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Analysis of Mining Damage Notifications in Single-Family Buildings after the Occurrence of Intensive Mining Tremors**

1. Introduction

Mining damage is caused by changes in ground surface topography due to the movement of the rock mass elements towards the working, by mining tremors, possibly by a change in hydrological conditions in the substrate (e.g. [5]). The damage may occur in building structures in the form of failures, accelerated technical wear and additional nuisance of use (e.g. [4, 13]). In accordance with the applicable provisions of the Polish law [11, 12], the entrepreneur running the mining plant is held responsible for the damage caused by the activities of the mine, as well as has an obligation to remove the damage caused. In practice, however, to assess the extent of the damage and to estimate the value of the loss turns out to be problematic. Valuation of mining damage in a building should be preceded by an analysis of the potential causes of damage and failures. Damage or accelerated wear may in fact be caused by other factors, unrelated to mining [13]. The purpose of such an analysis should therefore be isolating these failures which, in whole or in part, are the result of mining activities and for the removal of which the Mining Plant is held responsible.

The main elements of mining impacts on space development in the Legnica-Głogów Copper District are mining tremors. They occur due to a sudden movement, bursts or cracking of the rock mass layers. The associated release of energy is a threat both to workings in the underground part of the mine, as well as to objects located on the surface, e.g. [2, 7–10]. Occurrence of mining tremors in the area of the Legnica-Głogów Copper District is stimulated by both natural factors as well as technical and operational ones. Deposits of limestone, sandstone and anhydrite, lying over copper ore deposits, have the ability to accumulate elastic energy, releasing it during the burst of the rock mass. A circumstance which is favourable for energy accumulation is also considerable operating at a depth, of 600 to over 1000 meters [10].

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A violent stress relief in the rock layers in the epicenter of the tremor at the hypocentral depth *H* generates elastic seismic waves that propagate to the surface layer, generating longitudinal and transverse surface waves, propagating over long distances and affecting the housing development in the area (Fig. 1).

They are an additional dynamic load for building structures. The horizontal component of the vibration has a particularly significant impact on the threat to a housing development [3, 6, 10].

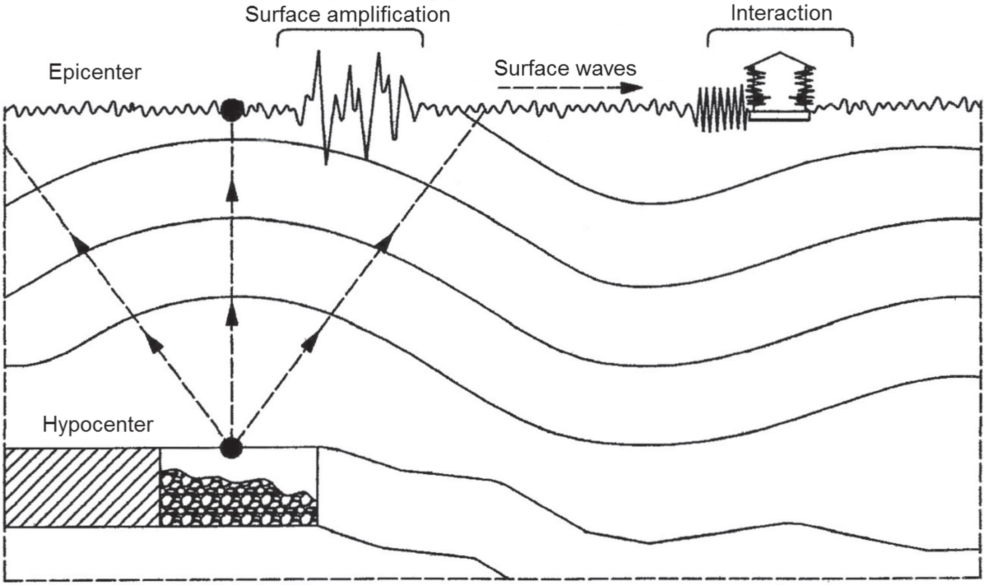

Fig. 1. Propagation of seismic waves in the rock mass

Source: [1]

High-energy tremors, with energies $E \geq 10^8$ J, are considered to be of significant importance in the issues of protection of building structures in mining areas [6].

