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A CASE STUDY OF DETERMINING THE INTENSITY OF VIBRATION ACCELERATIONS AND THE POTENTIAL IMPACT ON STRUCTURES

Krzysztof TOMICZEK[1]

Ph.D. Eng. Krzysztof Tomiczek, Department of Geoengineering and Resources Extraction, Faculty of Mining, Safety Engineering and Industrial Automation, Silesian University of Technology, Gliwice, Poland

Summary.

Assessment of vibrations caused by tremors accompanying by exploitation of useful minerals, both by opencast and underground methods, on surface structures consists in checking whether the analysed building object can take over, without damage, ground vibrations caused by underground tremors. It is the dynamic resistance of the object to vibrations caused by tremors in the rock mass. After the theoretical introduction, two simplified analyses of the assessment of the resistance of ground structures are presented.

Keywords: rock mass seismicity, tremors induced by mining, dynamic resistance of buildings, threat to building stability, safety of structures

1. Introduction

Ground vibrations related to high-energy tremors induced by the exploitation of useful minerals, both by opencast and underground methods, may pose a threat to structures on the surface. Vibrations may cause discomfort for residents. Therefore, regardless of the continuous observations of rock mass stability and seismological observations carried out by the geophysical services of mines plants; surface measurements of ground vibration accelerations are often performed. Vibration measurements are the most appropriate way to assess the dynamic impact of rock tremors on the elements of the land surface infrastructure. Vibration measurements also allow to determine the maximum, instantaneous component amplitudes, horizontal and vertical, vibration accelerations, dominant frequency and amplitude values for this frequency, and the duration of vibrations with a specific level of acceleration amplitude.

1 Krzysztof.Tomiczek@polsl.pl , k.tomiczek@yahoo.co.uk ,
https://orcid.org/0000-0001-9227-310X Researchgate: Krzysztof_Tomiczek

2. Acceleration of ground vibrations and the amplification factor

The intensity of ground vibrations depends on many factors that are more or less measurable or predictable. Therefore, the prediction of the expected intensity of vibrations is extremely difficult.

The obvious and most important factors are:

- the size of the seismic phenomenon measured by magnitude, seismic energy, seismic moment or epicentre size as well as the size of the fracture in the rock mass,
- epicentre depth and distance of the observation site and medium damping properties,
- direction of seismic propagation.

What is also important, as shown by the results of many years of seismometric research, are the local soil and rock conditions at the observation site, including the type of soils and rocks, quality and thickness of loose overburden, their waterlogging, and topography.

In the absence of measurement data, it is possible to estimate, with some approximation and claims, the acceleration of ground surface vibrations on the basis of empirical formulas relating to a given area. Even in the absence of knowledge of the vibration duration, amplitude of the dominant frequency, etc.

These formulas allow to estimate the vibration accelerations on the basis of the knowledge of the tremor energy and the distance of the epicentral location of the tremor at the given point on the ground surface.

For example, for strong phenomena with energies in the range $2\times10^5 J<\mathrm{E}<1\times10^8 J$ and epicentral distances up to 10 km, the acceleration of rockground vibrations can be estimated by the empirical formula proposed by Prof. Mutke (e.g., 1991)

$$a_{MD}=[1.33\cdot10^{-3}\cdot(\log E)^{2.66}-0.089]\ [1.53\cdot R^{0.155}\exp(-0.65R)+0.14]$$

where a_{MD} - amplitude of acceleration of subrock vibrations, m/s^2,

E - seismic energy, J,

R - epicentral distance, km; object - the epicentre of the tremor.

Empirical relationships are determined on the basis of research and measurements.

The area around the epicentre, which is the near-wave field boundary on the surface, can be treated as the epicentre. For strong tremors induced by mining in the Upper Silesian Coal Basin (USCB), phenomena with a magnitude of $M \geq 1.7$ or seismic energy $E \geq 2\ 10^5$J, the radius of such a zone is about 1000 m.

