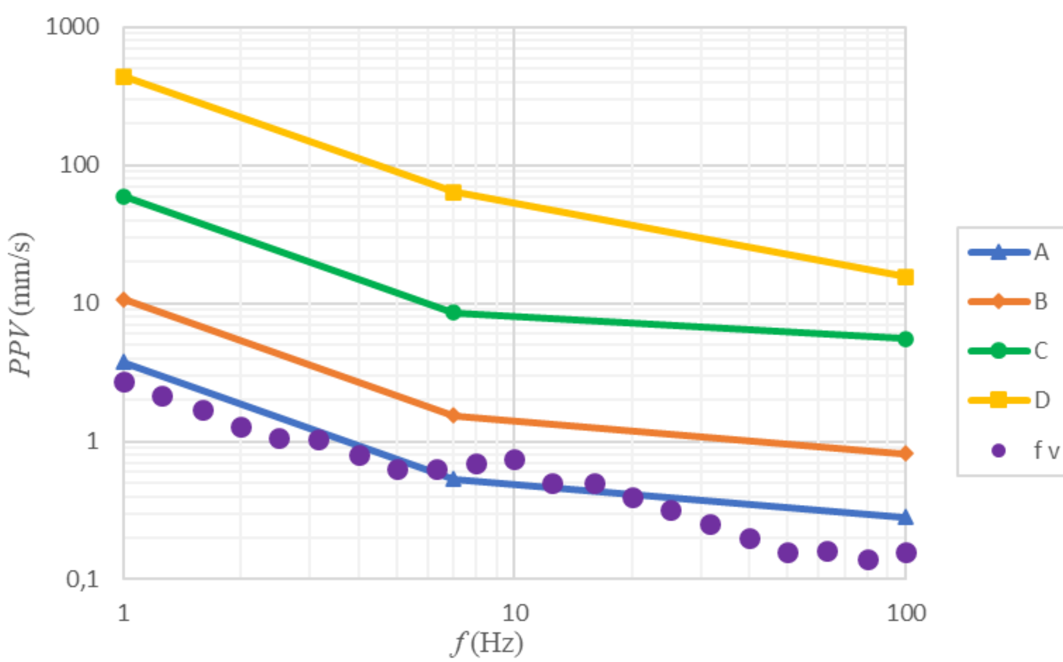


Figure 9: Results of impact analysis of the example building.

"Vimea" measurement apparatus (see Fig. 8b), velocity time courses have been recorded for various vehicles: passenger cars, buses with two axes, vans and trucks with a total weight of up to 10 t, and buses and trucks with a weight of over 10 t and more than two axes.

After measurements were conducted in the field, each time for each tested building, an in-depth analysis was performed by subjecting the time courses to filtration.

Fig. 9 shows the results of vibration monitoring. Research conducted on the building showed that the situation could be classified as zone II, which means that the vibrations are felt by the building, but are not harmful.

Cracks and peeling off of the paint may occur. The tests were carried out at the request of the investor because the vibrations had been felt by him. However, it turned out that the dynamic impact on the building was small. This is because the threshold of human perceptibility to vibrations is much lower than the threshold of perception of vibrations by a building. After performing field tests using specialized equipment, it often turns out that there is no direct threat to the structure. Therefore, carrying out such tests for all buildings located along the road may prove to be unprofitable from an economic point of view.

4 Summary and conclusions

Vibration monitoring is a very useful tool to estimate the possibility of structure failure during dynamic excitation. The whole process to prevent structures from damage is described by various standards, as described in Section 2. They give criteria depending on various technologies used, construction materials, and excitation characteristics. The aim of the paper is to compare different international and Polish legislations based on the real measurements made on different types of structures and different dynamic load characteristics – long-term and short-term excitations, geotechnical works, traffic effects. Also, we formulated some detailed remarks from our own experience, consistent with the conclusions reported by other researchers in the literature.

The following similarities can be formulated for most codes, based on the presented research:

- In most of the international standards, PPV is introduced to compare the measured value with the appropriate limit given by codes. In this way, the hazard level during dynamic excitation can be determined. Usually, PPV is the maximal value of velocity vector components [1]; however, in SN 640312, the whole velocity vector is considered [24] in contrast to DIN 4150-3 (the case of vibration-sensitive structures) [23], and Polish [30] code where horizontal components are crucial.
- In all standards analyzed in the paper, threshold values of PPV depend on the type of excitation, especially the excitation frequency and excitation duration (short- and long-term vibrations) and the type of structure being analyzed (sensitive or insensitive to the dynamic load).
- Limit values introduced by the international and Polish codes are usually presented in the form of curves in the frequency domain [21-30] – more rigid requirements are formulated for relatively low vibration frequencies to prevent resonant vibrations, as the frequencies below 10 Hz are close to the natural frequencies of majority of buildings or their structural elements.
- For both Polish and international standards, measurements of PPV should be performed at the foundation level or on the load-bearing wall (level ~0.5 m). However, in most of the standards, the need of observing the whole structure is underlined. Additional points should be in the area where resonant amplification can be observed – highest floor for the horizontal components and middle of the ceiling for the vertical components.