The article presents an analysis of notifications to recognize mining damage in single-family housing estates in Polkowice after the occurrence of three strongest tremors in that area. This applies to:

- the tremor of 20 February 2002 with the energy of $1.5 \cdot 10^9$ J,
- the tremor of 16 May 2004 with the energy of $8\ 4 \cdot 10^8$ J,
- the tremor of 21 May 2006 with the energy of $1.9 \cdot 10^9$ J.

A group of 256 single-family residential buildings were studied, representing the three housing estates in Polkowice, located in the mining area. The construction data of individual buildings were collected during a detailed architectural and constructional inventory, complemented by the analysis of the available design documentation as well as interviews with the owners and users of the real properties.

The informations about the damage in the buildings reported by the residents, which occurred after each of the analyzed tremors, were obtained at the Mining Plant. The analysis took into account the structural and material characteristics of the buildings, as well as subdivision into damage to structural elements and to secondary elements.

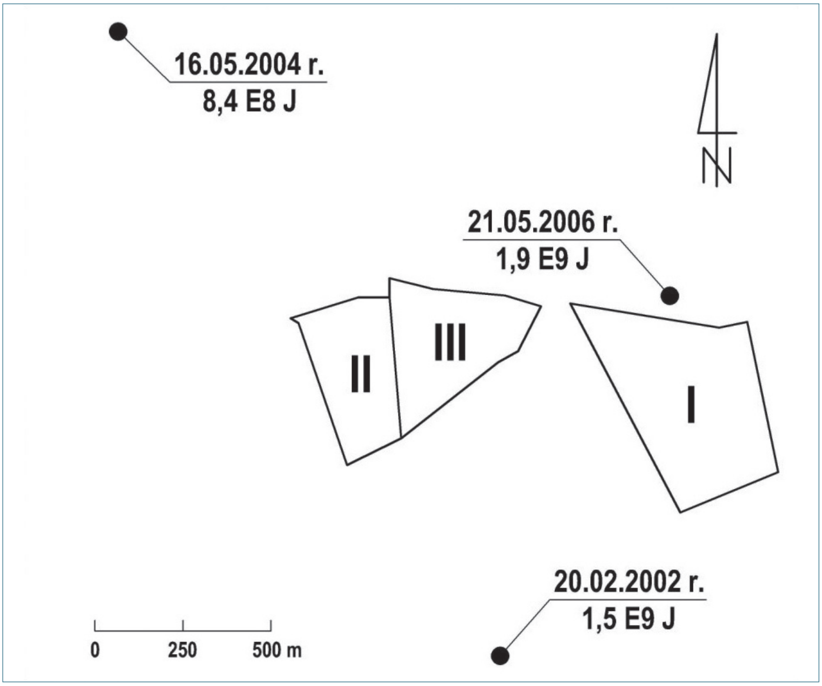

Fig. 2. Location of the epicenters of the analyzed high-energy mining tremors and of the development of the studied housing estates

The location of the epicenters of the analyzed tremors in relation to the development of the studied housing estates has been presented in Figure 2.

2. Specifications of the Studied Buildings

The subject of the analysis were single-family residential buildings located on three housing estates in Polkowice, erected after 1980 (Tab. 1).

Considering the scope of the research, the study was limited to the buildings erected before the first of tremors that is before 2002. These buildings are either detached (30.1%), semi-detached (29.7%) or terraced (40.2%). The shapes of the plans and of the buildings took a variety of forms (Tab. 2), but the majority of the buildings had a simple or slightly fragmented plan (70.3%) and a compact form (55.5%).