The research was conducted in Poland, incl. by the Central Mining Institute, Cracow University of Technology, AGH University of Science and Technology, and the Rock Mass Mechanics Institute of the Polish Academy of Sciences in Cracow. Based on the measurements made on subrock at different distances from the tremors, it follows that the amplitudes of velocity and acceleration of subrock vibrations decrease with increasing epicentral distance. The phenomenon is less strong in the epicentral zone, while the phenomenon is strong outside of its. The physical justification is that absorption damping dominates in the near-wave field, whereas in the far-wave field the influence of geometric damping is much stronger. In practice, it means that the global damping function in the epicentral zone shows a flattening effect, while outside the epicentral zone it is a monotonically decreasing function. Assuming that only strong mining tremors can in practice be damaging to buildings, the standardized vibration damping function for high-energy phenomena is described (see, e.g., Mutke 1992).

The relationship describing the normalized decrease of the horizontal components of the V_D velocity of the vibrations of the bedrock in the USCB for tremors with energy $5\ 10^8 \geq E \geq 2\ 10^5$J, as a function of the epicentral distance D (up to 10km from the epicentre), for accelerations a_D

$$a_D = 1.53\ R^{0.155} \exp(-0.65\ R) + 0.014$$

where $R^2 = D^2 + 0.5^2$

D - epicentral distance, km.

The coefficient of 0.5 in the formula for R corresponds to the average depth of tremor centre, equal to 0.5 km.

Apart from the maximum acceleration amplitudes or the vibration velocity of the ground of building structures, an important parameter is also the dominant frequency of vibrations with maximum amplitudes. The dynamic responses of structures in particular ranges of vibration frequencies are not the same.

The dominant frequency intervals are obtained by targeting the accelerograms in the frequency domain. Their essence is, for example, a Fourier Transformation (FT) and on this basis determining the minimum F_{min} and maximum F_{max} values for which the level of the spectral amplitude decreased twice in relation to its maximum value.

The determined equations of the regression curves, limiting the range of occurrence of dominant frequencies at the bottom and top, may have the following form (e.g., Chudek after Mutke, 2008)

$$F_{max}=[99\exp(-0{,}491\mathrm{og}E)]+1.27$$

$$F_{min}=[91\exp(-0{,}781\mathrm{og}E)]+1.79$$

where E - seismic energy, J.

The frequency range determined by the equations is for the vibration accelerations of the subrocks in the epicentral zone.

In order to calculate the subrock coefficient, it is important to know the dominant frequencies of vibrations reaching the overburden layers. If there is no database of tremors from a given area at a rock site, this frequency can be determined from the above-mentioned relationships.

The frequency range of the dominant vibrations with the highest velocities and accelerations is important in determining the base coefficient of tremor amplification. This coefficient depends on the frequency of the dominant vibrations. On the other hand, the occurring tremors of a short input, e.g., 1 peak, are not a big threat to buildings, even at a high value of velocity or acceleration expressed by this peak (see the GSI-GZW scale).

Measurement premises and theoretical solutions for the passage of a seismic wave through a multilayer rock mass are characterized by a change in vibration amplitudes when the wave passes through each layer.

The following factors influence the change of vibration amplitudes:

- incident wavelength γ, or its frequency f,
- thickness of layer H,
- layer density ρ,
- wave velocity v, as well as wave type and wave incidence angle.

Practice shows that if the rock layer is less stiff, more cracked and the velocity of the seismic wave is lower in it, then it is easier to increase the vibration amplitudes with the appropriate incident wavelength.

The measurement data prove that, depending on the structure of the subsurface layers, the maximum values of the ground surface vibration acceleration caused by mining tremors may be both partially damped and/or strengthened. The parameter quantifying this phenomenon is the substrate factor, also known as the amplification factor.

The maximum values of the amplitudes of the surface vibration accelerations

$$V = V_{MD} \, W_f$$

$$a_{MSK} = a_{MD} \, W_f$$

where W_f - substrate factor, vibration amplification.

