GOSPODARKA SUROWCAMI MINERALNYMI – MINERAL RESOURCES MANAGEMENT

2025 Volume 41 Issue 1 Pages 163–179

DOI: 10.24425/gsm.2025.1531680

PIOTR STRZAŁKOWSKI[1]

Resource management in conditions of occurrence of linear discontinuous deformations

Introduction

Underground extraction of deposits causes adverse effects on the surface and structures (Kowalski 2015, 2020; Kratzsch 1983; Knothe 1984; Whittaker and Redish 1989). These effects manifest in continuous and discontinuous deformations, rock mass shocks, and changes in water conditions. Continuous deformations, observed as subsidence troughs, pose a certain threat to buildings; however, there are various safeguards that effectively mitigate their damage (Szojda 2019; Szojda and Wandzik 2019). Discontinuous deformations (Kowalski 2020) are categorized into surface-type deformations (mainly sinkholes) and linear-type deformations (commonly seen as ground steps). Discontinuous deformations of both types pose a much more significant threat to buildings and infrastructure facilities (Strzałkowski 2015, 2017; