Terrain discontinuous deformations created near underground technical infrastructure

K Szafulera
Silesian University of Technology, Faculty of Mining and Geology, 2 Akademicka Street, 44-100 Gliwice, Poland
E-mail: katarzyna.szafulera@polsl.pl

Abstract. The paper presents the results of an analysis of geological, mining and other conditions on the formation of discontinuous surface deformations. The deformations occurred in an area with buildings, in adverse natural conditions and under the direct influence of current mining activity. The form and the size of the deformations clearly indicate that their genesis could have involved both mining and non-mining factors.

1. Introduction
Geological factors play a decisive role in the formation of linear discontinuous surface deformations, including particularly: the lithology, stratigraphy, tectonics, and the broadly understood mining factors.

Linear discontinuous deformations occur over rapidly advancing exploitation, exploitation with caving, especially in case of a single common edge, as well as due to interruptions in the exploitation of the useful mineral [1-15]. The deformations occur in the areas of pillars for the main development headings: shafts, cross-cuts and cross-headings, as well as the boundaries of the mining areas. Linear discontinuous deformations occur in high tensile strain zones caused by mining exploitation [1-5, 8-9, 13-15]. In the papers [6-7], it has been indicated that the deformations are at least 12 mm/m and are activated at tensile strain deformations reaching approximately 2 mm/m.

A high hazard of linear discontinuous deformations also occurs in areas of underground technical infrastructure. When damaged – often due to the direct impact of mining exploitation – such infrastructure might cause deformations on a much larger scale. This may be exemplified by a failure of the water line resulting in a leak, suffusion and the formation of a sinkhole or the washout of the loose overburden material.

Information regarding discontinuous deformations in the professional literature concerns mostly their forms and causes [1,6-7,9,16-17]. Discontinuous surface deformations are most of all characterized by the difficulty of prediction. New deformations are formed abruptly, causing irreversible changes in the surface layer of the rock-mass. Due to these reasons, it is highly important to identify the causes of their formation and to analyze the contributory factors, oftentimes despite the problems related to distinguishing them.

The paper presents a case study of formation of a discontinuous linear and surface deformation.

2. Characteristics of discontinuous deformations
Discontinuous deformations described in this paper have been formed at a plot located in the area of an active hard coal mine, in a tensile strain zone caused by current exploitation. The deformations occurred along an access road to a residential building – figure 1-2. The occurrence took place in July of 2013, during high precipitation, which – in view of the significant dimensions of the deformation – highly contributed to the washout of the surface layer of the rock mass. The deformations were manifested in the forms of fissures and a graben cutting the surface in the SE-NW direction. The width...
of the deformations reached from approx. 10 cm to approx. 70 cm and their depth was from approx. 10 cm to approx. 60 cm. According to the information presented in the article [#], the structure located at the plot in concern was tilted due to the proceeding mining exploitation and was intended for rectification in 2005.

Figure 1. Discontinuous deformations observed in June of 2013 [18].

Figure 2. View of the discontinuous deformation and the information regarding its dimensions – June of 2013 [18].
3. Geological and mining conditions

3.1. Geological structure
The geological structure was established based on the lithological profile of the shaft located several dozen meters to the south of the location where the deformation was identified. The structure of the rock mass includes the overburden and Carboniferous formations. The overburden is comprised of Quaternary formations with a thickness of approx. 3 m. Lithologically, mostly loams have been observed. Younger formations are separated from the older formations with a layer of firm clay. The Carboniferous formations are comprised of Orzesze beds (from the seam 357) with a thickness of approx. 145 m. These include mostly clay slate layers characterized by low permeability and a lower percentage of sandstones. The Ruda beds occur from the roof of the 401 seam and reach the thickness of approx. 600-700 m. They are mostly represented by claystones, mudstones, coal seams and carbonaceous shale. The saddle beds occurring from the roof of the 502 seam constitute a rock complex comprised mostly of sandstones, claystones, carbonaceous shales and coal seams. The thickness of these beds is approx. 100 m.

3.2. Tectonics
The plot at which the discontinuous surface deformations occurred is located in a tectonic disturbance area in the form of a horst. The deformations are in the form of meridional faults crossing the exploited coal seams. Fault I is located NW of the analyzed deformations, throwing the beds by 30 m towards the west. Two faults at the SE side. Fault II separates two tectonic blocks in the deposit, throwing the beds towards the east by approx. 25 m and 10 m. The fault III throws the rock mass to the east by approx. 10 m. The rock mass beds subside towards the south-west at an angle of 5°. Directly below the identified deformations, no faults or other tectonic disturbances occur – figure 3.

![Figure 3](image)

**Figure 3.** Map of the roof of the Carboniferous with the location of the main tectonic faults and the identified discontinuous deformations.

3.3. The former mining exploitation
The region in which the discontinuous deformations have been identified was a subject of an intensive mining exploitation. The exploitation was conducted since the 1920s in the Ruda and Saddle beds. Directly before the deformations occurred, the exploitation proceeded in the seam No. 416, using longwall 5.

