Loads from Compressive Strain Caused by Mining Activity Illustrated with the Example of Two Buildings in Silesia

Marta Kadela¹, Leszek Chomacki¹,
¹ Building Research Institute (ITB), ul. Filtrowa 1, 00-611 Warsaw, Poland

m.kadela@itb.pl

Abstract. The soil’s load on retention walls or underground elements of engineering structures consists of three basic types of pressure: active pressure ($p_a$), passive pressure ($p_b$) and at-rest pressure ($p_0$). In undisturbed areas without any mining, due to lack of activity in the soil, specific forces from the soil are stable and unchanging throughout the structure’s life. Mining activity performed at a certain depth activates the soil. Displacements take place in the surface layer of the rock mass, which begins to act on the structure embedded in it, significantly changing the original stress distribution. Deformation of the subgrade, mainly horizontal strains, becomes a source of significant additional actions in the contact zone between the structure and the soil, constituting an additional load for the structure. In order to monitor the mining influence in the form of compressive load on building walls, an observation line was set up in front of two buildings located in Silesia (in Mysłowice). In 2013, some mining activity took place directly under those buildings, with expected horizontal strains of $\varepsilon_x = -5.8$ mm/m. The measurement results discussed in this paper showed that, as predicted, the buildings were subjected only to horizontal compressive strains with the values parallel to the analysed wall being less than -4.0 ‰ for first building and -1.5‰ for second building, and values perpendicular to the analysed wall being less than -6.0‰ for first building and -4.0‰ for second building (the only exception was the measurement in line 8-13, where $\varepsilon_x = -17.04$‰ for first building and -4.57‰ for second building). The horizontal displacement indicate that the impact of mining activity was greater on first building. This is also confirmed by inspections of the damage.

1. Introduction
Underground exploitation of minerals in mines leads to displacements of the elements of rock mass, which result in surface land deformations. They most often take shape of continuous deformations that occur in form of ‘mining subsidence basins’ (figure 1) and are described using indicators, i.e. vertical displacement (subsidence) of $w$, horizontal displacement $u$, land tilt $T$, curvature $K$ or curvature radius $R = 1/K$, horizontal strains $\varepsilon$.

Due to the impact of horizontal soil strain ($\varepsilon_x < 0$), increased pressure on external building walls occurs in the part below ground level and horizontal compression loads cumulate in the structure of building walls [1-3]. This causes damages in basement walls shown in figure 2 that take form of horizontal shear (1) in walls located perpendicular to the land deformation direction and shear around window openings (2) observed in walls parallel to this direction. Furthermore, this impact often results in pushing the foundations towards the inside of the building (3).
This article presents two buildings in which the structure of exterior walls was damaged due to the negative impact of horizontal soil strains from mining that causes soil compaction. It also discusses the performance of compensation trenches as a prevention method used in construction and aimed at limiting the negative impact of horizontal soil strains ($\varepsilon_x < 0$) on the structure of walls of buildings located in the area where deformation impacts from mining become evident.

2. Technical description

The analysed residential buildings were erected in 1960s as traditional structures. They have one storey above the ground and basements under a part of the building plan. Each of the buildings has three sections (figure 3) and the overall dimensions of the structures in plan are approx. 10 x 33 m.

The buildings have longitudinal structural walls. The walls above the ground are 0.25 m thick (figure 4) and are made of brick and/or aerated concrete blocks, whereas the 0.38 m basement walls are made of brick. The foundation level is approx. 1.0 m below land surface and consists of foundation walls 0.38 m thick, made of brick.

At the level below the floor slab covering the basement there is a reinforced concrete tie beam following the line of all exterior walls and the longitudinal interior wall.
Initially, the sections were separated by expansion joints filled with expanded polystyrene. As a result of previous mining activities, the joint has been closed. Moreover, due to the impact of mining operations in form of horizontal soil strains on underground building walls, the structures have been damaged. Damages to structural components, which have mostly been observed at basement level, propagate on the ground level structure. There is a horizontal crack with displacement on the northern
gable wall of the western building (figure 5a). The crack appeared at the level below the reinforced concrete tie beam (figure 6), where the waterproofing layer is placed. In the middle of the wall’s length, a vertical crack has also appeared. Furthermore, the rising of entrance stairs to the building has been observed (figure 5b).

