EFFECT OF TRAIN VIBRATION ON BUILDINGS - COMPARISON OF THE FFT AND 1/3 OCTAVE METHODS

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Abstract

As appears from international and national standards, there is a great variety of descriptors of building vibration. Standards such as German DIN 4150-3 or British BS 7385-2 use Peak Particle Velocity and Dominant Frequency as the mathematical operators whereas others standards use reference curves expressed in 1/3 octave bands (e.g. American IEST VC curves or Polish SWD curves). Each method uses different criteria for building damage so the same vibration event can be assessed differently, as has been shown in this study. The variety of building vibration standards often cause misunderstanding and can lead to the incorrect assessment of results.

The test object is the foundation plate of a multi-storey building located around 30 m from the railway tracks. Additional measurements have been taken in the soil to observe the soil-foundation transfer function.

The real inputs of vibration induced by trains were measured and obtained using the SV 258 PRO. The vibration level induced by trains on the building were determined using four different standards.

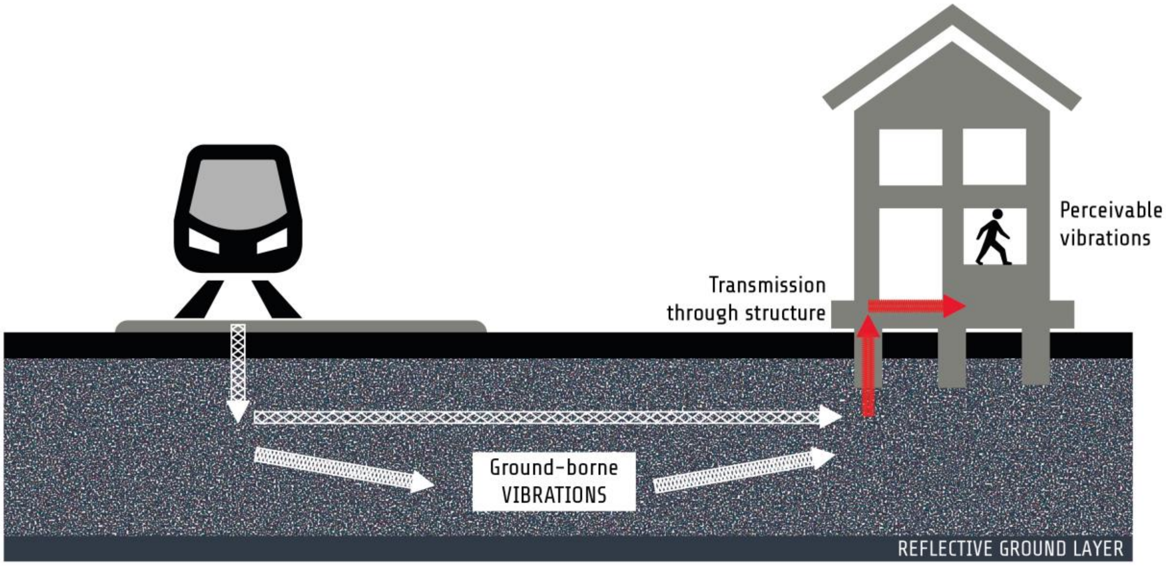
Keywords

Train-induced vibrations • DIN 4150-3 • BS 7385-2 • ISO 4866 • VC Vibration Criteria • SWD curves

1. Introduction

1.1. Building Vibrations induced by trains

Trains running on tracks and in tunnels induce vibration in the underlying track-bed and sleepers. Vibrations penetrate the surrounding ground layers and their propagation depends on the ground structure. What is more, the structure has an impact on the propagation amplitude and speed. When reaching a building, the vibrations may be perceived as general vibrations or a low-frequency noise. Obviously, this type of vibration may cause structural damage and disturb vibration-sensitive equipment.



Picture 1 Generation mechanism and transmission path of ground-borne vibration

Vibration propagation from passing trains to the surrounding ground and, subsequently, the nearby buildings is complex and depends on various factors. The generation of train-induced vibration propagation path is often divided into three stages [Melke J. p. 381, 1988]. The first stage is the source, the next one – the propagation path and last one – the recipient. In this case, trains and tracks constitute the source, the analysis of propagation path takes into account tunnels and the ground, and buildings are identified as recipients. However, the purpose of buildings is to house people, therefore residents are also considered as recipients. During propagation from the source to the recipient, vibrations are attenuated by a number of factors but they may be amplified as well. The attenuation and amplification of vibrations, the impact they exert on the structures of existing or planned buildings and the impact on people and equipment in buildings are of particular interest for researchers exploring the subject of **train-induced vibrations**.

Train-induced vibrations are caused by the movement of trains along the track and the interactions between the wheels, the rails and the trackbed structure. A train standing still on the trackbed generates force due to the weight transferred from the wheels to the rails, sleepers, embankment and the ground. Such load is considered as static. When the train moves, the force is transferred accordingly and the load changes due to the multitude of train-rail determinants, for example the irregularities on rail and wheel surface, complexity of train suspension system and rail connections. Therefore, the generated vibrations are transferred from the track to the surrounding ground. Many factors influencing the level and characteristics of vibrations caused in such a manner have been identified. [Möller B. 2000]. They include the weight, geometry and category of the train (length, type – passenger or cargo) and the train speed. Other significant issues are the impact of the wheels, e.g. their improper balance and other defects, the train's suspension system, its rigidity and structure as well as the condition, irregularities, connections and corrosion level of the rails.

The above mentioned factors may be present in the case of trains running both on the ground and in underground tunnels. ISO 14837 standard for ground-borne vibration generated by the operation of rail systems defines the relevant frequency scope as 1 to 80 Hz. The vibration frequency resulting from the above mentioned factors depend of the speed of the train. The table below illustrates the scope of frequency for the selected sources of vibrations at the speed of 40, 80 and 160 km/h.

Vehicle speed	***40 km/h***	***80 km/h***	***160 km/h***
Moving load (axle spacing approx. 1.8m)	3 Hz	5 Hz	11 Hz
Track unevenness	≥ 1 Hz ≤ 100 Hz	≥ 2 Hz ≤ 200 Hz	≥ 4 Hz ≤ 400 Hz
Wheel unevenness	≥ 4 Hz	≥ 8 Hz	≥ 15 Hz
Rail corrugation	approx. 500 Hz	approx. 1000 Hz	approx. 2000 Hz
Wheel polygonisation	approx. 100 Hz	approx. 200 Hz	approx. 400 Hz
Inter boogie spacing	approx. 1 Hz	approx. 3 Hz	approx. 5 Hz

Table 1 Frequency of typical vibration for each of the generating mechanisms depending on the train speed in accordance to Railway induced vibration, state of the art. Report International Union of Railways November 2017

The literature suggests that the hearing range begins at 16 Hz. Additionally, the sound generated by the vibration of the ground ranges from 15 Hz to 125 Hz. A comparison of this data and the above mentioned scope of ground vibration between 1 and 80 Hz allows one to observe that the identification of received stimuli and differentiation of the phenomenon within 15-80 Hz may be hindered. The masking effect or an accumulation of phenomena may occur as well. The vibrations may seem more intense when accompanied by an audible sound or low-frequency sound.

The ISO 4866:2010 standard, establishing the principles for carrying out vibration measurement and evaluation of their effects on structures, defines the structural responses for various sources.

Vibration source	***Frequency range (Hz)***	***Amplitude range (μm)***	***Particle velocity range (mm/s)***	***Particle acceleration range (m/s^2)***
Traffic (road, rail, ground-borne)	1-100	1 - 200	0,2 – 50	0,02 - 1
Blasting vibration	1 – 300	100 – 2500	0,2 – 100	0,02 – 50
Pile driving (ground borne)	1 – 100	10- 50	0,2 – 100	0,02 -2
Earthquakes	0,1 – 10	10 – 10^5	0,2 – 400	0,02 -20

Table 2 Extract from ISO 4866:2010 Mechanical vibration and shock – Vibration of fixed structures – Guidelines for the measurement of vibration and evaluation of their effects on structures.

One should remember that the above mentioned values are the extreme values and the span of vibration levels is very wide. It may be observed that vibrations induced by road traffic, including vehicles and trains, is close to negligible as regards structural damage to buildings. Nevertheless, such vibrations may be disturbing. The distance at which vibrations may be perceivable and may exceed limits specified in the German standard DIN 4150-2 are the following:

– cargo lines, highly soft soil, wooden floors and ceilings: 200 m,

– railway lines: 60 m,

– subway lines (underground): 50 m [DIN 4150-2].