The performed mining exploitation has been presented as a map of exploitation boundaries and thicknesses of the mined deposit - figure 4 for the conducted mining exploitation in its entirety. Table 3.1, and figure 5 present the detailed drawings and data regarding the mining exploitation during the 10 years preceding the occurrence of the discontinuous deformations.
Figure 4. Map of the thicknesses (0-24 m) of a selected deposit along with the boundaries of the performed mining exploitation in the region of the observed discontinuous deformations.

Table 1. Geological and mining data regarding the exploitation conducted in the years 2003-2013 in the area of the observed discontinuous deformations.

| Seam  | Longwall | Expl. commencement | Expl. completion | Thickness (m) | Depth (m) | Distance (km) | Relative direction of deformations |
|-------|----------|--------------------|------------------|---------------|-----------|---------------|----------------------------------|
| 416   | 1        | 01-03-2010         | 31-03-2013       | 2             | 595       | 0             | direct 0.8                      |
| 416   | 5        | 01-06-2013         | 01-02-2014       | 2             | 675       | 0.24          | W 0.8                           |
| 416   | Hsc.1    | 15-03-2005         | 03-09-2005       | 1.8           | 552       | 0.59          | E 0.8                           |
| 504   | Hsc.4    | 21-12-2002         | 03-09-2004       | 1.9           | 818       | 0.16          | SW 0.6                          |
| 504   | P-418a   | 01-01-2003         | 20-10-2003       | 1.9           | 725       | 0.28          | E 0.6                           |
| 415/1 | Hsc.5    | 01-07-2003         | 03-06-2005       | 2.8           | 635       | 0.13          | W 0.6                           |
| 415/1 | Hsc.6    | 01-01-2005         | 31-12-2006       | 3.4           | 609       | 0             | direct 0.6                      |
| 415/1 | Hsc.8    | 01-10-2007         | 30-06-2009       | 3.2           | 561       | 0.13          | E 0.6                           |
| 415/1 | Hsc.7    | 15-09-2009         | 01-10-2010       | 3.5           | 551       | 0.3           | N 0.6                           |
| 415/1 | Hsc.4    | 15-08-2002         | 31-12-2003       | 3.2           | 659       | 0.42          | SW 0.6                          |
| 502wg | P-222    | 04-01-2006         | 11-01-2006       | 2.7           | 715       | 0.3           | E 0.6                           |
| 502wg | P-223    | 09-01-2008         | 07-01-2009       | 2.7           | 695       | 0.32          | N 0.6                           |
| 510wd | P-04/I   | 01-01-2004         | 04-01-2005       | 2.1           | 790       | 0.04          | NE 0.8                          |
| 510wd | P-05/I   | 01-01-2004         | 04-01-2005       | 2.1           | 790       | 0.06          | N 0.8                           |
| 510wg | P-04     | 04-01-2001         | 15-01-2003       | 2.6           | 790       | 0.03          | NE 0.6                          |
Figure 5. Drawing illustrating the mining exploitation conducted in the years 2003-2013 in the area of the observed discontinuous deformations.

As indicated by table 1 and figs. 4-5, the region in concern was under the influence of intensive mining exploitation. Below the discontinuities, numerous exploitation fields were mined in the Ruda and saddle beds. Directly before the deformations occurred, the exploitation proceeded in the seam No. 4, using longwall 5 – table 1. The total thickness of the mined deposit reached a value from approx. 18 m to approx. 20 m directly below the deformation.

4. Impact of the mining exploitation on the analysed region

In order to identify the causes of the observed discontinuous deformations, the relation between the state of rock mass deformations and their location and time of occurrence was investigated. To achieve that, a prognosis of the impact of the exploitation was performed once again while considering various solutions of summing the deformations in long periods of time [19,20-21-23].

The calculations of the values of rock mass deformations were performed using the Budryk-Knothe theory [21] while assuming the immediate manifestation of the influences using the DEFK-Win software [24]. The following parameter values were used in the calculations:

- Roof control coefficient \( a = 0.8 \);
- tangent of the main impact range angle \( \tan(\beta) = 2.0 \);
- proportionality coefficient of horizontal displacements to the \( B \) inclinations. A value of \( B=0.32r \) was assumed in line with B. Popiołek and J. Ostrowski’s proposal (where \( r \) – radius of the main impact range).

