INVESTIGATION OF THE ALLOWABLE DEFORMATIONS OF BUILDINGS SUBJECTED TO MINING INFLUENCE [1]

by

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Abstract. Due to ground deformations caused by underground mining serviceable values of buildings are distinctly diminished, and in extreme cases, seriously damaged structures may be exempted from further service. These deformations can even several times surpass the allowable values determined by appropriate building standard codes. In such situations the allowable deformations should be defined to maintenance the original functioning of a building. One of the most important factors for the determination of the allowable deformations are the serviceability criteria understood as the occupants' reaction to mining damage. The paper presents the results of the investigations of the occupants' reaction to the deformations and damage to their buildings and the concept of shaping the allowable values of deformations of buildings in mining areas. On this ground the proposals for the allowable deformations of buildings in mining areas are given with regard to: tilt of the buildings, width of a single wall crack or failure and relative deflection of the walls.

Additional Key Words: mining areas, performance concept of buildings, allowable deformations of buildings.

Introduction

The concept of mitigated conditions for the serviceability of buildings in mining areas was presented during ASSMR conference in 1994 (Kawulok, Sulimowski 1994), entailing the acceptance of the lowered criteria of the performance of buildings subjected to mining influence as compared to the generally obliged standards.

To implement this concept the allowable values of the parameters describing the deformations and damage to buildings must be determined, following the building serviceability criteria in accordance with the designed function of buildings and on the level generally accepted by the occupants.

The results discussed in the paper have been obtained in the course of the research conducted by Building Research Institute, Division in Gliwice, into the occupants' reaction to damages and deformations of housing and public utility buildings located in mining areas of the Silesian Mine Basin in the south of Poland. The results, after the relevant serviceability criteria fulfilling the requirements of the occupants are accepted, may constitute a basis to determine the allowable values of the parameters.

Some practical proposals are presented in the final part of the paper, taking into account the publications referring to this issue.

Description of research

The purpose of the research was to collect data on the reaction of users (occupants) of housing and public utility buildings to deformations and damages induced by the mining activity.

The conclusions drawn on the basis of the results should be generally acceptable, yet, at the same time, they are dependent on very subjective factors such as the occupants reaction to the state of damages to the building (flat). In view of this, the following assumptions were made in planning the investigation:

1) the investigation should be concerned with different conditions of the performance of buildings, especially with:
   - area,

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[1] Paper presented at the 1997 National Meeting of the American Society for Surface Mining and Reclamation, Austin, Texas, May 10-15, 1997.

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Proceedings America Society of Mining and Reclamation, 1997 pp 376-381
DOI: 10.21000/JASMR97010376

- type of structure,
- technical condition of buildings,

2) the data collected in the course of the investigation should refer to different periods of time to diminish the influence of temporary prosperity period (economic affluence or social and political boom) on the occupants' reaction,
3) housing and public utility buildings should constitute the basis of the investigation, but some parameters could refer to industrial (production or production and accessory) buildings, provided that the users of the building stay in it temporarily; all buildings should be located mainly in mining areas but the buildings damaged by the influence of mining yet not directly connected to mining excavation may also be considered.

Altogether, 87 buildings were examined, including detached buildings or bigger housing settlements, the data concerning all these buildings related the state of damage to the structure to the conditions of the building performance.

The investigated structures may be generally described as:

- age: from 110 to 10 years old,
- technical condition: from good to poor,

height: up to 11 stories,

their general characteristic is presented in Table 1

The occupants' reaction to the state of deformations and damage to buildings was assessed, in line with ISO standards (1984), on the basis of the information obtained in the direct survey of the users, or, in some justified cases, basing on the expert's opinion. Four levels of the users' reaction were assumed (comp. Figure 1) to account for various conditions of the performance of buildings:

- imperceptible, designated as IL,
- perceptible, designated as PL,
- troublesome, designated as TL,
- excluding a building from its designed functioning, designated as EL.

It was assumed that the users' reactions reflected in the above division result from two basic factors of a subjective nature:

- direct influence on the users,
- lowered performance of the building (flat) entails unwieldiness to the users.