The above data indicates that railway traffic causes vibrations in the ground which may travel to residential buildings. If such buildings are located close to railway tracks, the vibrations may be so intense that the residents may be able to feel them. Apart from numerous factors influencing the force of transmitted vibrations, such as frequency, ground characteristics or dynamic properties of buildings, scholars also identify individual sensitivity to vibrations, which has a great impact on annoyance and sleep problems.

1.2. Vibration influence on buildings

Ground vibrations may reach the foundations of buildings in the vicinity of railway tracks. As for buildings located further away, the vibrations are usually effectively attenuated and thus barely noticeable. Still, vibrations in foundations are transferred to the building, which responds at various resonance frequencies. The frequency and power of resonance enforcement is largely dependent on the structure of buildings and used materials. Research proves that amplification of foundation vibration related to floor vibration falls within 0.5 (reduction) and 5.0 within the frequency of 25 to 30 Hz [Kurzweil, 1979, p. 363]. In the case of highly urbanised big city areas with a large number of buildings with varied structure, it is difficult to unambiguously assess and guarantee the compliance with the values assumed by different standards, since amplification is almost unpredictable and may vary greatly.

Moreover, vibrations transmitted to buildings depend on the connection between the ground and the foundations. The typical frequencies in residential areas do not exceed 10 Hz, analogically to loose soil. Train-induced vibrations fall within the same frequency scope, which is highly significant. If the width of a building is equal to wavelength (n−1/2), there is a possibility of the building swaying [Dawn, Stanworth, 1979, p. 355] and if it is equal to the natural frequency of the building, amplification may occur. When vibrations reach the foundations of a building, they will be propagated to different parts of the building and, subsequently, either attenuated or amplified. Individual elements of buildings, such as floors, walls and ceilings may act as amplifiers, whereas in light constructions no attenuation is observed [Kurzweil, 1979, p. 363]. This suggests that damage may occur regardless of the source of vibration, be it an earthquake, an explosion, road traffic or the operation of railway systems. There are many categories and classifications of damage to buildings due to vibrations. Leventhall distinguishes three categories of damage to buildings [Leventhall, 1987, p. 54]:

– minor damage resulting in cracks of several millimetres in width, loosening and minor displacement, etc. Small repairs required;

– serious damage in the form of wall and lintel cracks of 10 mm in width. May result in plaster falling off the ceiling. Professional repair required;

– heavy damage causing cracks of about 25 mm in width which may lead to the deterioration of a building. Major repair works required to maintain fitness for residential purposes.

The potential damage to buildings may be influenced by the age, type, structural strain, structural resonance frequency and structure of a building. Leventhall estimates that the safe limit for residential buildings is 50 mm/s (PPV). The impact threshold for architectural damage is 5 mm/s (PPV), while for old-type structures and historical buildings it falls within 2 mm/s (MAX). Still, vibrations are often blamed for e.g. wall cracks in residential buildings, even though vibration levels are seldom high enough to be the cause. Many people associate noise with vibrations and one should consider the fact that it is far easier to obtain financial benefits for physical damage than for annoyance, the latter being a rather psychological matter.

1.3. Vibration influence on humans

Vibrations may be perceived in two ways, either as perceptible vibrations or audible sound. Perceptible vibrations occur when a body part is in direct contact with the vibrating surface. Audible sound may be a low-frequency rumble or rattle of window panes or porcelain caused by the vibration of the floor or the walls. The manner in which people perceive vibrations and noise depends on their activeness and the size and frequency of the vibrating objects.

The human body perceives vibrations in all frequencies if the vibration amplitude is high enough. The human perception of vibrations is influenced by the following aspects:

– the characteristics of the body exposed to vibrations,

– disrupting phenomena (physical, physiological and psychological),

– acceptable level, time and frequency of exposure [Eitzenberg A. 2008 p. 20].

Perceptibility threshold is the lowest level at which people perceive vibrations. It is to a great extent an individual matter and is largely based on psychological conditions. Additionally, the level of perception depends on the frequency of vibrations and for a focused individual it is 0.01 mm/s2 (RMS) at low frequencies (1 Hz) and increases with frequency to about 0.1 mm/s2 at 100 Hz [Griffin M.J. 1990]. If, on the other hand, vibrations are measured taking velocity into account, the perceptibility threshold is within 0.1 to 0.3 mm/s (RMS) with the frequency range of 10 to 100 Hz. Parameters influencing the perception of vibration threshold include:

– position (standing, sitting, lying),

– direction in relation to the spine,

– performed activity (idleness, walking, running),

– opportunity to share perceptions with others,

– age and sex,

– frequency and duration,

– the nature of the vibrations.

Three categories of the effects of vibrations on humans are usually considered [Eitzenberg A. 2008 p. 22]. They include effects on health, comfort and perception, and motion sickness. The effects on humans may reveal as increased heart rate, increased pulse and rapid breathing. Nonetheless, train-induced vibrations in buildings are relatively low and usually do not result in permanent health deterioration and do not affect everyday activities. Vital functions typically affected by vibrations are sleep and concentration problems as well as lower effectiveness. It appears obvious that vibrations may cause uneasiness and annoyance among residents, thus leading to complaints. Motion sickness is caused by low-frequency vibrations of about 1 Hz mainly during travelling, therefore it may be ignored in the analysis of train-induced vibrations.

1.4. The methods of structure vibration assessment

There are a great number of local and international building vibration standards, both for structure vibration and human vibration in buildings. The most recognizable standards for structure vibration are ISO 4866, British BS 7385-2, and German DIN 4150-3. All these three standards use Peak Particle Velocity (**PPV**) method and **FFT** to define the Dominant Frequency.

The method for PPV and Dominant Frequency is described in German Standard DIN 4150-3. The PPV is a maximum value of the amplitude of the vibration velocity time-domain signal. The method requires to perform FFT analysis for the PPV, in the way that the middle of a FFT window is placed exactly on the PPV. The result of such analysis is the PPV value and its corresponding Dominant Frequency (DF) for each axis (X,Y,Z). Each pair of PPV and its DF are used as point coordinates that are compared with the limit curve.

In America one of recognizable building vibration standards is **IEST** that uses 1/3 octave bands curves (**VC** Vibration Criterion curves) expressed in RMS vibration velocity. The IEST standard is not the sole one that uses 1/3 octaves, the Polish standard **PN-B-02170** also uses 1/3 octave band curves.

The 1/3 octave band method compares RMS or RMS MAX results in each band to the limit curve. So in fact the whole spectrum is used for comparison unlike in FFT method where the point (PPV, DF) is positioned versus the curve.

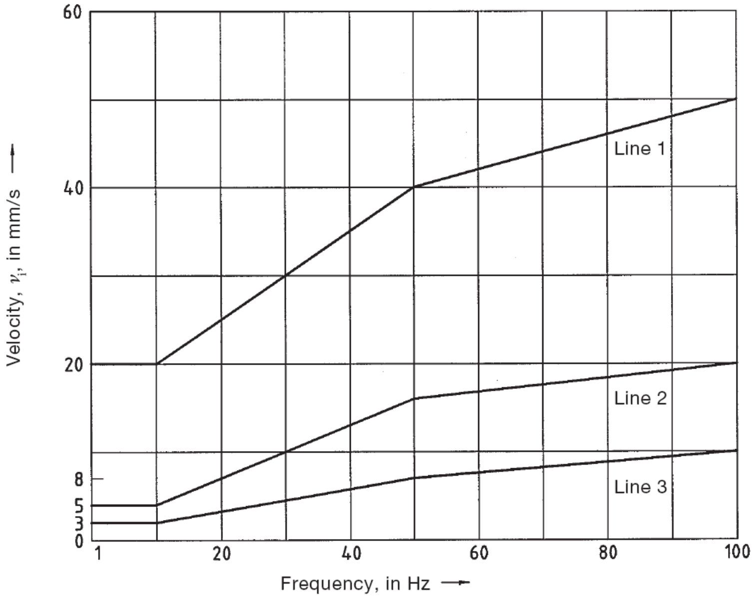
The existence of two methods often causes confusion and faulty assessment where for example 1/3 octave bands are compared to the FFT Dominant Frequency limits.

1.4.1. German Standard DIN 4150-3

One of the most often used standards describing vibration measurement and evaluation of their effects on structures is the German standard **DIN 4150-3**. The international standard ISO 4866 is referring to DIN 4150-3 as the reference method.