The calculations were made by means of a computer simulation of longwall advancement for point...
No. 1, reflecting the analysed discontinuous deformations. The calculations were made with the assumptions of immediate manifestation of the impact \((c \rightarrow \infty)\) [24]. The performed exploitation was taken into consideration – table 2 and figures. 3-5. The calculations of the maximal horizontal deformations were made for the entire range of the performed exploitation, with and without consideration to the so-called “relaxation” phenomenon and while assuming the immediate manifestation of the impact. In the above, the following formula was used [19]:

\[
\varepsilon(t) = \int_0^t \frac{d\varepsilon(\tau)}{d\tau} A_{rel} + \left(1 - A_{rel}\right)e^{-(t-\tau)/T_{rel}} \right) d\tau
\]

where:
- \(\tau\) – time variable,
- \(\varepsilon(t)\) – equivalent deformations, mm/m,
- \(t\) – time,
- \(A_{rel}\) – relaxation coefficient: \(A_{rel} = 0.4\) in line with [19], \(A_{rel} = 0.45\) in line with [20],
- \(T_{rel}\) – relaxation time [years]: \(T_{rel}=2.0\) in line with [19], \(T_{rel}=0.90\) in line with [20].

In the calculations, the values of the coefficients provided in [19-20] were used. The maximal subsidence, maximal inclinations and maximal horizontal deformations have been presented in table 2. Figure 6. presents the distribution of the maximal horizontal deformations calculated in line with [19-21] for the entire range of exploitation. Only the range of years 2003-2013 has been exhibited.

**Table 2.** Values of the maximal subsidence, inclinations and horizontal deformations for the entire range of exploitation, considering the so-called „relaxation“ \((\varepsilon_{max rb}\) in line with [19], \(\varepsilon_{max rk}\) [20]) and without considering it \((\varepsilon_{max})\), while assuming the immediate manifestation of the impact [24].

| Without considering relaxation | \(W_{max}\) (mm) | \(T_{max}\) (mm/m) | \(\varepsilon_{max}\) (mm/m) |
|-------------------------------|------------------|------------------|------------------|
| In line with formula (1), \(A_{rel}=0.4, T_{rel}=2.0\) | -19750.1 | 44.23 | -16.71 |
| In line with formula (1), \(A_{rel}=0.45, T_{rel}=0.9\) | -14.54 |  |  |

While analysing the results presented in table 2 and in figure 6, one should note that the value of the maximal horizontal deformation for the location of the observed discontinuous deformations, calculated based on various opinions regarding the method for summing the deformations in long periods of time, is very high and reaches approx -22 mm/m. At such values, linear discontinuous deformations could have occurred even earlier and the effects of the current exploitation could cause their activation. Such a scenario is possible according to papers [6-7]. The remaining calculation results, presented in the table, confirm the high impact of the mining exploitation on the analysed region: the maximal subsidence is approx. -19750 mm, and the maximal terrain inclination is approx. 44 mm/m.
Figure 6. A graph of the maximal horizontal deformations for the entire range of exploitation, considering the so-called „relaxation” (εxmaxrb in line with [19], εxmaxrk [20]) and without considering it (εxmax), while assuming the immediate manifestation of the impact, years 2003-2013.

In summary, it should be stated that although the manifestation of discontinuous deformations may be explained based on the results of the calculations, their form and scale is harder to explain. The mining-induced formation of grabens at the surface is related to the existence of voids in the rock mass [16-17], which is extremely rare with the exception of the areas of fault outcrops and shallow working. In other cases, the action of non-mining factors causing the deformation process should be identified, such as e.g. a defective underground technical infrastructure.

5. Underground technical infrastructure
The form and the dimensions of the discontinuous deformations presented in figures, 1-2, suggest that the process of their formation could have been influenced by non-mining factors. The land survey and height map indicate that underground technical infrastructure is located along the location of the discontinuous deformation. A distribution water line with a diameter of 32 mm, made of PVC or polyethylene along with connections, supplies water to households in a building located in the vicinity of the deformation and is fed from a water grid pipe with a diameter of 90 mm, running along the main road. The water grid pipe is located so that a distance of 1.5 m is maintained from the surface to the top of the water line. The location of the discontinuous deformation in relation to the water grid has been presented in figure 7.

Based on the analysis of the discontinuous deformations manifested as fissures and a graben with large dimensions, one may assume that the underground technical infrastructure was subject to a failure. As an effect, suffusion occurred, causing the discontinuous deformation at such a scale.
6. Summary and conclusions
The subject of the study was a selected case of discontinuous deformations induced by underground mining exploitation conducted by a selected mine in the area of USCB.

The analyses of geological and mining conditions and the repeated prognoses of rock mass deformations caused by mining exploitation allowed to identify the factors that were decisive in the formation of the discontinuous deformations observed at the surface.

The discontinuous deformations occurred in the area of firm Carboniferous formations covered by a thin overburden and in the vicinity of Carboniferous faults' outcrops constituting a horst.

The discontinuities occurred in an area subject to multiple horizontal compressive and tensile deformations caused by mining activity, in unfavourable mining and geological conditions and in a region of high seismic activity, characterised by the presence of a defective underground technical infrastructure.

The presented example of the occurrence of the surface discontinuous deformations, the genesis thereof and the analysis of the mining and geological conditions constitute a significant practical study concerning linear discontinuous deformations. Due to the highly random character of these phenomena, it is very important to identify the causes of their formation and to analyse the contributory factors despite the problems related to distinguishing them.

7. References
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