Occurrence consequences of mining terrain surface discontinuous linear deformations in a residential building

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Abstract. In the article a case study of consequences of underground mining exploitation of hard coal deposit on terrain surface and in a residential building has been presented. It was realized an exploitation of two hard coal seams (in three layers) in Poland, in the Upper Silesian Coal Basin, in 2013 – 2019. Operation was conducted at relatively small depth and by use of five longwalls with significant height and large decline. There were observed exploitation influences of fifth longwall on terrain surface and in the building by use of geodetic surveys. Measurements were carried out on the ground and wall points located in two perpendicular directions. Heights differences and distances between next points before and after the end of exploitation of last longwall have been measured. There the inclinations changes of particular sections have been determined. Analysis of surveys results shown that processes of the terrain and buildings deformations take place differently and terrain inclinations and building deviations have other values. Moreover, next to the building four discontinuous linear deformations of terrain surface (one in front of the building, one under the building, two behind the building) have been occurred. The ground steps location was detected by use of profile leveling of road located on the east of the building. A ground step with height of 15 cm under the building caused its crack. Example of the building with a partial basement proved that a consolidation type of building in the ground has a significant influence on values of its deviations.

1. Introduction

Underground mining exploitation of hard coal deposits can cause discontinuous deformations of terrain surface [1, 2] which have a linear [3-8] or superficial [9-13] character. They can also have various forms [4] e.g. ground steps, funnels, craters, etc.

There exist some geological, technical and mining conditions which are conducive to formation of discontinuous deformations, namely [8]:

- a migration of ground- and rainwater in subsurface layers of soil (a mechanical and chemical suffusion);
- a thin overlayer;
- a loose, direct roof rock;
- a high, caved-in area;
- a mining exploitation of metal ores on small depths;


– a chamber or chamber-pillared exploitation system;
– a reactivation of old goafs;
– the fires of coal seams remains;
– a concentration of exploitation edges in one zone;
– a mining exploitation on one site of fault.

In the article a case of discontinuous linear deformations forming on surface of mining terrain has been described. The ground steps due to mining exploitation of the coal seams have been occurred. Hard coal deposit is characterized by great thickness and inclination, and relatively small depth. These geological conditions and some mining conditions (mainly direction of longwalls and concentration of their edges in one area [8]) caused many discontinuous deformations of a linear type.

In the article effects of this exploitation in a residential building have been presented. Damages outside and inside the building have been occurred. Cracks, slits and scratches in a building elevation, the load-bearing and partition walls, the ceilings have been upraised. Results of an on-site visit in this paper have been shown.

2. Building characteristics
Damages in a detached, residential building with workshop part have been analyzed.

A single – family house has two storeys and cellar in a south – western part. Building horizontal projection has a rectangular shape and dimensions 18 m × 10 m. Height of a building above terrain level is 7.8 m.

Object has a wall – bearing structure. Walls on the ground floor have thickness from 0.38 m to 0.42 m and from bricks have been made. Walls on the floors have thickness from 0.24 m to 0.44 m. All ceilings are made of concrete with steel girders.

Building roof was made as a ceiling – roof without ventilation. Thermal insulation was made from a slag. Concrete screed was covered by the bitumen paper layers.

House was built in three stages.

Western part was built in 1956. It consists of a residential part (10.04 m × 9.98 m) and a vestibule (3.28 m × 2.35 m). A residential segment has a cellar in the southwestern part.

In 1980 was built an eastern part. It has dimensions 9.98 m × 5.60 m.

Last stage of an object expansion took place in 1981. A vestibule has been enlarged by additional space.

The building underwent numerous renovations.

It took place a change of roof construction above western part of building. A new roof was made from wood covered by bitumen paper.

A reinforced concrete band was made in 2016 on an object foundations level. It runs around the building and load – bearing walls.

Outdoor band has rectangular shape and dimensions 0.5 m × 1.0 m. It’s reinforced by 22 longitudinal rods with a diameter of 18 mm.

Band fragments inside the building (along the load – bearing walls) have shape of rectangle and dimensions 0.4 m × 0.2 m. They’re reinforced by 8 rods with a diameter of 18 mm.

Currently, the building has only residential functions. Building eastern part is excluded from the use due to a poor technical condition. In this part was a car workshop and a convenience store in the past.

Figures 1 and 2 show the horizontal projection and cross – section of the building.
3. Mining exploitation characteristics

Exploitation of the 404 and 405 hard coal seams took place in Poland (the Upper Silesian Coal Basin). It was carried out in 2013 ÷ 2019, in three seams layers: 3rd and 5th layers (the 404 seam), 1st layer (the 405 seam). A longwall system with a roof rocks cave – in has been used.