The standard may be applied for structures which do not need specific design requirements with reference to dynamic load. The standard defines the values which must be met to avoid damage and impact on structures. It is worth noticing that the above mentioned standard describes simplified values on numerous occasions. Vibrations are divided into short-term vibrations, which do not occur frequently enough to cause fatigue and do not cause resonance in the assessed structures. Long-term vibrations, on the other hand, are all vibration types which cannot be classified as short-term vibrations.

Vibration velocity values used in the impact assessment of short-term vibrations on structures are divided into three categories, depending on the type of the assessed structure [DIN 4150-3 p.4]. Each category features a curve illustrating the permissible vibration velocity limit. The analysis of the measured velocity and the prevailing frequency allows one to obtain a clear picture of the impact of vibrations on the tested structure. The first category and the corresponding Line 1 refers to buildings used for commercial purposes, industrial buildings etc. Dwellings and buildings of similar design and/or occupancy fall into the second category. The third category includes structures that, because of their particular sensitivity to vibration, cannot be classified under lines 1 and 2.



Picture 2 DIN 4150-3 Building Vibration Criteria

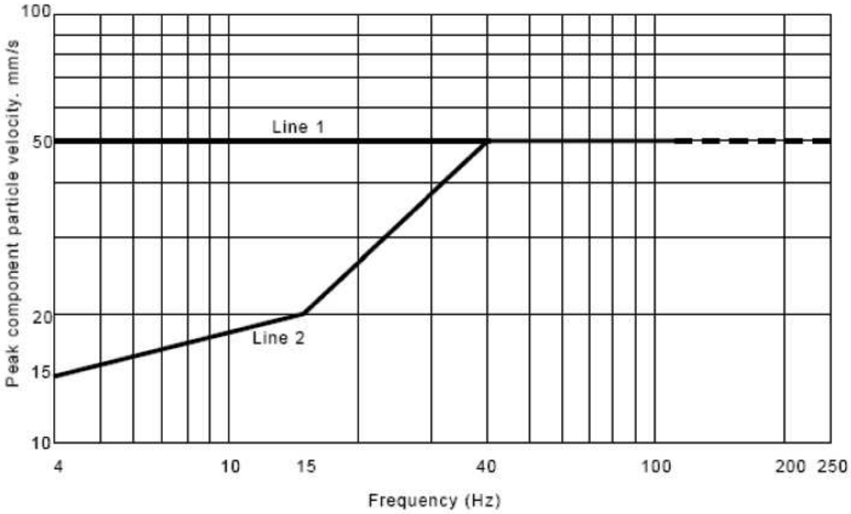
For long-term vibrations, the standard assumes one limit value of vibration velocity measured in mm/s for vibrations in a horizontal plane on the top floor. And so, in the first category, which lists industrial buildings, it is 10 mm/s, in the second category – 5 mm/s and for sensitive structures and those not classified under the first two categories – 2.5 mm/s. The DIN 4150-2 standard is centred mainly on the impact of vibrations on the residents.

1.4.2. British Standard BS 7385-2

BS 7385-2 provides guidance on the assessment of the possibility of vibration-induced damage in buildings due to a variety of sources. Sources of vibration which are considered include blasting, demolition, piling, ground treatments (e.g. compaction), construction equipment, tunnelling, road and rail traffic and industrial machinery. It gives guidance on the levels of vibration above which building structures could be damaged. Only the direct effect of vibration on buildings is considered. The indirect effects on the building structure due to ground movement, the movement of loose objects within buildings, the possibility of damage to sensitive equipment and the effect of vibration on people are outside the scope of this standard. The lowest frequency originating from man-made sources is 1 Hz and the highest frequency expected from either machinery or close-in construction blasting in hard ground is 1 000 Hz, however for the purpose of selecting guide values more limited range of 4 Hz to 250 Hz is taken into consideration. BS standard indicate two types of buildings:

- Reinforced or framed structures Industrial and heavy commercial buildings,
- Unreinforced or light framed structures Residential or light commercial type buildings.

Similarly to German standard DIN limits for transient vibration, above which cosmetic damage could occur are given numerically and graphically.

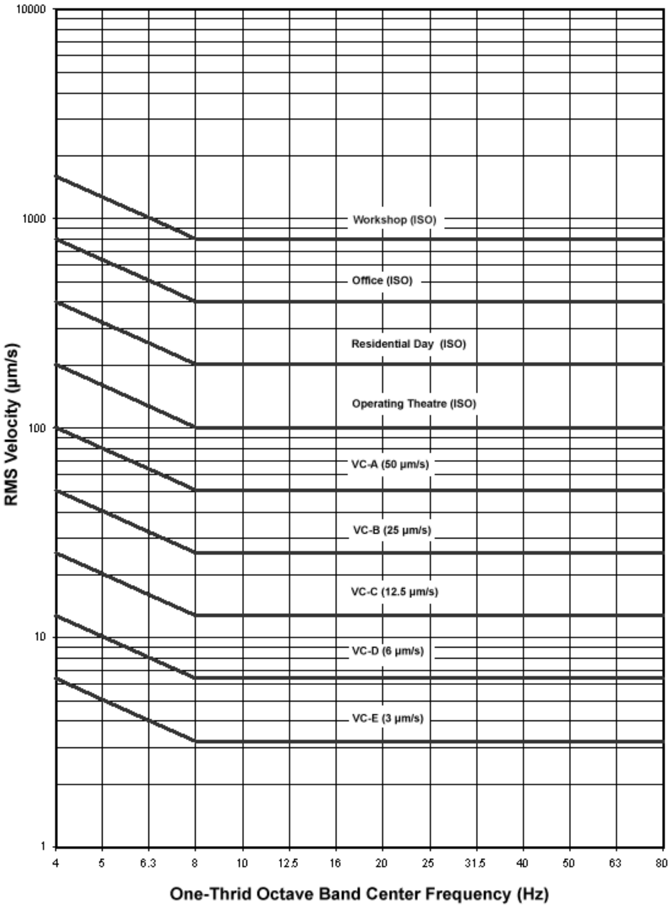


Picture 3 BS 7385-2 Building Vibration Criteria

1.4.3. American Standard IEST

The vibration criterion (**VC**) curves, commonly used in the design of facilities which house vibration-sensitive instruments and tools, were developed in the early 80's, published by SPIE in 1991 and by **IEST** in 1993 (Institute of Environmental Sciences and Technology). VC curves take the form of a set of one-third octave band velocity spectra, labelled vibration criterion curves VC-A through VC-E. The criteria apply to vibration as measured in the vertical and two horizontal directions. The vibration criteria are expressed in terms of its root-mean-square (rms) velocity.

The average RMS values in 1/3 octave bands are used when measuring vibration sources relatively constant in time — generated for instance by continuously running mechanical systems (fan, pumps, etc.) or by heavily travelled highways. Levels can be measured at multiple locations, if the area being evaluated is large, and the collective data can be summarized statistically. It is considered reasonable to classify the VC performance based on the “average plus one standard deviation” level at each frequency. When the environment is not constant in time—impacted for instance by walkers (footfall excitation), or nearby trucks—it may be necessary to measure the “maximum RMS” (sometimes called “peak hold”) vibration levels.



Picture 4 IEST VC Vibration Criteria

1.4.4. Polish Standards PN-B-02170:1985 and PN-B-02171:1988

In Poland the necessity to take into account the impact of vibrations results comes from regulation of the Minister of Infrastructure. The regulation references the following standards as applicable to the subject matter: **PN-B-02170:1985 and PN-B-02171:1988** The first one considers the evaluation of harmfulness of vibrations transmitted by the ground to buildings while the second is connected with evaluation of the impact of vibrations on people in buildings. Damage to buildings includes non-structural damage and damage to load-bearing structures [PN-B-02170, s. 14, 2016]. Non-structural damage is recognised in the form of paint coating and plaster cracks, tiles falling off, partition wall cracks etc. Damage to load-bearing structures leads to decreased durability of structural elements and may be visible as cracks in foundations, bearing walls, wall connections etc.

The assessment of vibrations transferred by the ground to specific types of buildings uses an approximate method of assessment by means of the SWD scales. The legislator specifies precisely which scale should be applied to a particular building type: "The SWD-I scale of dynamic impact may be applied to compact, one- or two-storey buildings with small external dimensions in the horizontal projection (below 15 m), the height not exceeding any of the horizontal projection dimensions." The SWD-II scale "may be applied to buildings housing five or less storeys above the ground, the height of which does exceed double the smallest width of the building and to low buildings (up to 2 storeys above the ground) which do not comply with the conditions specified for the SWD-I scale."

The SWD scales allow to determine five areas divided by margin lines A, B, C and D with the following criteria of division:

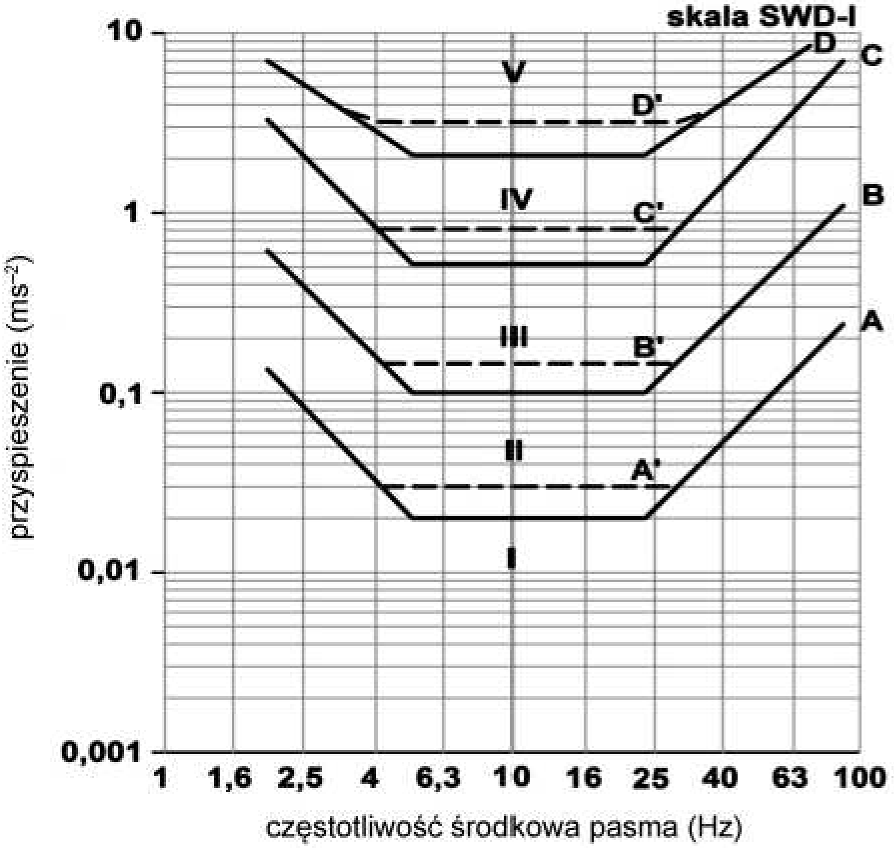
– area I – vibrations negligible in the assessment of vibration effects,

– area II – vibrations harmless for structures,

– area III – vibrations harmful for structures,

– area IV – vibrations highly harmful for structures,

– area V – vibrations causing damage to buildings, e.g. walls and ceilings collapsing.



Picture 5 SWD-I Vibration Criteria

2. Testing object and measurement performance

2.1. Measurement instrumentation and localisation of measurement points

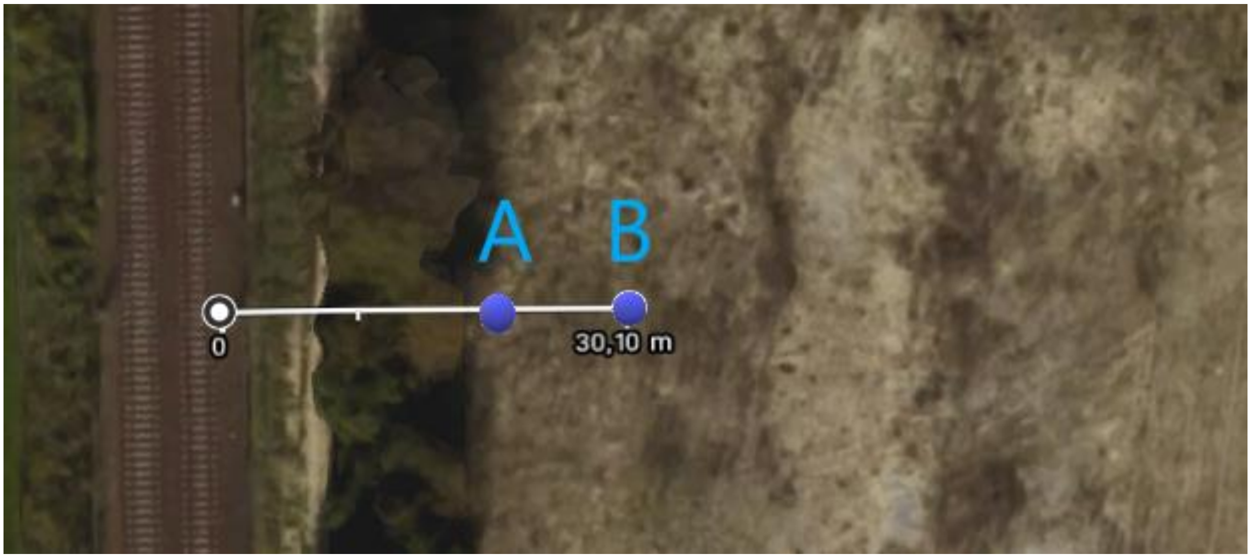
The study has been performed with two instruments:

- **SV 258 PRO** 4-channel building vibration and noise monitoring station.
- **SVAN 958A** hand-held 4-channel noise and vibration analyser

During the measurement, the instruments were battery powered.

Picture 2 SV 258 PRO vibration and noise monitoring station.

The objectives of the study are to determine the level of vibration on building structure at the construction stage on the foundation plate of a multi-storey building located around 30 meters from the railway tracks.



Picture 3 Distance of the measurement point from the railway tracks.

2.2. The measurement goal and method

Two measurement points were used

- **Point A** – the sensor has been attached to the mounting spike of 0.5m length at a distance around 20 m from the railway tracks
- **Point B** – the sensor has been attached to the foundation plate in accordance to DIN 45669-2 with use of the mounting plate of 2.5 kg with additional weight of a sand-bag put on it (around 15 kg) in a distance of 30 m from railway tracks

The goal of the experiment was to perform measurements of vibration velocity on the building façade with the use of SV 258 PRO station described in p. 2.1 and compare the results with 4 different standards:

- DIN 4150-3
- BS 7385-2
- IEST vibration criteria (VC curves)
- PN-B-02170 (SWD curves)

The method of the study was to measure the unweighted vibration velocity in three directions X,Y,Z.

The SV 258 PRO station has been set up to measure in accordance to DIN 4150-3. However, thanks to time-domain signal recording to WAVE format, the results have been also compared to other standards mentioned above using SvanPC++ post-processing software.

The following instrument settings have been used:

- Standard DIN 4150-3 that uses FFT to define the dominant frequency
- Band 1-80 Hz – filter used by DIN 45669-2 and DIN 4150-3 used for short-term vibration assessment
- Building type – L2 defined in the DIN 4150-3 as type of structure “dwellings and buildings of similar design and occupancy”
- Human vibration: off – additional evaluation of vibration acceleration is not used
- Sound: off – class 1 sound measurements are not used
- Logging – velocity step 30s – each 30s the PPV values together with their dominant frequencies are stored
- FFT VEL (Continuous) – whenever the PPV exceeds the L2 criterion the full FFT spectrum is stored
- WAVE VEL (Continuous) – whenever the PPV exceeds the L2 criterion the time domain signal is stored in a separate file that will be used for analysis by SvanPC++ software
- Event 1 – source Line (L2), reduction factor 1.0, alarm interval 1m
- Event Duration 10s – to cover train passage time

