The influence of para-seismic vibrations, induced by blasting works, on structures: a Case Study

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Abstract. Underground mining operations are often associated with the necessity to use explosives. Several hundreds of kilograms of explosives, subdivided into small charges suitable for a specific mining job, are used each time in a blasting operation. In many cases, mining engineers carry out remote central blasting works, which means that all the charges placed at faces are initiated from one control point (usually, a control room in the mine) at the same time. Such coordinated explosions generate para-seismic movements whose consequences can be felt on land surface, with subsequent effects identified in buildings and structures. This paper discusses briefly selected standards applicable to the harmful para-seismic impacts. The author presents the results of the research conducted with the intention to identify harmful effects of the basting works carried out in the "Kłodawa" Salt Mine.

Keywords: underground mining, para-seismic impact

1 Introduction

Each type of mineral extraction operation influences the natural environment in some way. Generally, adverse effects are recorded, with various degrees of intensity. The quality, size, magnitude, and range of impact depends on a number of factors, although the type of mining operations is a dominating factor.

In the case of open-pit mining, we usually observe changes in local landscapes and hydrogeological conditions, forcing subsequent transformations of the local biocenosis. Besides, the method of extraction is also essential here, since blasting works generate para-seismic vibrations that can adversely influence e.g. engineering structures and people.

However, underground mining operations are associated with mining menace, e.g. in the form of land subsidence or sinkholes and rock-mass tremor or collapse etc.

This paper is devoted to the issue of para-seismic vibrations caused by underground rock salt mining. Specific research was prompted by the complaints filed with the "Kłodawa" Salt Mine, which company allegedly contributed to the occurrence of damages in surface structures located around the mining fields where blasting works were carried out.

2 What are para-seismic vibrations

Para-seismic shocks are those induced by human activities. Those include rock-mass vibrations induced by underground mineral extraction (as a result of e.g. chamber ceiling collapse, tremors or rock bursts), or blasting works etc. Moreover, para-seismic vibrations are propagated by heavy vehicle traffic (vehicle impact) or e.g. heavy pile drivers.

Consequently, an underground mine relying on blasting works can be perceived as a potential source generating para-seismic vibrations.

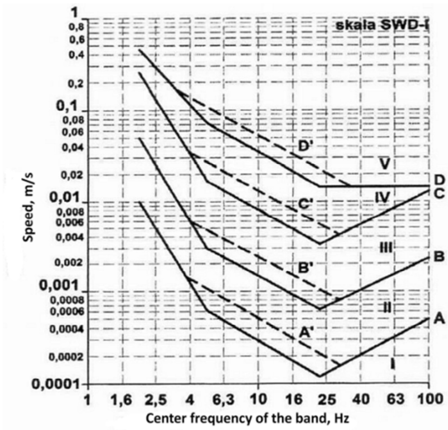
3 Harmful effects of para-seismic vibrations, measured according to scales and standards

Para-seismic impacts cause the vibrations that can be harmful for engineering structures and people. However, how can we assess harmfulness of para-seismic vibrations? That is fairly complicated, owing to the multitude of the sources of vibrations. Different effects are caused by tremor or rock bursts initiated several hundreds of metres underground and still different are those induced by heavy vehicle traffic on land surface, or by blasting works conducted in a quarry. Each of those phenomena will be characterised by specific vibration velocity, acceleration, and frequency. All those parameters should be considered in connection with the source of vibration, as well as the nature of the engineering structures being affected. Apparently, one may think that the issue of the determination of the parameters of the impacts that adversely affect an engineering structure is not complex. However, the number of various classification scales and standards applied to such determinations indicates the opposite.

The Polish Standard [1] is currently applicable in the field under discussion. Actually, it is not the soil or bedrock vibration that is subjected to assessment, but rather the vibrations of the structures being affected by mining operations. The standard in question concerns the dynamic impact scale (SWD) that is presented, for engineering needs, in the form of two nomographs showing the dependence of the vibration velocity on vibration frequency (Fig. 1).