Figure 5. Examples of building damages: a) gable wall, b) entrance stairs leading to the building

In view of the existing significant damage to the residential buildings and the impact of the planned mining activities, a decision was taken to reduce the impact of mining on the buildings. Taking into account the solutions presented in [1-4], a trench of a diagram shown in figure 6 was proposed at gable walls of the buildings.

Distance of compensation trenches to the building $d_{\text{min}}$ and their depth $h$ was established in consideration of soil conditions, building structure and foundation depth $g$. When selecting their location, it was also recommended to take into account proper protection against wall slides and the position of underground utility connections, in order to avoid their destruction during the performance of works.

Figure 6. Scheme of trench realization: a) plan view, b) cross-section A-A

Due to the proximity of neighbouring buildings to the south of the structures, only the trenches on the north side could be performed. Compensation trenches 0.5 m wide and located approx. 2.2 m from the building were planned. The method of determining their dimensions and location is presented in [5]. Trenches were filled with highly compressible calumite in order to reduce compression strains $\varepsilon_c$. 
3. Mining situation
Mining operations have been going on in this area since the erection of the buildings discussed in this paper. Mining works performed directly under the buildings at strata 405/2 and 501 had the strongest impact on the structures. According to the predictions, the final coefficients of horizontal soil strains amounted to approx. \( \varepsilon_x = -7.9 \) mm/m.

In 2013, mining activity in longwall 521 at 510 (w3) strata took place directly under those buildings, with maximum expected horizontal strains of \( \varepsilon_x = -5.8 \) mm/m.

Due to the distance between the exploitation edge and the buildings (figure 7), they were located in a permanent concave mining area basin, which is characterised only by compressive horizontal strains.

In the closest neighbourhood of the analysed structures (figure 7), the exploitation of longwall 522 began in the end of November 2016. In the coming years the exploitation of the second layer (w2) is planned in strata 510.

![Figure 7. Mining activity performed in 2013 directly under the analysed buildings](image)

4. Measurement description
In order to observe the impact of mining operations at longwall 521 in strata 510 (w3) on vertical building walls embedded in the ground and the influence of the prevention measures adopted, an observation system using geodetic surveying was planned. For each building, the following elements were adopted:

- 13 benchmarks on the gable wall of the buildings (marked with Roman numerals in figure 8)
- 15 soil benchmarks located in front of each building; measurement points have been stabilised (marked with Arabic numerals in figure 8).

Furthermore, benchmarks were installed on each building section. The location of benchmarks is shown in figure 8. The location of benchmarks was selected considering the nature of the measurement, the technical conditions and possibilities of performing observations and the anticipated consequences of mining activities and the way they affect the buildings.

Horizontal displacements were measured along the established observation line (figure 8) using a steel tape. Firstly, measurements were taken in order to determine initial lengths. This measurement was taken when mining exploitation started, i.e. before mining activity’s impact on the analysed structures became evident. In the following days measurements of length were taken in cycles selected in accordance with the disclosure of the impacts of mining operations on the ground.
Figure 8. Measurement benchmarks in the analysed buildings

5. Results and discussions

Basing on measurements it was stated that the first impacts were revealed approximately 3 months after exploitation began. For the following 4 months their gradual growth was observed, and after that period the values started stabilising. No further changes were observed.

The maximum change of length on individual sections, compared to the initial state, is shown in Table 1. Basing on the measurements above, horizontal strains acting along the gable wall and perpendicular to the wall were determined using formula (1). The results are presented in Table 1. The calculations take into account the change of length caused by the change in height of individual measurement points due to land deformation.

$$\varepsilon = \frac{\Delta l}{l_0} = \frac{l-l_0}{l_0}$$ (1)
Table 1. Change in length of measurement sections