C:\Users\jkuczynski\Downloads\!test - bv\test 7\S_18JUL1.SVT

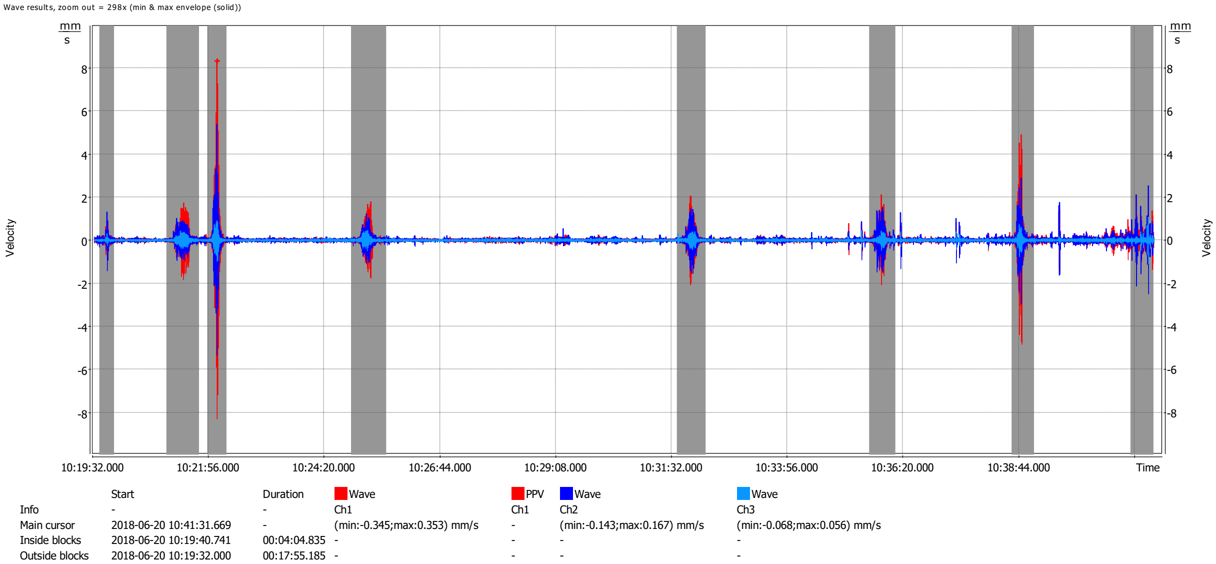
Current Setup File - SVAN 958AG #69011 (ver. 4.11.3)*

- Application
  - Standard (DIN-4150-3)
  - Band (1-80Hz)
  - Building Type (L2)
  - Human Vibration (Off)
  - Sound (Off)
- Sound
- Logging
  - Vel. Step (1 s)
  - Human Vibr. Step (1 m)
  - FFT Vel. (Continuous)
  - Wave Vel. (Continuous)
- Events
  - Event 1
    - Active (On)
    - Name (EVENT1)
    - Source (Line)
    - Reduction Factor (1.00)
    - Lamp Alarm (On)
    - SMS Alarm (On)
    - SMS Recipient (Item 1)
    - Email Alarm (On)
    - Email Recipient (Item 1)
    - Alarm Interval (1 m)

Picture 4 Screen of the setup editor from Svantek SvanPC++ software.

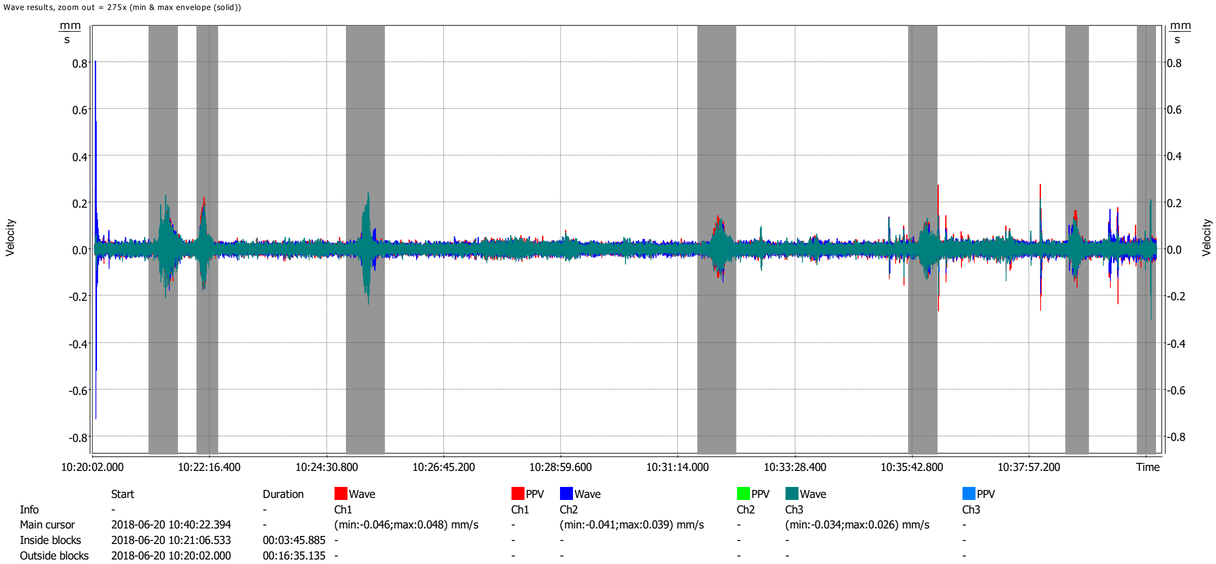
3. Measurement results

The measurement has been conducted during the break period at the construction site to eliminate the background noise and vibration emitted by the construction site itself. During the 22 minutes of measurement 8 train passages have been recorded and analysed.



	Start	Duration	🟥 Wave	🟥 PPV	🟦 Wave	🟦 Wave
Info	-	-	Ch1	Ch1	Ch2	Ch3
Main cursor	2018-06-20 10:41:31.669	-	(min:-0.345;max:0.353) mm/s	-	(min:-0.143;max:0.167) mm/s	(min:-0.068;max:0.056) mm/s
Inside blocks	2018-06-20 10:19:40.741	00:04:04.835	-	-	-	-
Outside blocks	2018-06-20 10:19:32.000	00:17:55.185	-	-	-	-

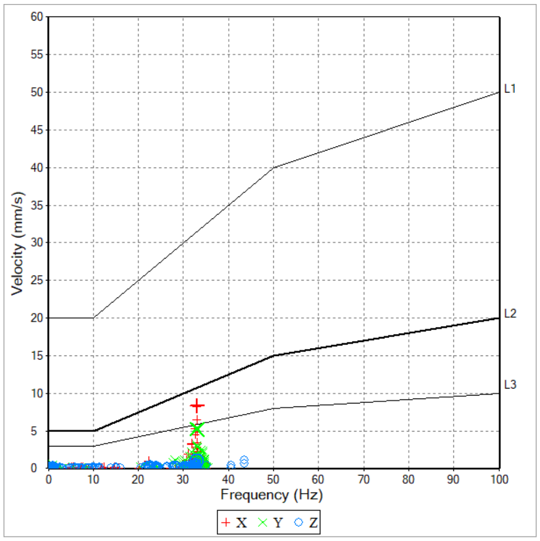
Picture 5 Vibration recordings at the point A (mounting spike).



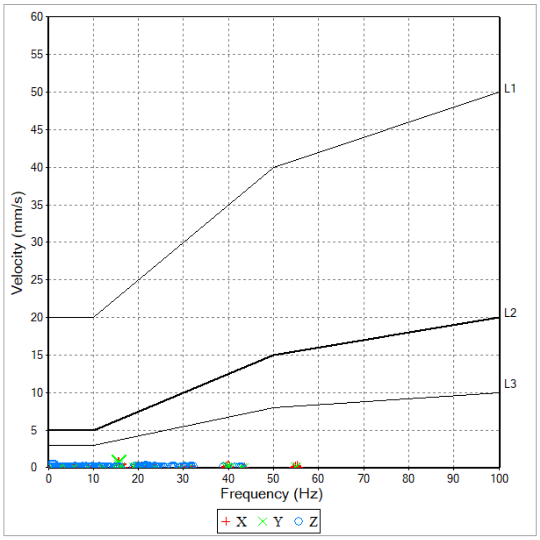
	Start	Duration	🟥 Wave	🟥 PPV	🟦 Wave	🟩 PPV	🟩 Wave	🟦 PPV
Info	-	-	Ch1	Ch1	Ch2	Ch2	Ch3	Ch3
Main cursor	2018-06-20 10:40:22.394	-	(min:-0.046;max:0.048) mm/s	-	(min:-0.041;max:0.039) mm/s	-	(min:-0.034;max:0.026) mm/s	-
Inside blocks	2018-06-20 10:21:06.533	00:03:45.885	-	-	-	-	-	-
Outside blocks	2018-06-20 10:20:02.000	00:16:35.135	-	-	-	-	-	-

Picture 6 Vibration recordings at the point B (foundation plate).

The analysis of vibration amplitudes showed higher results at the point A (mounting spike) than at the point B (foundation plate) which indicates the effect of the vibration attenuation by the foundation plate.