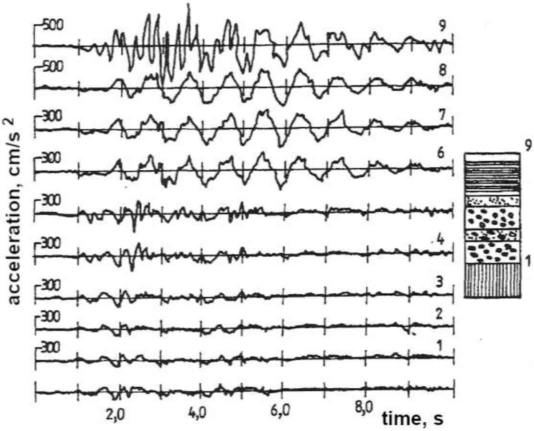


Fig. 1. Examples of vibration accelerograms recorded in a multilayer medium at the boundary of each layer (after Okamoto, 1954, 1984).

Many cases of damage of buildings, often at large distances from the epicentre of the tremor, have their source in the phenomenon of local vibration amplification. The vibrations are amplified by the overburden made of loose layers. An example of the influence of a stratified medium, and especially of the weakly coherent layers of this medium, on the change in the magnitude of the vibration acceleration amplitudes is shown in Fig. 1 (see Okamoto, 1954, 1984).

The highest values of vibration accelerations in USCB are related to direct waves. In particular, they relate to horizontally polarized lateral waves, i.e., "*SH*" waves. This wave, when passing through horizontal boundaries, does not create other types of waves.

For waves "*SH*" that fall on the ground at any angle and for vertically falling "P" longitudinal waves, the vibration amplitude is doubled. This is due to the boundary conditions that the wave encounters at the layer-air interface. If these waves propagate through the flat horizontal boundary of the layer separation (z=0), then they are partially reflected and partially refracted. The substrate factor calculation algorithm was based on the solution in an elastic medium with damping and rock mass described by the Kelvin rheological model.

In practice, the vibration recordings on the same overburden layer will be significantly different from each other and only some of them will show the maximum value of the substrate factor, vibration amplification. The reason for this is the simultaneous influence of several seismogeological factors on the surface effect. Seismic waves are, in fact, non-harmonic, and the resultant amplitude is determined by the composition of harmonic waves. The frequency range of the maximum vibrations is different for tremors with different seismic energies, epicentral distances, etc. As a result, the recorded amplification result refers to certain averaged amplification in the range of dominant vibration frequency. Moreover, a slight change in the wavelength incident on the layer or the angle of incidence of the wave is sufficient for the gain in W_f to change. When assessing the vibrations for the development of the surface and the safety of people, the possibility of the strongest vibrations i.e., the occurrence of the highest value of the substrate factor for the vibrations recorded in a given area, should always be taken into account.

In fact, in many situations the wave is incident at an angle and the recorded gains will be less than the maximum. However, it should be assumed that, in practice, we must take into account the occurrence of the least favourable situation.

1. Examples of a simplified assessment of the dynamic resistance of objects

The problems of the dynamics of buildings based on computational models with a limited number of degrees of freedom, described in detail with harmonic equations, lead to very complex analytical solutions describing structures that exist in reality. Due to the difficulties in determining the seismic wave characteristics caused by mining tremors and the high complexity of the computational model of real building, the search for solutions to complex problems is carried out using simplified calculation models. Empirically correlated data are used from many years of observation of the behaviour of buildings subject to dynamic influences, with simultaneous theoretical analysis of the phenomenon.

This sub-chapter presents examples of a simplified assessment of the underground mining dynamic impact on two selected structures:

- primary school building,
- the building of the sports hall.

The method of assessing the harmfulness of surface vibrations on buildings was used in accordance with the applicable PN-85/B-02170 standard (the standard was updated in 2016) based on, inter alia, on the dynamic impact scale (SWD).