Table 1. The general description of the investigated buildings

Structure description		Number of structures	%
Location	Mining areas	85	98
	Outside mining areas	2	2
Function	Housing structures	41	47
	Public utility buildings	26	30
	Other	20	23
Structure type	Unreinforced brick bearing walls	55	64
	Concrete bearing walls	9	10
	Frame buildings	15	17
	Other	8	9
Development	City center	45	52
	Dispersed city development and suburban rural	42	48

In the course of the investigation, the information on the relation between the state of the deformations and damages and the performance of the building was collected for the following parameters:

- tilt of the building (T_b) - 40 buildings,
- width of a single crack or failure in walls (Δa) - 50 buildings,
- relative deflection of the walls (γ) - 20 buildings; relative deflection is defined as $\gamma = f/L$, where f - deflection of a building (wall), L - length of a building (wall)

Taking into consideration above mentioned levels of the users' reaction, the statistical study of the collected data seems to be of little usability. Therefore they are analyzed in the qualitative range to indicate only the tendencies in shaping the levels of these reactions.

Results of research

Tilt of the buildings

The results of the investigation of the influence of the tilt of buildings on their performance

Table 2. The occupants' reaction to the tilt of the buildings

Tilt of the buildings T_b[‰]	Occupants' reaction								Σ
	IMPERCEPT. IL		PERCEPTIBLE PL		TROUBLESOME TL		EXCL. FUNC. EL		
	Number	%	Number	%	Number	%	Number	%	
0 - 5	5	100	-	-	-	-	-	-	5
5 - 8	3	75	1	25	-	-	-	-	4
8 - 10	5	63	3	37	-	-	-	-	8
10 -12	2	67	1	33	-	-	-	-	3
12 - 15	-	-	5	63	3	37	-	-	8
15 - 20	-	-	2	67	1	33	-	-	3
20 - 25	-	-	-	-	3	100	-	-	3
25 - 30	-	-	-	-	1	50	1	50	2
> 30	-	-	-	-	2	50	2	50	4
									40

are presented in Table 2. On the basis of the achieved results, the following tendencies are to be distinguished in the levels of the occupants' reaction to the tilt of the buildings:

- imperceptible level prevails to 12‰,
- the lowest tilt value for the perceptible level is in the range from 5‰ to 8‰ ,
- perceptible level prevails in the range from 12‰ to 20‰,
- rise of the troublesome level occurs in the range from 12‰ to 25‰ ,

and any further increase signifies the level excluding the building from its designed functioning.

Width of a single crack or failure [x)] in walls

The results of the investigation of the influence of single cracks in walls on the conditions of the building performance are compiled in Table 3.

[x)] a crack is understood to be a separation which does not occur through the entire thickness of the element, otherwise such separation is called a failure.

Table 3. The occupants' reaction to damage to the walls

Width of a single crack Δ a [mm]	Occupants' reaction								Σ
	IMPERCEPT. IL		PERCEPTIBLE PL		TROUBLESOME TL		EXCL. FUNC. EL		
	Number	%	Number	%	Number	%	Number	%	
up tol	1	100	-	-	-	-	-	-	1
up to 3	5	38	7	54	1	8	-	-	13
up to 5	1	17	5	83	-	-	-	-	6
5-10	1	8	5	42	5	42	1	8	12
10-20	-	-	-	-	5	83	1	17	6
20-30	-	-	-	-	4	100	-	-	4
>30	-	-	-	-	3	38	5	62	8
									50

The occupants' reaction to single cracks in walls may be generally characterized as:

- imperceptible level for the width up to 1 mm,
- perceptible level was recorded for the width of 1÷3 mm among about 50 % of the investigated population, decisively prevailing for the width in the range of 3 ÷5 mm,
- troublesome level was recorded for the values $\Delta a > 5$ mm, predominating at $\Delta a = 10 \div 30$ mm,
- the level excluding the building from its designed function is achieved above $\Delta a = 30$ mm (involving the necessity of the repair of damage).