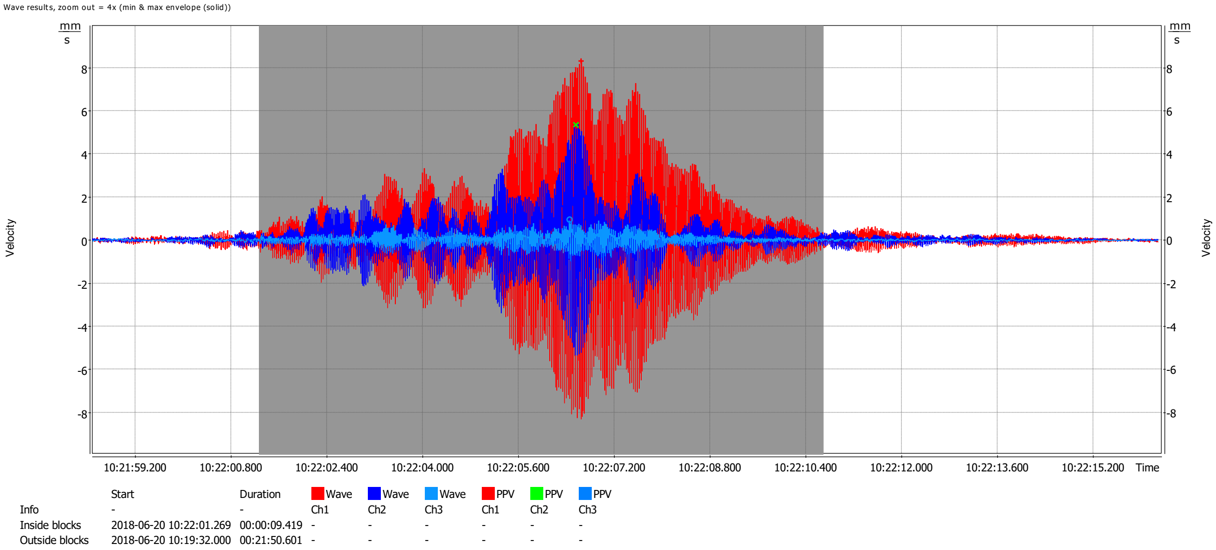


Picture 7 Vibration time history at the point A (mounting spike) analysed by SVAN 958A



Picture 8 Vibration time history at the point B (foundation plate) analysed by SV 258PRO

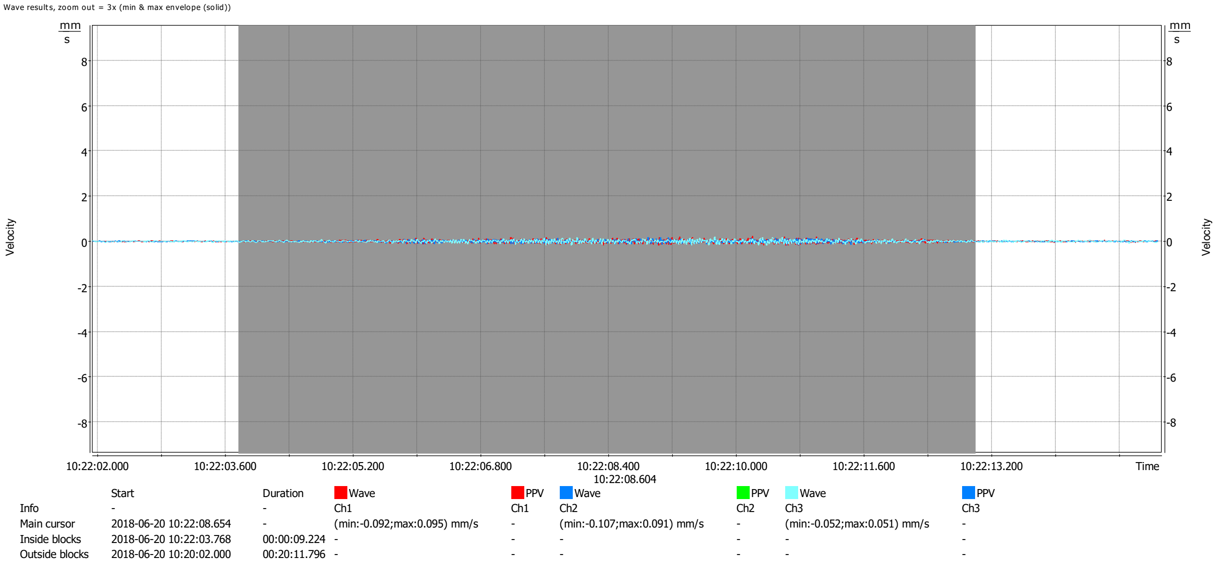
The highest result has been recorded for the third event at the point A, therefore it has been analysed with the SvanPC++ post-processing software in accordance to 4 different standards (see 3.1 – 3.4)


Wave results, zoom out = 4x (min & max envelope (solid))

	Start	Duration	🟥 Wave	🟦 Wave	🟦 Wave	🟥 PPV	🟩 PPV	🟦 PPV
Info	-	-	Ch1	Ch2	Ch3	Ch1	Ch2	Ch3
Inside blocks	2018-06-20 10:22:01.269	00:00:09.419	-	-	-	-	-	-
Outside blocks	2018-06-20 10:19:32.000	00:21:50.601	-	-	-	-	-	-

Picture 9 The highest event at the point A - view in Svantek SvanPC++ software.

It is noticeable that the highest amplitudes have been recorded in the X axis, that was pointed perpendicularly to the railway tracks. The same vibration event measured at the point B – on the foundation plate has been greatly attenuated by the foundation plate.

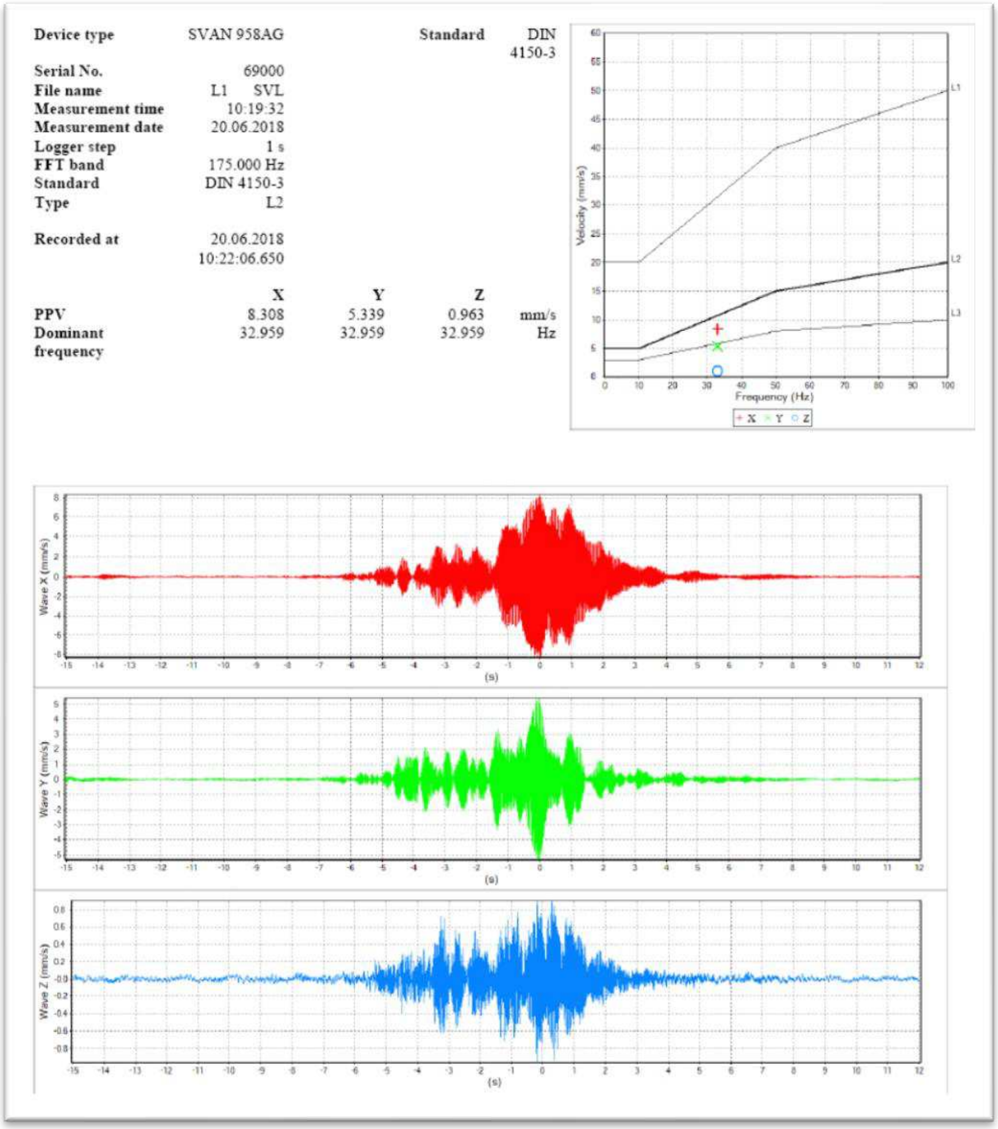

Wave results, zoom out = 3x (min & max envelope (solid))

	Start	Duration	🟥 Wave	🟥 PPV	🟦 Wave	🟩 PPV	🟦 Wave	🟦 PPV
Info	-	-	Ch1	Ch1	Ch2	Ch2	Ch3	Ch3
Main cursor	2018-06-20 10:22:08.654	-	(min:-0.092;max:0.095) mm/s	-	(min:-0.107;max:0.091) mm/s	-	(min:-0.052;max:0.051) mm/s	-
Inside blocks	2018-06-20 10:22:03.768	00:00:09.224	-	-	-	-	-	-
Outside blocks	2018-06-20 10:20:02.000	00:20:11.796	-	-	-	-	-	-

Picture 10 The vibration recording at the point B - view in Svantek SvanPC++ software.