3.1. Primary school building

The characteristics of the primary school building:

- building height (including cellars, approximately 3.30 m and attic approx. 3.0 m)×approx. 18.75 m,
- total length of the building (without the outhouse) - approx. 23.45 m,
- width - approx. 18.76 m,
- usable area of 1320 m^2,
- cubature - approx. 7265 m^3.

General building characteristics: brick building, Klein ceilings on steel beams, reinforced concrete stairs, wooden roof, covered with tar paper. Flat window and door lintels.

The building was kept in relatively good condition. The roof is covered with tar paper on the boarding without visible damage. The walls of the overground, made of solid brick, 2 bricks thick, showed no visible damage. The ceiling in the basement was in good condition and was made of hollow ceramic bricks. Basement walls, made of brick, with no visible damage. Window lintels were changed as a result of renovation in 1984, combined with the replacement of window frames. Door lintels unrecognized. Foundations not recognized. Reinforced concrete staircase, no damage. The building was secured against mining damage in the form of anchoring, with all external corners secured with steel angles. The condition of the facade after renovation did not raise any objections. From a technical point of view, the essential elements of the building were in good condition.

The building had a partial basement. On the ground floor, 1st and 2nd floor, there were 12 classrooms with a secretary's office and auxiliary rooms.

Threats of underground exploitation

The seams located at various depths were continuously exploited throughout practically the entire area of the city district. For the expected effects on the surface of the site, the IIIrd category of land surface protection was adopted, with the risk of tremors with an energy E of up to $10^8 J$.

Current technical condition and visible damage to the building.

There were clear diagonal cracks in the gable wall of the building, significant cracks in the terrazzo floor, and cracks in the walls in the basement part.

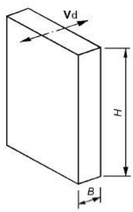
Assessment of dynamic resistance to mining tremors.

The proper vibration of the building.

To determine the frequency of natural vibrations of the building, the approximate method included in the PN-85/B-02170 (and 2016-12) and PN-77/B-02011 standards was used, as shown in Table 1.

Table 1

Scheme of determining the approximate values of the basic periods of horizontal proper vibrations T_1 for typical multi-storey residential and public buildings according to PN-85/B-02170

Scheme of the building	Frequency of vibrations T_1, s	Building type and height H, m
	T_1=0.015 H	monolithic, brick or concrete, H<30m
	T_1=0.02 H	reinforced concrete large-panel H<30m
	$T_1 = 0{,}09 \frac{H}{\sqrt{B}}$	reinforced concrete skeleton H<50m
	$T_1 = 0{,}10 \frac{H}{\sqrt{B}}$	steel skeleton H<50m

H - building height, m,
B - lateral width of the building, m.
Comments:
1. If the walls of the load-bearing are significantly weakened by 40-50% of the openings, the vibration period T_1 should be increase by 10÷20%, respectively.
2. In the case of the foundation of the building on soils with high deformability, e.g., silty sands, the vibration period T_1 should be increased by 10%.

The following values were taken:

for H=18.75 m→T_1=0.28 s

Due to the existing window and door openings in the walls of the school and the fact that the structure of the structure (walls) was subject to the effects of previously conducted mining, the value of the vibration period T_1 was increased by 20%.

T_1=0.336s → the proper frequency n=2.98 Hz

After analysing the existing geological and mining conditions, 3 variants of the subsoil acceleration prediction were considered:

- 1st variant based on the "Provisions on the expansion of the school building of the District Mining Office"; assumed the IIIrd category of land suitability for development, maximum shocks with energy $E=10^8 J$ and acceleration $a_{MD} \leq 300$ mm/s^2,

- 2nd variant based on the "Provisions on agreeing the conditions of development and land development for the construction of a sports hall" of the District Mining Office assumed: IInd category of land suitability for development, tremors with energy $E=10^8 J$ and acceleration $a_{MD} \leq 300$ mm/s^2,