Nomograph SWD-I (left) refers to the buildings with massive structure, small external dimensions in the horizontal plane (not exceeding 15 m each side), single- or two storey buildings, with the height that does not exceed any of the horizontal plane dimensions.

Nomograph SWD-II (right) refers to the buildings not exceeding five storeys above ground, whose height is lower than the double length of the smallest width of the building, as well as low buildings (up to two storeys), all those that do not meet the conditions specified in the SWD-I scale.



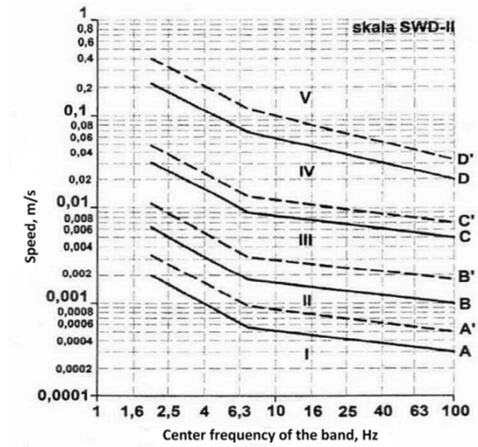


Fig. 1. The lines describing the zones of vibration impact on buildings, in the SWD-I scale (left) and SWD-II scale (right), specified within the following coordinates: central ⅓-octave band frequency – maximum vibration velocity in the band

The nomographs show five harmfulness zones, separated by boundary lines,. The zone boundaries were specified in two options, based on the technical assessment of the building and the types of the substrate (soil, or bedrock) and of vibrations. Assignment to the respective option is effected depending on the dominating number of specific features: Table 1.

Table 1. The features allowing to select the boundary lines of harmfulness zones, within the SWD scales.

Assessment Criteria	Features Allowing to Apply a Boundary	
	Lower Boundary (Continuous Line in Fig. 1)	**Higher Boundary** (Dashed Line in Fig. 1)
Building's Condition	Old buildings, with damages; modified or reinforced buildings	Undamaged buildings, without structural modifications
Building's Material and Structure	Masonry, reinforced-concrete, or stone buildings, poorly structured; no foundations, no ceiling cornices, vaulted ceilings, large or irregular openings in walls, with storey floors at various levels	Solid-brick walls, good workmanship, reinforced-concrete or concrete foundations, massive ceilings binding the walls, with a ceiling cornice
Types of Substrates and Foundations	Low-rigidity substrate (e.g. silty or loose sands), discontinuous or intermediate footing (various heights)	Rigid substrate (e.g. hard silts or clays), flat footing
Types of Vibrations	Long-term or continuous vibrations	Short-term vibrations

The classification of the structures presented in the Polish Standard is limited only to the masonry buildings of up to five storeys. Other types of structures (e.g. reinforced-concrete ones) are omitted, similarly to other engineering structures (e.g. steel towers, reinforced-concrete smoke-stacks etc.).

The vibration issues are regulated in a different way by the German Standard [2]. Synthetic conclusions are presented in Table 2 below.

Table 2. Allowed values of vibration velocity v_i for the assessment of the influence of short-term impact on a building.

Class	Type of Building	Allowed values of vibration velocity v_i [mm/s]			
		Foundation Frequency			Top Storey
		1 ÷ 10 Hz	10 ÷ 50 Hz	50 ÷ 100 Hz*)	All frequencies
1	Commercial and industrial buildings and similar structures	20	20 ÷ 40	40 ÷ 50	40 (10)**)
2	Residential buildings and their structures and/or similarly used buildings	5	5 ÷ 15	15 ÷ 20	15 (5) **)
3	The buildings outside Classes 1 and 2 that are worthy of preservation owing to their resistance to vibrations (e.g. landmarks)	3	3 ÷ 8	8 ÷ 10	8 (2.5) **)

*) For the frequencies exceeding 100 Hz, the reference values for 100 Hz may be applied
**) The values in parentheses relate to the impacts that can be considered to be short-term shocks

Besides the standards mentioned here, there are also other classification systems used to determine the threshold of harmfulness, defined as velocity, acceleration, or relocation associated with the intensity of the specific impact, below which no building damages occur, provided that the building's technical condition is assessed as at least good. And again, owing to the multitude and diversity of assessment criteria, such classifications assume various thresholds of harmfulness, distinguishing e.g. between the building's foundation substrates, types and ages of the buildings etc., as well as the sources of vibrations [3].