3.1. Evaluation in accordance to DIN 4150-3.

Analysis in SvanPC++ software indicated the highest PPV value in the X axis (8.3 mm/s) at Dominant frequency around 33 Hz. There was no exceedance for the L2 vibration criterion, however the PPV in the X axis was close to the limit.



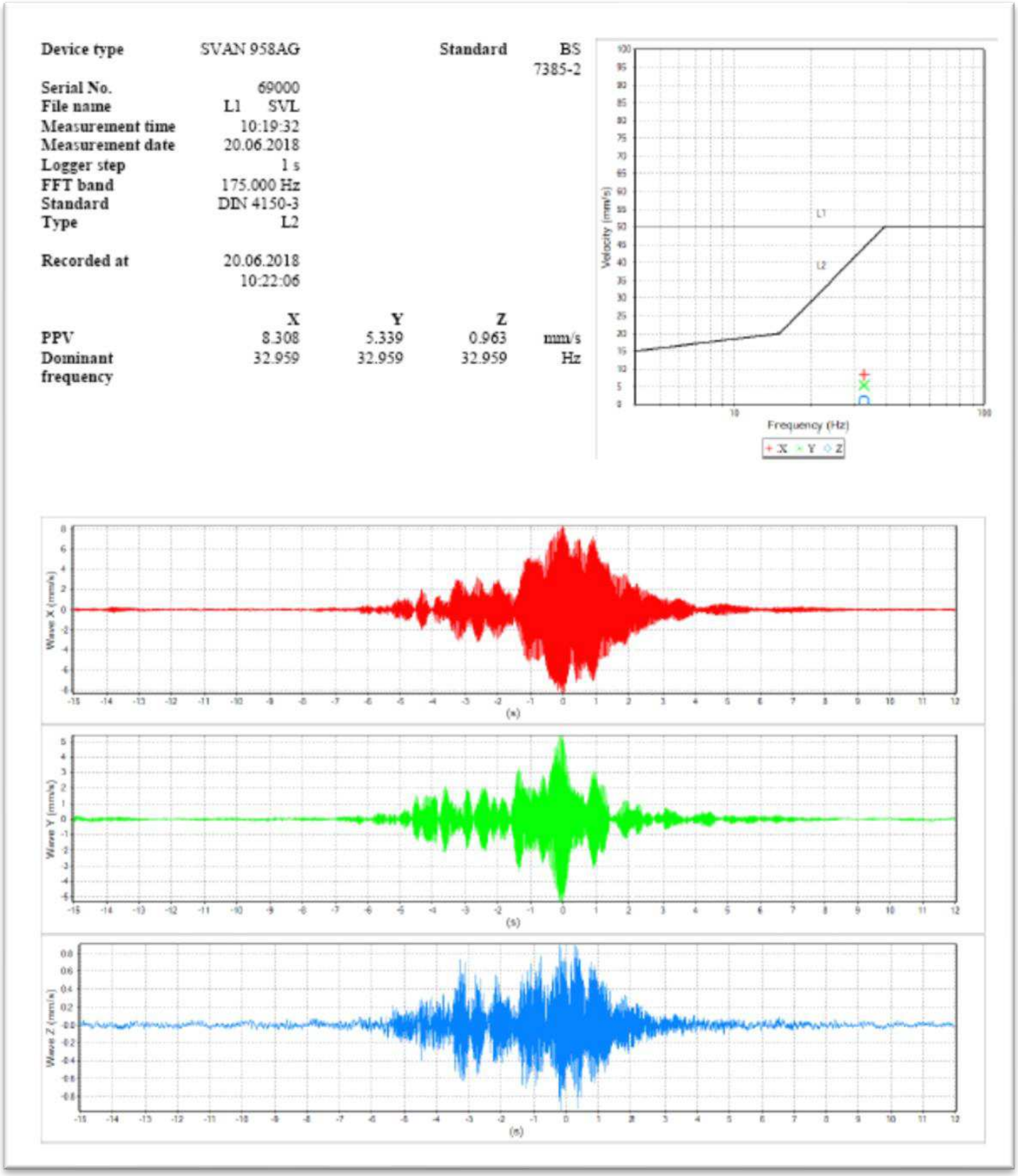
Device type	SVAN 958AG	**Standard**	DIN 4150-3
Serial No.	69000		
File name	L1 SVL		
Measurement time	10:19:32		
Measurement date	20.06.2018		
Logger step	1 s		
FFT band	175.000 Hz		
Standard	DIN 4150-3		
Type	L2		
Recorded at	20.06.2018 10:22:06.650		

	X	Y	Z	
PPV	8.308	5.339	0.963	mm/s
Dominant frequency	32.959	32.959	32.959	Hz

Picture 9 DIN 4150-3 event view in Svantek SvanPC++ software.

3.2. Evaluation in accordance to BS 7385-2.

Analysis in SvanPC++ software indicated the highest PPV value in the X axis (8.3 mm/s) at Dominant frequency around 33 Hz. There was no risk of exceedance for the L2 vibration criterion. It is noticeable that BS limits are much less strict than DIN.



Device type SVAN 958AG
Standard BS 7385-2

Serial No. 69000
File name L1 SVL
Measurement time 10:19:32
Measurement date 20.06.2018
Logger step 1 s
FFT band 175.000 Hz
Standard DIN 4150-3
Type L2

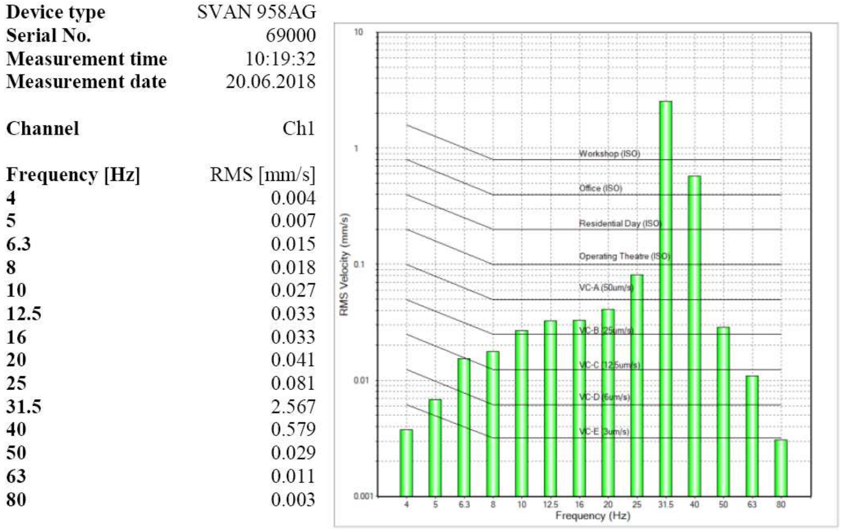
Recorded at 20.06.2018 10:22:06

	X	Y	Z	
PPV	8.308	5.339	0.963	mm/s
Dominant frequency	32.959	32.959	32.959	Hz

Picture 10 BS 7385-2 event view in Svantek SvanPC++ software.

3.3. Evaluation in accordance to IEST VC-curves.

Analysis in SvanPC++ software indicated the highest RMS value in the X axis (2.567 mm/s) at 1/3 octave band of 31.5 Hz. The VC curves analysis indicates that this vibration level is too high for installation of vibration-sensitive equipment and is too high for people's comfort in accordance to old ISO curves.