3.1. Exploitation of the 404 seam

Exploitation of the 404/3 seam was conducted by use of two longwalls: the 1/II longwall and the 2/II longwall. Height of operating excavations successively amounted 4.0 m and 3.4 m. Exploitation was carried out on the depth from 410 m (region eastern part) to 575 m (region western part). Inclination of 3rd layer of seam had a value of 17° in the north – western direction. Exploitation of the 1/II longwall took place from May to December 2013. The 2/II longwall was exploited from August 2016 to February 2017.
Exploitation of the 404/5 seam was also carried out by use of two longwalls (the 1/II longwall, the 2/II longwall). Height of these longwalls was amounted 3.3 m and 3.5 m. Exploitation depth was amounted from 470 m (the 1/II longwall) to 550 m (the 2/II longwall). Slope of the 404/5 hard coal seam had a value of 19° in the north – western direction. Extraction of hard coal from the 1/II longwall took place from November 2015 to June 2016 and from the 2/II longwall from October 2017 to April 2018.

3.2. Exploitation of the 405 seam
Exploitation in the 405 hard coal seam was conducted with seam division into the layers. From March to August 2019 exploitation was carried out in 1st layer by use of the 1/II longwall. Height of this longwall was amounted 2.0 m and its depth from 500 m to 610 m. Angle of declination had a value of 21° and a seam was inclined in the north – western direction.

Geometric and geological – mining parameters of exploitation in the 404 and 405 hard coal seams in the Table 1 have been shown.

| Parameter      | the 404/3 seam | the 404/5 seam | the 405/1 seam |
|----------------|----------------|----------------|----------------|
| Longwall number| 1/II           | 2/II           | 1/II           |
| Run [m]        | 460            | 245            | 500            |
| Length [m]     | 220            | 243            | 230            |
| Height [m]     | 4.0            | 3.4            | 3.3            |
| Declination [°]| 18.8           | 15.8           | 16.9           |
| Depth [m]      | 410÷500        | 500÷575        | 430÷510        |
| Time           | 05.2013÷12.2013| 08.2016÷02.2017| 11.2015÷10.2017|
|                | 03.2019         |                |                |

Figure 3. Longwalls in the 404 and 405 hard coal seams and the building on background of situational – altitude map
4. Exploitation effects

Effects of exploitation can be observed on terrain surface (the discontinuous and continuous deformations, e.g. inclinations) and in objects located on it (the buildings deviations and deflections from vertical [14 – 20]).

An influence of realized exploitation on a residential building and a terrain adjacent to it has been taken into account. Analyzed house is located 40 m from exploitation edges in a straight line.

4.1. Exploitation effects on terrain surface

Consequences of mining exploitation on surface of a terrain located nearby the building by use of appropriate geodetic surveys have been observed. Especially, changes of inclinations values have been observed.

For this purpose an observational network has been established. It consisted of six measuring points which in the ground have been stabilized. They were placed along two perpendicular directions located longitudinal to the southern and eastern walls of a building (three points in each direction). Distance between next points was amounted about 5.7 m. Points along a southern wall by use of wooden stilts and at a distance of 2.2 m from wall have been stabilized. In turn, points along an eastern wall were made from 30 cm long metal rods and at a distance of 1 m from the building have been stabilized. Location of the ground points at the Figure 4 has been presented. They by a brown colour have been marked.

Geodetic surveys between the ground points have been conducted. There distances and heights differences between subsequent points have been measured. Lengths were measured twice by use of a geodetic steel tape. Accuracy of distances measures was amounted ±1 cm. Heights differences on a way of geometric, technical levelling have been determined. Accuracy of altitude measures had a value of ±1 mm.

Heights differences and distances between next points before beginning (4th of March 2019) of exploitation of the 1/II longwall in the 405/1 hard coal seam and after its end (17th of August 2019) have been measured.

There changes of sections inclinations based on the inclinations observed before and after termination of longwall exploitation have been determined. Segments inclinations values as a quotient of heights differences and distances between the measuring points have been calculated. Terrain inclinations around the house and caused by exploitation of the 1/II longwall in the 405/1 coal seam at the Figure 4 have been shown.

Figure 4. Building deviations and terrain inclinations along the southern and eastern walls
From the Figure 4 results that a terrain along an eastern wall between the z01p and z02p points is inclined towards an operating longwall and has an inclination of 5.3 mm/m, while between the z02p and z03p points is inclined in opposite direction and has an inclination of 3.7 mm/m. In turn, a terrain along a southern wall is also inclined towards an exploitation and has an inclination of 3.0 mm/m (between the z34d and z35d ground points). There is no inclination between the z35d and z36d points.

Discontinuous linear deformations of terrain surface have been occurred. They were mainly caused by an exploitation of the 1/II and 2/II longwalls in the 404/3 and 404/5 hard coal seams [8].

In order to detection of discontinuous deformations and their location on a terrain surface, it a geometric leveling of road profile located near a building eastern wall has been done. Profile start 17 m from a southern wall of building has been placed. Profile end was located 30 m to the north from a southern wall of building. Pickets (27 pieces) were arranged every 2 m and in characteristic places of terrain surface folds. Height difference between the first and last measuring points was amounted more than 2 m. Road profile (B) and heights differences between the subsequent points at the Figure 5 have been shown.