- 3rd variant based on the information and situational maps of the mine's surface with information on the predictioned deformations and accelerations of surface vibrations under the impact of mining. The forecasts assumed: the energy of the recorded tremors $E=10^3 \div 10^6 J$, in the absence, weak and medium degree of stress increase and seismic hazard, ground acceleration 120 mm/s$^2 \leq a_{MD} \leq 200$ mm/s^2, acceleration for E=1 10^7-5 10^7, based on the Mutke's equation

$$a_{MD}=1.33 \cdot 10^{-3} \cdot (\log E)^{2.66}-0.089$$

where a_{MD} - amplitude of acceleration of rock vibrations, m/s^2,

E- seismic energy, J.

$a_{MD} \approx 145\text{-}215$ mm/s^2

It was assumed that the expected ground surface vibration accelerations in the range of up to 10 Hz, caused by mining tremors for all analysed objects, should be in the range from 145-300 mm/s^2.

With regard to the assessment of the dynamic impact of tremors induced by underground mining on the terrain surface, it is used, inter alia, the SWD scale (Scale of Dynamic Influences), which is the basis of the Polish standard PN-85/B-02170 (and 2016-12) - "Assessment of the harmfulness of vibrations transmitted through the ground onto buildings". It was developed in 1984, and after 2016 updates it can be used.

The PN-85/B-02170 (and 2016-12) standard allows the use of dynamic impact scales (SWD) as an approximate method of verifying dynamic effects on buildings. The SWD scales were developed in 1984 for the needs of the Polish Standard. SWD scales can be used for buildings made of masonry elements and for buildings made of large blocks. It was assumed that they apply only to the most common types of building in practice. Based on analyses of selected buildings considered model buildings, dynamic influences calculations were performed, which were used to construct the SWD scales. The calculations included, inter alia, type of structure, various types of ground on which the building is erected and the technical condition of the building. The criteria for selecting individual degrees of harmfulness were based on checking that the conditions of stiffness, strength, and stability were met. The SWD scales were defined with the assumption of long-term harmonic vibrations e.g., several hours a day.

The SWD-I scale applies to compact buildings with small dimensions in the horizontal direction, not exceeding 15m, one or two-storey buildings and with a height not exceeding any of the dimensions of the horizontal direction. The indications of the SWD-I scale apply to brick buildings, hollow blocks,, slag concrete blocks or similar.

The SWD-II scale is used in the case of multi-storey buildings, up to 5 storeys, with masonry or mixed construction, the height of which is less than twice the smallest building width, and in the case of low-rise buildings, up to 2 storeys, but not meeting the conditions specified for the SWD-I scale.

The SWD scales have five zones (I, II, III, IV and V) separated by four boundary lines (A, B, C and D). The axes of the figures are: vibration frequency *f* (Hz) and acceleration *a* (m/s^2). Both axes are logarithmic. Continuous boundary lines marked with A, B, C and D (lower lines) are used for old buildings with damage. High (dashed) lines A ', B', C' and D' are used for undamaged buildings. In engineering practice, the most common vibrations qualify for the first three of the above-mentioned zones, known as harmful zones.

The following criteria for the division into damage zones were adopted:

- zone I vibrations imperceptible by the building;

boundary *A* - the lower boundary of vibration perception by the building and the lower boundary of taking into account dynamic influences; when vibrations below this boundary, dynamic influences may not be taken into account,

- zone II - vibrations felt by the building, but not damaging to the structure; there is only accelerated wear of the building and the first scratches in mortars, plasters, etc.;

boundary *B* - boundary of building stiffness, lower boundary of the formation of scratches and cracks in structural elements; many years of research and observation of buildings conducted at the Institute of Structural Mechanics of the Cracow University of Technology show that usually no scratches in mortars and plasters appear then,

- zone III - damaging vibrations for the building; they cause local scratches and cracks, thus weakening the building structure and reducing its load-bearing capacity and resistance to dynamic influences. Mortars and plasters may loosen.