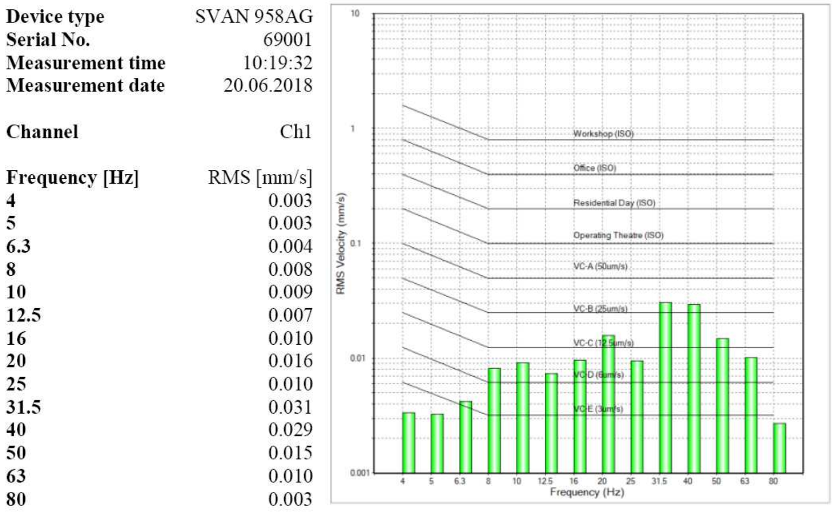


Device type	SVAN 958AG
Serial No.	69000
Measurement time	10:19:32
Measurement date	20.06.2018
Channel	Ch1

Frequency [Hz]	RMS [mm/s]
4	0.004
5	0.007
6.3	0.015
8	0.018
10	0.027
12.5	0.033
16	0.033
20	0.041
25	0.081
31.5	2.567
40	0.579
50	0.029
63	0.011
80	0.003

Picture 11 IEST VC-curves Point A event view in Svantek SvanPC++ software.

The analysis of the same vibration event at the point B (at the foundation plate) shows however much less risk for vibration-sensitive equipment (effect of attenuation of the concrete).



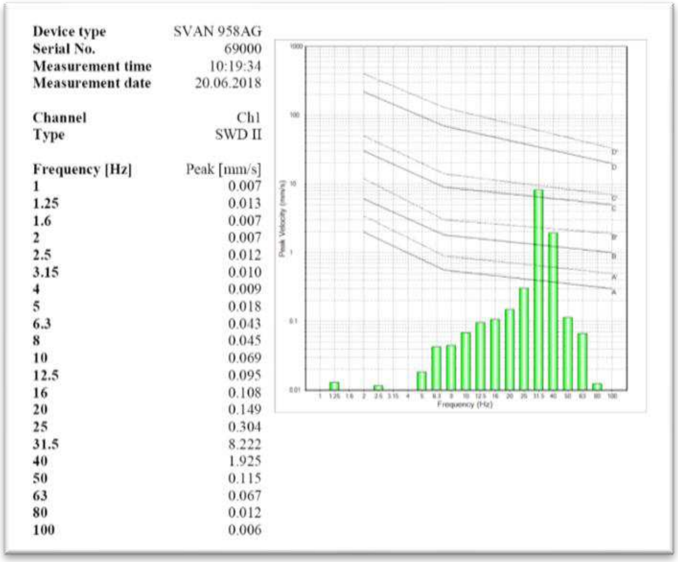
Device type	SVAN 958AG
Serial No.	69001
Measurement time	10:19:32
Measurement date	20.06.2018
Channel	Ch1

Frequency [Hz]	RMS [mm/s]
4	0.003
5	0.003
6.3	0.004
8	0.008
10	0.009
12.5	0.007
16	0.010
20	0.016
25	0.010
31.5	0.031
40	0.029
50	0.015
63	0.010
80	0.003

Picture 11 IEST VC-curves point B event view in Svantek SvanPC++ software.

3.4. Evaluation in accordance to PN-B-02170.

Analysis in SvanPC++ software indicated the highest Peak value at the X axis (8.22 mm/s) at 1/3 octave band of 31.5 Hz. The PN-B-02170 indicates the risk of building damage such as local cracks. It is also noticeable that the Peak in the 1/3 octave is lower than Peak recorded in time-domain signal (8.3 mm/s), this is due to applying 1/3 octave filters to the time-domain signal.

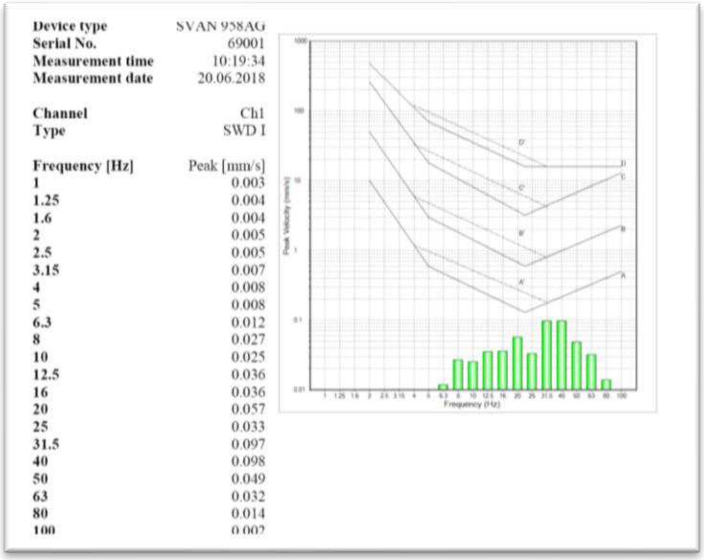


Device type	SVAN 958AG
Serial No.	69000
Measurement time	10:19:34
Measurement date	20.06.2018
Channel	Ch1
Type	SWD II

Frequency [Hz]	Peak [mm/s]
1	0.007
1.25	0.013
1.6	0.007
2	0.007
2.5	0.012
3.15	0.010
4	0.009
5	0.018
6.3	0.043
8	0.045
10	0.069
12.5	0.095
16	0.108
20	0.149
25	0.304
31.5	8.222
40	1.925
50	0.115
63	0.067
80	0.012
100	0.006

Picture 11 PN-B-02170 event view in Svantek SvanPC++ software.

The analysis of the same vibration event in the point B (at the foundation plate) however, shows much less risk for vibration-sensitive equipment (effect of attenuation of the concrete).



Device type	SVAN 958AG
Serial No.	69001
Measurement time	10:19:34
Measurement date	20.06.2018
Channel	Ch1
Type	SWD I

Frequency [Hz]	Peak [mm/s]
1	0.003
1.25	0.004
1.6	0.004
2	0.005
2.5	0.005
3.15	0.007
4	0.008
5	0.008
6.3	0.012
8	0.027
10	0.025
12.5	0.036
16	0.036
20	0.057
25	0.033
31.5	0.097
40	0.098
50	0.049
63	0.032
80	0.014
100	0.002

Picture 11 IEST VC-curves point B event view in Svantek SvanPC++ software.

4. Summary

The study shows that the same vibration values can be differently assessed in accordance to different standards. The vibration event chosen for analysis has been assessed by 2 methods based on FFT and Dominant Frequency and 2 methods based on 1/3 octave bands.

It has been observed that limits in German standard DIN 4150-3 are more strict than those in British BS 7385-2. The same vibration event assessed by the Polish standard PN-B-02170 based on 1/3 octave Peak has been assessed as dangerous to building structure.

In relation to VC curves that are widely in use in Northern America, the same vibration event has been assessed as exceeding all limits, in particular VC-A and ISO, for residents.

The study also shows that vibration measured in the ground at the point A has been greatly attenuated on the concrete foundation plate at the point B. ISO 4866 recommends to measure the soil-foundation transfer function. When the soil vibrations are transferred to the building foundation, they are altered by the elasticity of the soil, the mass of the building, and wave passage effects.

5. Conclusion

The values assessed as not dangerous with methods based on PPV and FFT dominant frequency were assessed as dangerous with the 1/3 octave Peak method. Additionally the modification of Peak values have been observed when using 1/3 octave filters.

The variety of building vibration standards often cause misunderstanding and can lead to incorrect assessment of results. Generally there are two methods of building vibration measurements: one that uses PPV method with the FFT for dominant frequency analysis and second that analyses vibrations in 1/3 octave bands. Both methods use different criteria for building damage and they might interpret the same vibration event differently, as it has been shown in the study.

6. References

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