Figure 5. Leveling of road profile and location of discontinuous, linear deformations
Road profile leveling for a detection of four, linear, discontinuous deformations around the house has been allowed. One of them was located under the building, in its central part, parallel to its northern wall. A ground step had a height of 15 cm with dropped wing directed towards the south. Two ground steps to the north from a building northern wall have been noted. They had the heights of 7 cm (dropped wing towards the south) and 25 cm (dropped wing towards the north). One linear deformation in front of the house has been occurred. Its height was amounted 10 cm and dropped wing was directed towards the south.

4.2. Exploitation effects in the building

In order to observation of building deviations, there the measuring points at a house elevation have been installed. They by use of a metal bolts, parallel to the ground points, in two perpendicular directions (in the southern and eastern walls) have been stabilized. Their arrangement at the Figure 4 (on orange colour) has been presented.

From results of geodetic surveys arise that an eastern wall is inclined towards an exploitation. Inclination between the s01 and s02 wall points is two times larger (5.3 mm/m) than an inclination of the s02 – s03 section (2.6 mm/m). It can result from a location of segments: the s01 – s02 section is closer to the longwall 1/II in the 405/1 hard coal seam than the s02 – s03 section. A western part of a building southern wall is inclined towards an exploitation and its inclination is considerable (22.7 mm/m between the s37 and s38 wall points). It’s caused by the fact that this part of the building hasn’t a basement. Therefore, a house is weakly connected to the ground and more undergoes deformations than a terrain surface.

From the Figure 5 results that between the z02p and z03p ground points and the s02 and s03 wall points a linear, discontinuous deformation has been occurred. A ground step had 15 cm of height and its dropped wing was located in the south. This is a reason why a terrain is inclined in the opposite direction than a building on the same section.

This ground step caused a crack of a building eastern wall. Elevation crack is very deep and has maximally 1 cm of width. Moreover, there the slits and the scratches symmetrically to a linear, discontinuous deformation have been formed. It at the Figure 6 has been presented.

![Figure 6. Crack, slits and scratches of a building eastern wall](image-url)
Significant damages of a building southern wall have been also occurred (Figure 7). The most important of them are: a crack of house in its central part (2 cm of width), a detachment of garage (workshop) from the main solid of building, the horizontal slits at a windows foundation level. Building crack in its middle is associated with a lack of basement in a south – western part of the building.

Underground mining exploitation caused also very serious damages inside the building.

On the ground floor a workshop (a garage) was seriously damaged. There can be observed: cracks of an eastern wall (especially near the windows – Figure 8a), slits on a wall separating the residential part, a ceiling deflection. Deflection of ceiling was so big that use of beams and pillars was necessary (Figure 8b). Moreover, a ceiling of a living room in a south – western part of the building (Figure 8c) and a living room in a northern part of the building (Figure 8e) had to be strengthened by steel girders. Many slits and scratches occurred in a bed room in a southern part of the building (room next to a crack of the building southern front wall – Figure 8d) and in a kitchen on ceiling and wall bordering with a living room in the building northern part (Figure 8f). Longitudinal slit in a kitchen ceiling is connected with occurrence of a ground step (h = 15 cm) which runs under the building, parallel to a northern back wall.

The most important damages occurred on the building first floor in a living room located above a workshop southern part and above a bed room on the ground floor. A crack of an eastern wall (Figure 9c), a partition wall (Figure 9a) and a ceiling (Figure 9b) have been observed. So significant crack runs exactly above a ground step located under the building. It should be emphasized that for safety reasons the beams and the pillars for supporting a ceiling have been used.
a) Masked cracks near the window on an eastern wall

b) Deflection of a workshop ceiling and its protections

c) Ceiling steel girders in a living room in a south – western part of the building (a part without basement)

d) Slit in a partition wall between a living room and a bed room in a southern part of the building

e) Ceiling steel girders in a living room and slit in a partition wall between a living room and a workshop in a northern part of the building

f) Slit in ceiling and in a partition wall between a kitchen and a living room in a northern part of the building

**Figure 8.** Building damages on the ground floor
5. Conclusions
Taking into account the foregoing considerations and analysis, there the following theorems can be formulated:

- underground mining exploitation of the hard coal seams has an influence on terrain surface and objects located on it;
- mining operation causes terrain inclinations and buildings deviations;
- exploitation conducted by use of the longwall system can cause discontinuous, linear deformations of terrain surface;
- occurrence of discontinuous, linear deformation changes direction of terrain surface inclination;
- a ground step running under the building can cause its crack and significant damages in it;
- a building crack being consequence of a discontinuous, linear deformation occurrence runs parallel to this deformation;
- consolidation type of the building in the ground has a significant impact on building deformation process;
- a building part without basement undergoes the greater deformations than a building part with basement;
- deformations processes of terrain surface and building are different;
- damages in the building caused by mining exploitation can be serious and hinder use of the object.

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