Relative deflection of the structure

The user does not react directly to the value of the relative deflection of the structure but to its result manifested in the following instances:

- crack or failures in plaster, facing and load-bearing structure of walls,
- relative deflection of window openings and doorways, which causes damages and difficulty in their performance (opening and closing).

Therefore, the occupants' reactions to relative deflection of the structure may be referred to the corresponding values of the width of single cracks (failures) of the walls, as it is their range that makes the performance of doors and windows difficult. The results of the investigation into the influence of relative deflection values on the conditions of the performance of buildings are of a fragmentary nature, nevertheless, the following tendencies may be distinguished:

1) for $\gamma \leq 1{,}0 \cdot 10^{-3}$ the effects on the condition of the structure and finish elements are basically imperceptible,
2) in the range of $1{,}5 \cdot 10^{-3} \leq \gamma \leq 3{,}0 \cdot 10^{-3}$ the effects are estimated as perceptible or troublesome,
3) above $\gamma = 12 \cdot 10^{-3}$ the effects excluded further functioning of the building,
4) for $\Delta a > 10$ mm, which in the investigated cases corresponded to $\gamma = (1{,}5 \div 2{,}0) \cdot 10^{-3}$, difficulties in the performance of window and door woodwork appeared, whereas for $\Delta a \geq 40$ mm ($\gamma \geq 12 \cdot 10^{-3}$) failures in glazing were detected.

General degree of damage to buildings

At the same time, in the course of the investigation, the occupants' reaction to the state of deformations and damages was found to depend on more than the value of a single parameter only, it also involved the general degree of damage and technical condition of the building, its usual wear and tear inclusive. The assessment of the building performance is significantly influenced by other factors, such as:

- state of cracks and damages in floors, and, in particular, unevenness of floors,
- range of wall cracks
- correlation of the state of damage of walls with the condition of wall plaster, and, in particular, plaster coming off the ceiling,
- dampness of the building (although dampness may not be related to the impact of mining),
- general technical condition of the building, determined by its technical wear and tear and the existing mining damage.

The above factors are also accountable for a considerable scatter of the discussed results. At the same time, it should be indicated that the occupants' reaction to the state of damage to the building is determined by two factors:

(1) local factor, related to the value of a given deformation or damage parameter,
(2) global factor, expressing the index of a general degree of damage and even usual wear and tear of the building.

Principles of shaping the allowable deformations of buildings in mining areas

The values of the allowable deformations of building structures should be deduced from the relevant building serviceability criteria. The existing standards (ISO, 1984) are principles of a general character, making it only possible to identify single factors which should be considered in the design of serviceability standards in civil engineering (Kawulok, 1996). In practice, the allowable deformations of building structures are freely shaped, which is indicated by a variety of approaches adopted in the attempts to determine the allowable tilt of building structures in mining areas (Gubrynowicz, Kawulok 1986, Kratzsch 1974, Marino, Mahar 1985).

Although proposals for the unification of some serviceability criteria (Digest 1990) or for the creation of more general model procedures undertaken in shaping the performance concept of buildings (Becker 1993) have recently been made, the method presented below has been designed by the author basing on his own experience. The discussed method is fully consistent with the general serviceability criteria of building structures in mining areas formulated by Kawulok and Sulimowski (1994), and based on two assumptions which have a direct impact on the serviceability of structures:

- deformations of building structures may evoke unwieldiness for the users but in a degree generally accepted by the majority of users,
- the degree of unwieldiness is adjusted to the period of its occurrence.

Applying the distinguished levels of the occupants` reaction., the following ranges of the allowable deformation and damage values were accepted (Figure 1):

- IL -PL for permanent mining influence (for example: permanent tilt of the building), perceptible for the occupants but not troublesome,
- PL - TL for periodic mining influence (periodic tilt of the structure), temporarily troublesome for the occupants,

assuming, at the same time, that the values of deformations designated by the standard serviceability limit states are contained in the range of imperceptible influence (IL). The difference between the standard serviceability level and the proposed allowable deformations values should be treated as the social costs of mining excavation.