|       | \( \Delta l \) [mm] | \( \varepsilon_x \) [%] |
|-------|----------------------|------------------------|
|       | 18 | 20 | 18 | 20 |
| parallel to the wall |
| line 1 | 5-4 | -12 | -7 | -2.45 | -1.43 |
|        | 4-3 | -25 | -4 | -5.13 | -0.83 |
|        | 3-2 | -16 | 0  | -3.29 | -  |
|        | 2-1 | -11 | -2 | -2.24 | -0.41 |
| line 2 | 6-7 | 0  | 0  |  -  |  -  |
|        | 7-8 | -21 | -5 | -4.30 | -1.03 |
|        | 8-9 | -22 | -5 | -4.54 | -1.02 |
|        | 9-10| -14 | 1  | -2.86 | 0.20 |
| line 3 | 15-14| -13 | -5 | -2.66 | -1.02 |
|        | 14-13| -22 | -3 | -4.51 | -0.62 |
|        | 13-12| -19 | 2  | -3.91 | 0.41 |
|        | 12-11| -14 | 1  | -2.87 | 0.20 |
| perpendicular to the wall |
| line 1 | 5-6 | -22 | -1 | -0.80 |
|        | 6-15| -1  | -  | -1.02 |
|        | 5-15| -8  | 1  | -1.63 | 0.21 |
| line 2 | 4-7 | -5  | -1 | -2.01 | -0.40 |
|        | 7-14| -13 | -8 | -5.43 | -3.34 |
|        | 14-III| -29 | -7 | -8.95 | -2.35 |
| line 3 | 3-8 | 13  | -1 | 5.18  | -0.40 |
|        | 8-13| -41 | -11| -17.34| -4.59 |
|        | 13-II| -30 | -6 | -11.48| -2.29 |
| line 4 | 2-9 | -6  | -3 | -2.41 | -1.21 |
|        | 9-12| -14 | -4 | -5.82 | -1.67 |
|        | 12-I| -29 | -2 | -9.85 | -0.71 |
| line 5 | 1-10 | -14 | -2 | -5.65 | -0.82 |
|        | 10-11| -5  | 1  | -2.06 | 0.42 |

Due to mining activities carried out at longwall 521 the area around the analysed buildings subsided by a maximum of approx. 2.0 m from the north and 1.5 m from the south. The buildings tilted and the vertical tilt of the buildings’ northern walls in the direction perpendicular to the wall plane falls within the limits of 5.15÷29.10 mm/m in the north-east direction.

The values of horizontal compressive strains determined on the basis of the measurements show that the structure was only exposed to compressive strains, which coincides with the mining prediction. The following values of horizontal compressive strains were established:

- parallel to the analysed wall less than -4.0‰ for building No. 18 and -1.5‰ for building No. 20,
- perpendicular to the analysed wall less than the assumed -5.8‰ for building No. 18 and -4.6‰ for building No. 20 (the only exception was the measurement in line 8-13, where \( \varepsilon_x = -17.04\% \) for building No. 18 and -4.57‰ for building No 20).
The assumed horizontal compressive strains equal to $\varepsilon_x = -5.8 \text{ mm/m}$ were revealed in the direction parallel to the gable wall of building No 18, whereas in the perpendicular directions the values for this building have been significantly exceeded. However, it should be noted that the large values of strains for building No 18 in the immediate proximity of the measured wall (14-Lbud, 13-Śbud and 12-Pbud) are not reliable because of the new plaster put on the gable wall adjacent to the apartments in the extreme section, which affected the length of the measured sections.

The values of horizontal displacement (table 1) indicate that the impact of mining activity was greater on building No 18, which is further confirmed by the observation of damages. This fact is associated with the location of the analysed buildings in relation to the subsidence basin (figure 9).

![Figure 9. Soil subsidence around buildings in the east-west direction according to [6]; symbols according to figure 8](image)

Values obtained for individual lines are similar. Hence, the impact of compensation trenches on horizontal strains of the soil have not been observed.

Horizontal displacement results do not reveal the impact of the applied prevention methods in form of compensation trenches. This is further confirmed by the occurrence of new damages and the intensification of previously surveyed defects that had been observed during the performance of mining activities and after their completion. Damages were mostly observed on building walls, in particular in their lower parts. Examples of such defects are shown in figure 10.

![Figure 10. Examples of building damages: a) wall in basement of building, b) exterior wall in basement level](image)
6. Conclusions
This paper presents measurement results aimed at determining horizontal strains caused by the impact of mining activities carried out in 2013 and the efficiency of the compensation trenches used.

The measurements revealed high values of horizontal soil strains, but they did not exceed the predicted values. Large values of strains for building No. 18 in the immediate proximity of the measured wall (measurement points 12’, 13’ and 14’ in figure 8) provide an exception, but they are probably caused by the new plaster put on the gable wall adjacent to the apartments in the extreme section.

The measurements have not shown the efficiency of using compensation trenches as a method of protecting buildings exposed to horizontal strains in form of compression, which does not comply with the theory and is inconsistent with previous observations [1, 7-11]. This may be caused by the excessive amount of fine fraction in the filler material and the closure of voids, which impeded compensation of land deformations. This issue will be further investigated.

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