Table 1. Location of the test stand (256 buildings)

Housing estate	Number of buildings	
	[items]	[%]
I	114	44,5
II	89	34,8
III	53	20,7

Table 2. Development type and shape of the plan and building form of the studied building structures

Feature	Form	Number of buildings	
		[items]	[%]
Development type	detached and semi-detached	153	59.8
	terraced	103	40.2
Shape of the plan and building form	simple or slightly fragmented, elongated	103	40.2
	simple or slightly fragmented, compact	77	30.1
	greatly fragmented, compact	65	25.4
	greatly fragmented, elongated	11	4.3

All the analyzed buildings were situated at a constant level on concrete foundations. Basement and foundation walls were monolithic concrete (51.6%) or made with concrete blocks (48.4%).

Most commonly, envelopes were diaphragm walls with thermal insulation inside, and a masonry layer of the façade made of ceramic bricks from the outside. The load-bearing walls of higher floors were built of cellular concrete (57.0%) or slag concrete blocks (43.0%). Stairs and lintels were generally made of monolithic reinforced concrete.

All the analyzed building structures had basements, under the whole or part of the structure, but always a constant level of foundation was retained.

The studied sample exhibited considerable variation in both basement ceilings and upper floors (Tab. 3). In the case of the buildings erected in the 80s of the twentieth century, the dominant group consists of prefabricated reinforced concrete floors, mainly of hollow core slabs, and ribbed slabs, mostly of DZ-type, prefabricated in whole (75.1% and 74.6%, respectively). Later, more popular were monolithic reinforced concrete floor slabs and ribbed, partially prefabricated slabs, most commonly of Teriva or Fert types (78.7% and 82.7%, respectively). A characteristic feature of the analyzed objects was diversified levels of ceiling supports within each floor (tie beams shifted by about 1 m – 62.9% of the considered buildings).

Table 3. Structure of the ceilings of basements and higher floors in the analyzed buildings

Ceilings	Structure	Total number of buildings		Buildings erected in the years 1980–1989		Buildings erected in the years 1990–2001	
		[items]	[%]	[pcs.]	[%]	[items]	[%]
Basement	prefabricated slabs	152	59.4	136	75.1	16	21.3
	monolithic reinforced concrete	104	40.6	45	24.9	59	78.7
Higher floors	prefabricated slabs	148	57.8	135	74.6	13	17.3
	monolithic reinforced concrete	108	42.2	46	25.4	62	82.7

The building systems of the 1980s most frequently used bipartite ventilated flat roofs with roofing of prefabricated hollow core roof plates based on openwork walls and covered with roofing paper. The buildings erected in the 90s of the twentieth century, and later, mostly had steep roofs with wooden rafter framing and were covered with steel sheet or ceramic tiles.

In the study group, the vast majority, i.e. 202 buildings (78.9%), had no protection against mining tremors. The other 54 objects were issued with a decision or planning permission by the District Mining Office, taking into account mining impacts on the planned investment. They specified, inter alia, the predicted maximum horizontal acceleration or velocity of the vibration on the surface, but only one building had a documented protection against tremors in the form of concrete studs.

3. Structure of Mining Damage Notifications

Damage reported by the residents was divided into two groups: regarding the structural and non-structural elements (in individual cases, the notifications also concerned furnishings that were omitted in the analysis). The set of structural components included foundations, load-bearing walls (foundation, basement, overground), lintels, walls (under the windows, firewalls), ceilings, roofs, roof structures, balconies and loggias. The secondary, non-structural elements included partition walls, internal plasters, façade layers, wall cladding, floors, damp proof insulation, roofing, flashings, gutters and downspouts, entrances to the buildings, windows, doors and installations.

The structure of the mining damage notifications after the above-mentioned tremors have been presented in Table 4, and their classification by the Mining Plant has been depicted in Table 5.

Table 4. Structure of mining damage notifications in the analyzed buildings after high-intensity tremors

Date of the tremor	Number of notifications		Notification of damage to structural elements		Notification of damage to secondary elements	
	[items]	[%]	[items]	[%]	[items]	[%]
20.02.2002	73	28.5	65	25.4	70	27.3
16.05.2004	13	5.1	11	4.3	11	4.3
21.05.2006	55	21.5	48	18.8	47	18.4