Assessment of the harmfulness of the analysed vibrations

For the described primary school building, dynamic resistance was assessed on the basis of the SWD-II scale of the PN-85/B-02170 standard (Fig. 2).

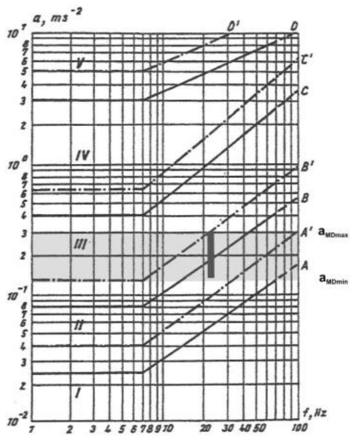


Fig. 2. Example of interpretation of the SWD-II scale (since 1985, after PN-85/B-02170, and 2016-12)

To assess the harmfulness, the value of the proper frequency of the building was adopted, Hz

$$n=2.98$$

and the predicted acceleration that the ground will reach at the foundation level, mm/s^2

$$a_{MD}=145\div300$$

The nomogram in Fig. 3 shows that the acceleration amplitude corresponding to the median frequency of 2.98 Hz is above the boundary line B' in the third zone of the SWD-II scale. From the information provided in point D, it would appear that vibrations, the parameters of which are within zone IIIrd of the scale, should be damaging to the building structure and cause damage to its structural elements. And this would be the case if the vibrations had a long-lasting effect on the structure of the analysed building i.e., several hours a day. The running time of the mining parasiteismic vibrations is very short and lasts on average about 8.0s, and especially the most intense phase of vibrations lasts about 0.5 seconds after activation of the structure; after this time the vibrations are damped. Therefore, the vibration waveforms with the characteristics shown in Figure 2 above will certainly be damaged by the building, but should not be damaged to its structural elements. There is only accelerated wear of the building structure; local scratches and cracks, as well as cracks in plaster mortars may appear. Prolonged stay in the zone of these vibrations may weaken the building structure and reduce its load-bearing capacity and resistance to dynamic influences.

3.2. Sports hall building

The characteristics of the sports hall building:

- building height - approx. 12.21 m,
- total length of the building - approx. 34.50 m,
- width - approx. 16.25 m,
- usable area - approx. 757 m^2,
- cubic capacity - approx. 4626 m^3.

The sports hall building was located on the west side of the existing school. The hall is connected with the school directly by a corridor. The main entrance is located on the eastern side of the room, with the front to the existing school and the entrance to the school surface. The entrance to the warehouses is on the south side of the sports hall. The building was designed in a rectangular shape. Thanks to this arrangement, the maximum use of the land area was ensured. The connecting corridor allows for convenient connection with the school premises by internal communication. The main body of the building is a room with a height of 8.80 m, covered with a gable roof. The building is located on the boundary of the lot according to the regulations.

Access to the sports hall is from three sides:

- from the south, through the layout of the designed sidewalks - the main access to the warehouse,
- from the west side - emergency exit,
- on the eastern side, the main entrance from the pedestrian path leading to the entrance to the school premises, and with internal communication routes from the premises of the existing school.

The sports hall has been designed in a way that enables its multifunctionality, including: conducting physical education classes included in the curriculum, classes with young people and conducting volleyball and basketball games.

The sports hall has an entrance for spectators from the side of the existing school and the street. The sports arena with dimensions of 28.25×16.00 m allows you to play basketball and volleyball; has been extended to include a seat belt for spectators. There is a trainer's room with a sanitary facility and a medical office next to the sports arena. The corridor and the hall provide communication between the coaches' room, the medical room, cloakroom, and sanitary complexes and the arena.

In the sports hall there is also a gym and a room for corrective exercises accessible directly from the corridor, indirectly from the sports arena. The facility has a warehouse for sports equipment and chairs available directly from the arena.