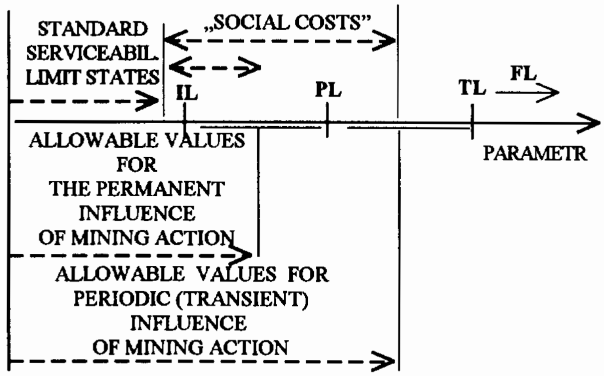

Figure 1. Principles of shaping of the allowable deformations

Proposals for the values of allowable deformations of buildings

The main results of the investigation for structure tilt [‰] and width of a single failure [mm] are compiled in Tables 4 and 5, together with the proposals for the selection of the range of the allowable deformation values for both periodic and permanent mining influence. These proposals have only been

Table 4 Tilt of buildings [‰] - proposals for the allowable values

Results of the investigation	Occupants' reaction	IL	PL	TL	EL
	Scope of variations	≤12	8-24	12-40	≥26
	Superior values	up to 12	12-20	20-25	-
Allowable values	Periodic influence	-	-	**20-25**	-
	Permanent influence	-	**15-20**	-	-

Table 5 Width of a single crack [mm] - proposals for the allowable values

Results of the investigation	Occupants' reaction	IL	PL	TL	EL
	Scope of variations	≤10	≤10	5-30	≥30
	Superior values	≤3	3-5	10-30	≥30
Allowable	Periodic	-	-	exterior walls: -basement **15** -above ground interior walls: **10-15**	-
values	Permanent influence	-	exterior walls: -basement **15** -above ground interior walls: **3-5**	-	-

Note : 1) Cracks of chimneys are inadmissible - even slight cracks have to be repaired at once
2) Mitigation of the performance concept of a building (flat) depends on a number of failures

made considering the unwieldeness for the users and assuming the „social costs" of living in mining areas.

It is more difficult to assess the allowable values of the relative deflection of the structure for the reasons already discussed. Nevertheless, on the basis of the rich literature devoted to the dependence on damage to structures and their relative deflections (e.g.:Skempton and Mac Donalds 1956, Burland and Wroth 1974) and the discussed results of the investigation, the following ranges of the allowable deformation values may be assumed for brick buildings:

$\gamma_{max} = (2 \div 3) \cdot 10^{-3}$,

for permanent mining influence, corresponding to insignificant, chiefly non-structural damages,

$\gamma_{max} = (3 \div 5) \cdot 10^{-3}$,

for periodic mining influence, corresponding to the possibility of major, mainly structural damages.

Nevertheless, it should be indicated that the above criteria are inferred from the analysis of the impact of curvature radius only.

Conclusion

The acceptance of the allowable deformation values of buildings in mining areas, although these values are not consistent with the standard requirements, has an important aspect of legal and financial responsibility. According to the presently binding Polish Geological and Mining Law, a mining contractor is obliged to liquidate the mining damage that has been made.

It should still be addressed how to account for the allowable deformations of buildings in practice, in view of the legal and formal regulations or actual procedures concerning the responsibility for the existing mining damage.

Thus, the allowable deformations should be understood as the limit values beyond which a mining contractor is obliged to liquidate the damage without delay or to make appropriate financial compensation for the use of the building under such circumstances. Therefore, if the allowable deformations are to be workable, a compromise must be reached between the occupants and owners of a structure and the relevant mining company.

The presented results and given proposals of the allowable values arise from the investigation of the users' reaction and they should be verified by other actors, which can have an influence on the allowable deformations. In this range first of all economical factors should be considered.

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