Table 5. Structure of qualifying mining damage notifications by the Mining Plant

Date of the tremor	Number of notifications	Qualification of the notification					
		accepted		rejected		qualified for further observation	
	[items]	[items]	[%]	[items]	[%]	[items]	[%]
20.02.2002	73	64	87.7	5	6.8	4	5.5
16.05.2004	13	7	53.8	3	23.1	3	23.1
21.05.2006	55	39	70.9	15	27.3	1	1.8

The presented data depicts that most notifications (73 cases) were submitted after the first high-energy tremor on 20 February 2002. As a result of the on-site inspections carried out by the staff of the Department of Mining Damage of the Mining Plant "Rudna" in the reported buildings, the majority of notifications (64 cases, or 87.7%) were recognized as valid. Therefor, the mine paid the owners one-off damages for the resulting losses or ordered reparation of the recognized damage by restoring the buildings to their original condition. The subject of the notifications submitted by the owners were mostly cracks and scratches occurring both on structural elements (load-bearing walls, ceilings) as well as on secondary elements (partition walls, wall and floor cladding, entrance to buildings).

As a result of the tremor on 16 May 2004, the Mining Plant had a much smaller number of reported damage to these buildings (13 notifications). This was probably due to the effectiveness of the repair and safety works carried out after the previously analyzed tremor. This thesis can be substantiated by the fact that the owners of 57 buildings (which is more than 89.0%), who in February 2002 reported the mining damage, which was then confirmed, did not submit the notification again in 2004. As a result of the on-site inspections conducted in the reported buildings, about half of the notifications (53.8%) were accepted.

The strongest tremor in Polkowice in the analyzed period occurred on 21 May 2006, with the energy of $1.9 \cdot 10^9$ J. As a result, the number of applications for compensation for mining damage increased again (55 cases). As in previous years, the majority of them (70.9%) were found to be justified, which resulted in a one-off payment of damages or repair of the resulting damage.

Due to the limited number of notifications after the tremor of 16 May 2004, further research examined the effects of the two high-energy tremors, of 20 February 2002 and of 21 May 2006.

4. Structure of Mining Damage Notifications and Technical Features of the Buildings

The studied buildings are either detached, semi-detached, or terraced. Shapes of the plans and building forms vary (c.f. Tab. 2), but predominantly these are objects characterized by a simple or slightly fragmented plan and compact form. Therefore, the structure of the damage notifications after the tremors was examined, depending on the type of a development, the shape of the plan and the shape of the building form. Pearson's chi-square test of independence was used, based on a comparison of the observed values with the hypothetical ones for categorical (qualitative) variables. The level of significance was adopted at $p = 0.05$. The obtained results have been presented in Table 6.

Table 6. Levels of statistical significance of Pearson's chi-square test obtained during the study of a relationship between development features and the structure of notifications after the tremors in 2002 and 2006

Development features	Notification of damage to structural elements	Notification of damage to secondary elements
	p	p
Type of development	0.00033	0.00063
Shape of the plan and building form	0.00000	0.00017

The above data proves that there are significant, in statistical terms, relationships between the structure of the damage reported by the owners, and both of the studied development features.

Table 7 illustrates the reported damage in percentage, and their qualification by the Mining Plant, depending on the category of the studied feature in a given group of buildings.

Table 7. Percentage of damage in a given group of reported buildings and its qualification by the Mining Plant, depending on the development features

Development features		Percentage of damage in a given group of reported buildings, with damage to:		Qualification of the damage in the reported buildings by the Mining Plant		
		structural elements	secondary elements	structural elements	secondary elements	structural elements
		[%]	[%]	[%]	[%]	[%]
Develop-ment type	terraced	30.1	30.6	82.6	13.0	4.4
	detached and semi-detached	16.7	17.6	78.0	18.6	3.4
Shape of the plan and building form	greatly fragmented, elongated	40.9	50.0	84.6	15.4	0.0
	simple or slightly fragmented, elongated	27.7	28.6	84.1	9.5	6.4
	greatly fragmented, compact	17.7	18.5	76.9	23.1	0.0
	simple or slightly fragmented, compact	13.0	14.9	73.1	23.1	3.8

These data show that the percentage of submitted applications for payment of damages was nearly twice as high for terraced houses than for detached and semi-detached ones. This trend is common both for the reported damage to structural elements and to secondary elements.