As we can see, it is not possible to assess clearly the impact of para-seismic vibrations on buildings and structures, especially in the process of measuring the parameters whose values alternate around boundary values. A noticeable increase or drop of such values allows to determine vibration class assessment. Of course, the applicable standard or classification scale will always be a point of reference, deciding whether a given impact is or is not harmful.

4 Case description

The "Kłodawa" Salt Mine is located in the eastern part of the Wielkopolska Region, close to National Road No. 92. The Salt Mine conducts extraction of rock salt in the central section of the Kłodawa salt dome. The mine workings are situated in the deposit, ranging from ca. 425 to 750 m under the ground level. Presently, the works continue on making Level 750 and below available for mining. The workings are cut in seven mining fields. Salt extraction is conducted by the room-and-pillar method. Low chambers are currently cut, in opposition to the previous system of cutting high, cuboidal or cylindrical shapes. Natural hazards occur in the Salt Mine: water encroachment, methane and other gas ejections, and rock bursts. Those hazards are presented in Table 3 [4].

Table 3. List of natural hazards identified in particular mining fields, with the numbers of events (as of 31 December 2015)

		Field No. 1	Field No. 2	Field No. 3	Field No. 4	Field No. 5	Field No. 6	Field No. 7	Outside fields
Water hazard	Degree	III	III	III	III	III	III	III	III
	No. of events	9 (53) [a]	48 (68)	1 (9)	28 (52)	1 (3)	3 (0)	0 (0)	59 (178)
Methane hazard	Category	- [b]	II	- [c]	- [b]	- [c]	- [c]	- [c]	- [d]
	No. of events	91							
Gas ejection, rock bursts	Category	- [e]	III	-	- [e]	-	-	-	- [f]
	No. of events	127, with methane ejection 329, with other gases (e.g. nitrogen, hydrogen sulphide)							

[a] The number of active events (inactive ones in parentheses).
[b] Mining fields belonging to methane hazard Category II, whenever mining includes cutting faces.
[c] Mining fields belonging to methane hazard-free zones, although that determination is cancelled when the methane concentration exceeds 0.1%.
[d] Methane hazard Category II also applies to underground corridors in the areas of the "Chrobry" Shaft, including the Shaft, and the ventilation routes connecting Field No. 2 with the "Chrobry" Shaft.
[e] Mining fields belonging to gas-ejection and rock-burst hazard Category III, whenever mining includes cutting faces.
[f] Category II also applies to the area between the S-W Cross-cut VII at Level 600 m and Field No. 4.

Mining operations are conducted with blasting. Owing to the specific natural hazards, blasting jobs involve ammonite and metanite blasting explosives. About 70 kg of the explosive is used at a face and about 100 kg in a chamber for one blasting job. Nevertheless, there are cases when larger quantities of explosive materials are used. Two blasting jobs are arrange per 24 hours, with several blasting jobs in corridors and chambers each, involving about 1,500 kg explosives in each of the two shifts. Charges are detonated by electronic millisecond-delay fuses.

Various types of measurement devices are used to measure the vibrations of the medium particles, energised by the blasting works. Measurements are conducted, depending on the needs, either in the ground or on the protected buildings or structures. Since direct 3D recording of particle vibrations in the natural medium is not technically possible, the measurement devices break the measured values into three mutually perpendicular components. Two of them being horizontal are marked x and y, where x is a parallel horizontal component and y is the horizontal component perpendicular to the line connecting the place of the blasting job and either the measurement point, or the longer axis of the building in which the vibrations are measured. The third component z is always a vertical axis, being perpendicular to the directions x and y.

The vibration intensity values measured at particular components can be expressed in amplitudes, velocities, or accelerations, as well as 2D or 3D vectors, as the geometric mean of component relocations. The measurement devices allow for data recording, using specialised software for data transfer to a computer for subsequent analysis.