Accessibility of the building for disabled people is ensured by using external ramps and doors with appropriate parameters. For people with disabilities, a generally accessible toilet and a toilet in cloakrooms are provided.

According to the attached geotechnical documentation, there are fine sands and sandy loams at the foundation level. No groundwater was found up to the foundation level. For these ground conditions, the limit resistance of the subsoil is approximately 150 kN/m^2.

On the basis of the decision of the mining experts, the area is subject to mining damage, defined for the IInd category of land suitability for development.

The sports hall has a skeleton structure - wooden girders based on reinforced concrete columns. On the eastern and southern sides, the outbuildings were designed in traditional technology.

The building of the sports hall is situated on an area with a slope towards the west with a level difference of about 1.80 m. The area is covered with greenery and a dozen or so trees of different ages. In addition, there are elements of small architecture in the area - terrain stairs and retaining walls up to about 1.0m high. In the western part, there is a land drainage system.

Due to the mining damage, the footings of the pillars, strip footings, and bowstrings were placed at one depth, on a 30 cm thick layer of compacted sand. On this layer, a 10 cm-thick lean concrete base was made.

The reinforced concrete structures of foundations, columns, and binders are made of B20 gravel concrete, the main reinforcement of AII18G2 steel and steel stirrups AISt3SX.

The foundation walls with a thickness of 30 cm are made of concrete blocks on a cement mortar of 10 MPa brand. In the gable walls there are posts that stiffen the wall 25×20 cm, reinforced with steel bars 4×16 mm.

Reinforced concrete pillars of the hall structure, 25×45 cm in size, are fixed in the foundation. Reinforcement at 3×18 on both narrower sides.

The outer walls of 25 cm thickness are made of megaterm blocks on a 5 MPa brand cement-lime mortar. There are 20×25 cm poles on the walls of the gable.

At the level of ceilings and windows, reinforced concrete wreaths 25×25 cm, 4×16 mm.

The internal walls are made of 25 cm thick megaterm hollow bricks. Partition walls, 6.5 and 12 cm thick, made of 3 MPa cement-lime mortar.

Lintels made of prefabricated L-19 beams. Over the windows on the long walls of the hall, reinforced concrete lintels, which also act as a wreath. Cross-section 25×25, reinforcement 4×16 mm. The lintels above the openings between the hall and the back room were made of 25×30 cm reinforced concrete beams, the reinforcement at the bottom 5×16 and the top 2×16.

Filigran type ceiling with a construction height of 25 cm. In places where the ceiling rests on the walls, reinforced concrete wreaths 25×25 cm. In the place where the AHU rests on the roof of the back room, in the ceiling, two 2×16 mm reinforced ribs with a width of 10 cm.

The supporting structure of the flat roof consists of double-trapezoidal glued wooden girders with dimensions of 125/65 and a thickness of 12 cm, made of K27 class wood. The girders are based on reinforced concrete columns with the use of anchored steel elements.

Wooden 10×24 cm panels are based on the girders, on which the remaining layers of the flat roof, i.e., 20 cm thick mineral wool and two layers of heat-welded roof felt, are laid.

The structure of the connector is separated from the structure of the sports hall and the existing school building 5 cm dilatation width.

Foundation benches, 40 cm wide, made on a ballast of compacted sand, 30 cm thick. Foundation level minimum 1.0m below ground level. The foundation walls of the ground floor and the flat roof are made as in the back room of the room.

The floor is on a 12cm thick reinforced concrete slab supported by foundation walls. Similarly, the flat roof. In the level of support of the ceiling slab, a reinforced concrete beam 20×20cm, reinforced 4×16 mm.

Current technical condition and visible damage to the building

Visible detachment of the ceiling slab from the walls. Horizontal cracks in window and door lintels. Few vertical cracks in the walls, mainly above reinforced concrete columns.

The proper frequency of the building

To determine the frequency of proper vibrations of the building, the approximate method included in the PN-85/B-02170 (and 2016-12) and PN-77/B-02011 standards was used, as shown in Table 1.