While analyzing the development of the housing estates with respect to the shape of the plan and building form, it can be noticed that the overwhelming number of submitted notifications regarded greatly fragmented buildings with elongated shapes. The percentage of reported notifications (both regarding the damage to structural and secondary elements) was more than three times higher than for the buildings with a simple or slightly fragmented plan and compact shape.

Among all the analyzed cases, about 75–80% of notifications were considered justified by the Mining Plant, confirming the occurrence of damage caused by mining activities.

5. Structure of Mining Damage Notifications and Design Features of the Buildings

The structure of the damage reported after the tremors was also examined, depending on the structural and material solutions used in the buildings. Damage to both secondary and structural elements was identified.

Again, Pearson's chi-square test of independence was used, with the level of significance adopted at $p = 0.05$. The obtained results have been presented in Table 8.

Table 8. Levels of statistical significance of Pearson's chi-square test obtained during the study of a relationship between design features of the buildings and the structure of the notifications after the tremors in 2002 and 2006

Elements of the building		Notification of damage to structural elements	Notification of damage to secondary elements
		p	*p*
Foundation and basement walls		0.42587	0.43932
Load-bearing walls of higher floors		0.03971	0.01653
Basement ceilings		0.81241	0.58749
Ceilings of higher floors	structure	0.71828	0.35283
	varied levels of support	0.01587	0.04017

A statistically significant relationship was observed between the adopted structural and material solutions of the load-bearing walls of higher floors and the occurrence of varied levels of ceilings, and notifications of damage to both load-bearing elements and non-structural elements. In other cases, there was no significant correlation between the variables observed.

Table 9 illustrates the reported damage in percentage, and its qualification by the Mining Plant, depending on the cases, significant in the statistical sense.

These data show that the percentage of damage to the structural and secondary elements in the buildings with walls made of cellular concrete is about 50% higher compared to the buildings with the walls made of slag concrete blocks.

Table 9. Percentage of damage in a given group of reported buildings and its qualification by the Mining Plant, depending on the structure of the building elements

Elements of the building			Percentage of damage in a given group of reported buildings, with damage to:		Qualification of the damage in the reported buildings by the Mining Plant		
			structural elements	secondary elements	accepted	rejected	qualified for further observation
			[%]	[%]	[%]	[%]	[%]
Walls of higher floors		of cellular concrete	25.3	26.7	81.2	14.1	4.7
		of slag concrete blocks	17.7	17.7	79.1	18.6	2.3
Ceilings of higher floors	structure	prefabricated slabs	22.6	24.3	83.3	10.3	6.4
		monolithic reinforced concrete	21.3	20.8	76.0	24.0	0.0
	levels of ceilings	shifted	25.5	25.8	83.3	12.2	4.4
		fixed	16.3	17.9	73.7	23.7	2.6

While analyzing the effect of varying height of ceiling supports, it is apparent that about 50% greater number of notifications (both referring to structural and non-structural elements) were submitted in the case of varied levels of the ceilings. As it was in the case of the development features analyzed in Chapter 4, about 75–80% of the notifications were considered justified by the Mining Plant.

6. Summary

The article analyzes the notifications of mining damage to buildings in single-family housing estates in Polkowice. The damage occurred after three high-energy mining tremors on 20 February 2002, 16 May 2004, and 21 May 2006. The study group was comprised of 256 houses built in the traditional brick technology between 1980 and 2002. The paper attempted to find a relationship between the structure of mining damage reported after the tremors and the development and design features of the buildings.

The obtained results proved the existence of statistically significant relationships between damage to both structural and secondary elements, as well as the type of development and geometry of the buildings (Chapter 4).

A significant effect of the applied structural and material solutions in load-bearing walls of the higher floors, as well as varied levels of ceiling supports on the scope of the damage, has been identified as well (Chapter 5).

These results confirm the necessity of applying structural and material solutions which would ensure to buildings exposed to mining tremors the appropriate spatial rigidity and, consequently, resistance to dynamic loads.

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