Five measurement stations were established for the needs of this research project. They were equipped with proper vibration gauges designed for the ground environment and the structural elements. Stations No. 1, 3, 4, and 5 were placed on buildings, while Station No. 2 in the ground. Each station was facing the source of vibrations, or the sites of blasting works conducted during two shifts in the salt mine [5].

The list of blasting works conducted at Shift I is presented in Table 4, and those of Shift II in Table 5.

Table 4. List of blasting work locations at Shift I.

No.	Blasting Location	Type of Mining Works
1.	Chamber KSR 8/750*)	rock cutting
2.	Chamber KSR 10/750	ceiling chamber stope cutting
3.	Chamber KSR 14/690	long-hole cutting
4.	Chamber KSR 21/750	rock cutting
5.	Chamber KSR 24/630	surface-attached charge
6.	Chamber Corridor KSR 24/660	rock cutting in the corridor
7.	Chamber KSR 26/660	rock cutting
8.	Chamber KS 1g/660	floor chamber stope cutting
9.	Chamber KS 1g/630	undercutting of a decline ceiling
10.	Chamber Corridor KS 7/720	rock cutting in the corridor
11.	Chamber KSR 11/720	rock cutting
12.	Chamber KS 16A/660	rock cutting
13.	Chamber KS 17/720	rock cutting

*) Working marks: a/b: a – Working Number, b – Mining Level

Table 5. List of blasting work locations at Shift II

No.	Blasting Location	Type of Mining Works
1.	Chamber KSR 8/750	rock cutting
2.	Chamber KSR 10/750	ceiling chamber stope cutting
3.	Chamber KSR 11/720	rock cutting
4.	Chamber KS 19/720	floor chamber stope cutting
5.	Chamber KSR 21/750	rock cutting
6.	Chamber KSR 24/630	½ of a stope + bottom surface
7.	Chamber KSR 26/660	ceiling chamber stope cutting
8.	Chamber KS 3/720	rock cutting
9.	Chamber Corridor KS 7/720	rock cutting in the corridor
10.	Chamber KS 14B/630	ceiling chamber stope cutting
11.	Chamber KS 17/720	rock cutting
12.	Chamber KS 19/720	floor chamber stope cutting
13.	Chamber KS 30/690	rock cutting

The distribution of measurement detectors and blasting work locations are presented in Fig. 2.

Vibration measurements were conducted on the basis of the guidelines specified in the then valid Polish Standard [6], upon placement of the vibration detectors on the building's foundation or load-bearing walls at the ground level (Stations No. 1, 3, 4, and 5) , facing the source of the vibrations. The coordinates of the rectangular grid x, y were assumed as the measurement directions for the horizontal directions and the coordinate z for the vertical direction. Besides, substrate vibration measurements were taken by placing one of the detectors in the ground, with special pins, also assuming the rectangular grid as the measurement direction at Station No. 2. Three-component vibration velocity gauges, type UVS, were use for taking measurements.

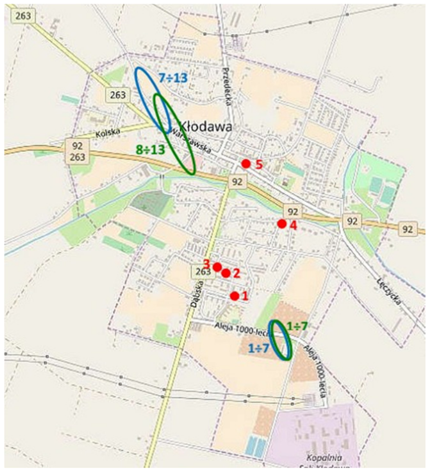


Fig. 2. Distribution of measurement detectors (red) and blasting work locations (blue: Shift I; green: Shift II). Numerals designate the blasting site according to Table 4 and 5

The recorded vibrations could be read only at Stations No. 1 and 5 where equipment was installed to set a low threshold of record initiation (0.10 mm/s), supplemented by abbreviated recordings of only the maximum velocity values, in two-minute periods. Such readings are possible when the vibration values exceed the seismic background noise. In the case of the "Kłodawa" Salt Mine, the low level of vibrations recorded during the measuring sessions allowed for such a reading method. The lists of the results obtained in shown in Table 6 [1].