The following are the significant differences between Polish and international standards:

- According to the Polish code, measurements of the vibration amplitudes should be performed for the acceleration/velocity vector components in two horizontal directions. In most of the international legislations, velocities in three orthogonal directions should be observed.
- In Polish code, the analyses are performed in one third octave bands for the center frequencies. This is opposite to the international codes, where PPV is measured without any filter.

Comparison studies of the international standards yield the following conclusions:

- For long-term vibrations and structures sensitive to the dynamic effects, the lenient approach is used in FTA [28], DIN 4150-3 [23], and Circulaire 23/07/86 [25] and more rigid approach in EC3 [26], SN 640312 [27], and BS 5228-4 [21]. Based on the example presented in the paper, it can be observed that assessments of the impact of vibrations on structures in the vicinity are inconsistent and can indicate different conclusions about the safety of the surrounding buildings (Fig. 5).
- For short-term loads and vibration-resistant structures, the lower limit is for FTA [28] and Circulaire 23/07/86 [25] and greater values of measured velocities are allowed in BS 7385-2 [22] and AASHTO [29]. Results presented in the paper show that application of different codes can yield opposite conclusions about the safety of the structure in the vibration source vicinity (Fig. 7, Table 1).

All considered standards were formulated approximately in a similar period, so variability of the permissible values in national codes may result from different regional types of structures or finishing elements. Moreover, especially for short-term vibrations, slightly different definitions are used to describe this type of excitation. While in Polish code, ~3 min/day is the maximal estimated period of time to include load to short-time excitations, BS 7385-2 considers even rapid blast excitations. On the other hand, in DIN 4150-3, the definition is more general and based on the possibility of vibration amplifications and structure fatigue as a result of the resonant effect.

From our own experience in decades of vibration monitoring of different structures, supported usually by DIN 4150-3:1999, the following observations, consistent with the conclusions found in the literature, were made:

- In most of the legislations, the threshold values of PPV depend on the type of structure, kind of the structure exposed to a dynamical load, and frequency of the vibration source. Usually, soil conditions are omitted in the structure safety predictions. However, the geotechnical aspects are important and should be taken into account, especially in the case of loose sands, saturated sands, or silty soil deposits. In these cases, settlements due to densification or liquefaction effect more likely cause damage than the direct effect of dynamic excitation and resonant vibrations. Such settlements can occur even far away from the vibration source as Woods reported [39] and are more likely when a large number of piles are driven [39]. The case studies that report this fact for vibratory sheet pile driving can be found in [40] and for pile driving in [41]. In the selected cases, significant effects of settlements can occur even for a PPV level below the threshold values of PPV defined in the legislation presented in the paper. These legal acts take into account only the vibration effect on structures and do not consider the significant and complicated aspects of the soil behavior under dynamical excitations. In our opinion, this issue is crucial for further investigations and improvement of the existing standards. Some predictions of sandy soil behavior and settlements due to dynamical loads can be found in the literature [39,42].

– PPV threshold values, defined in the standards presented in the paper, refer to the whole structure. For the selected structural elements or equipment sensitive to vibrations limit that ensures safety is usually much lower.
– From our experience, based particularly on the measurements supported by DIN, a single, even significant exceeding of the PPV values is not a danger to the structure's safety and does not cause even cosmetic damage.
– Usually, the human perception of vibrations generated by geotechnical works is more sensitive, corresponding to the limits defined in the standards. Vibrations are strongly felt by occupants of buildings, even if the measured PPV does not exceed the threshold values.
– To avoid long-term PPV exceeding for geotechnical works in the close vicinity of the structure, dynamical methods can be combined with others, like drilling.
– Most of the presented standards have been introduced in the 90s of the 20th century or earlier. Therefore, it is necessary to update the threshold values for further investigation. The dynamic sensitivity of the structures is different nowadays, as a result of the modern technologies and materials used. Moreover, the new technologies and machines used during geotechnical works affect structures in a different way.

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