Adopted:

for H=12.2 m → T_1=0.183s

Due to the appearance of window openings in the walls of the sports hall and taking into account the fact that the structure was already under the influence of previous mining, the value of the vibration period T_1 was increased by 20%.

T_1=0.22s → the proper frequency n=4.55 Hz

Acceleration of the substrata

The same values were adopted as in the case of the primary school.

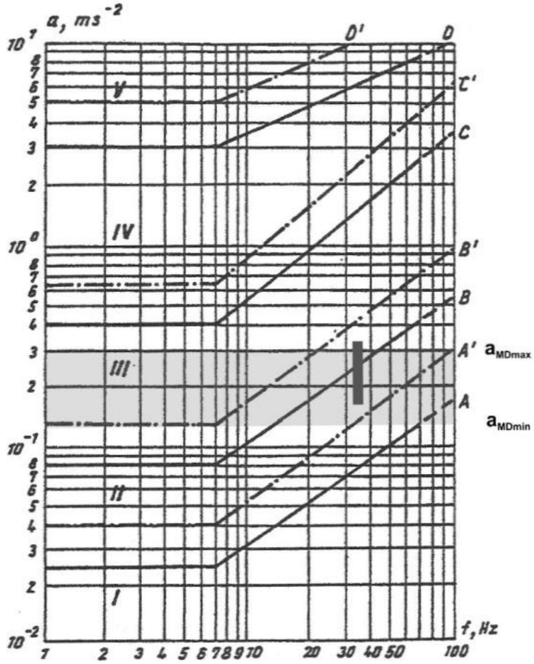


Fig. 3. Example of the interpretation of SWD-II scale (after PN-85/B-02170)

Evaluation of the damaging of the analysed vibration waveforms

As in the case of the Primary School, the PN-85/B-02170 (and 2016-12) standard and the SWD dynamic impact scale included in it were used to assess the dynamic effects on buildings.

To assess the damaging, the value of the natural frequency of the building was adopted

$$n=4.55 \text{ Hz}$$

and the predicted amount of acceleration that the ground will achieve at the foundation level, mm/s^2

$$a_{MD}=145\text{-}300$$

The nomogram in Fig. 3 shows that the acceleration amplitude corresponding to the frequency in the central part of 4.55 Hz is located near the borderline B in the IIIrd zone of the SWD-II scale.

From the information provided in the previous section:

- zone III - vibrations damaging the building, causing local scratches and cracks, thus weakening the building structure and reducing its load-bearing capacity and resistance to dynamic influences; mortars and plasters may fall off.

It should be assumed that vibrations caused by mining exploitation, due to their short-term nature, will be felt by the building, but generally not damaging its structural elements. On the other hand, the wear of the building structure will be faster, which in turn will lead to the appearance of cracks in mortars and plasters.

1. Summary and commentary to the simplified assessment of the dynamic resistance of buildings

Two buildings: a primary school and a sports hall were subjected to the effects of acceleration of ground surface vibrations in the range of up to 10 Hz with the values of a_{MD}=145-300 mm/s^2, according to the presented analysis.

The vibrations induced by mining were damaging to buildings and caused local scratches and cracks in walls and mortars. As the running time of the mining-related parasiteismic vibrations is very short and lasts about 8 s, and the most intense phase of vibrations lasts about 0.5 seconds after excitation; these vibrations were not damaging to the load-bearing elements of the structure. However, these vibrations certainly caused an accelerated wear of the building structure.

The analysis was carried out based on the assumed and forecast values of seismic energy in the area in question.

The potential occurrence of long-term vibrations could weaken the building structure and reduce its load-bearing capacity and resistance to dynamic influences.

Despite the simplicity of the solutions used to analyse this and similar problems related to the assessment of the dynamic resistance of a building 15 years after the implementation of these and other analyses, it can be concluded that all forecasts have been positively verified with the actual real state of structures.

Sources (*selected*)

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