Table 6. Results of the recorded vibration intensity readings

Blasting Location	**Station No.**	**Record**	**Vibration Velocity, mm/s**			**Frequency, Hz**			**Vector mm/s**
			u_z	u_x	u_y	f_z	f_x	f_y	u_{zxy}
KSR 14/690	1 5	258.741 251.qbar	0.225 0.135	0.100 0.050	0.090 0.060	77.0	22.0	38.0	0.226
KSR 24/630	5	251.qbar	0.060	0.035	0.035				
KSR 26/660	5	251.qbar	0.050	0.035	0.025				
KSR 24/630	5	251.qbar	0.125	0.055	0.030				
KS 1g/660	1	258.qbar	0.089	0.050	0.040				
KS 17/720	5	251.qbar	0.060	0.075	0.081				
KS 30/690	5	251.qbar	0.075	0.035	0.040				

Fig. 3 presents a selected seismogram of the vibrations recorded at Station No. 5 when 10 long holes were blasted in Chamber KSR 14/690, using a 33.5 kg explosive charges in a borehole, detonated with the delay of 25 ms each. The total weight of the explosive used in the series of boreholes amounted to 335 kg, which was about three times more than in the case of standard blasting works conducted on a chamber face. That was the only complete vibration record. The remaining records could be read from abbreviated recordings (*qbar* option).

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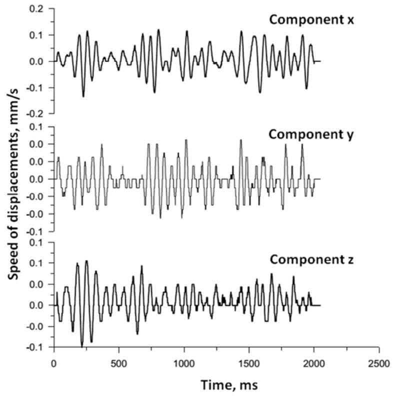

Fig. 3. A building vibration seismogram, Station No. 5

During a measurement session of about 20 minutes (equivalent to the period of blasting works conducted in the mine) the system recorded some vibrations that were not related to the specific blasting jobs. Station No. 5 recorded the vibrations energised by the travel of a heavy truck in the area, see Fig. 4. That event was used to compare the vibration intensity induced by both blasting works and heavy vehicles.

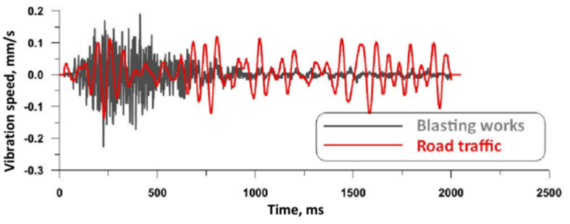

Fig. 4. Vibrations induced by heavy vehicles on the background of the seismic impact induced by blasting works

5 Conclusions

Low intensity of the recorded vibrations makes any analysis practically unproductive. Based on the applicable standards, one can conclude clearly that the para-seismic vibrations induced by blasting and mining works do not have adverse effects on any structures. The levels of the recorded vibrations should be recognized as imperceptible by the structures situated in the vicinity of the salt mine. It is necessary to mention that the recordable vibrations induced by the blasting works can be energised sporadically. However, the traffic, including that of heavy vehicles, is rather continuous in nature when we consider the types of vibration events.

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References

1. Standard PN-B-02170:2016-12
2. Standard DIN 4150-3:1999-02
3. A. Biessikirski, Przegląd Górniczy **6**, 1-6 (2014)
4. W. Andrusikiewicz, K. Krokos, Przegląd Solny **11**, 57-65 (2015)
5. W. Andrusikiewicz, J. Sieradzki, J. Winzer, Pomiary rekonesansowe drgań parasejsmicznych przy robotach strzałowych w Kopalni Soli „Kłodawa" S.A. (2005)
6. Standard PN-85/B-02170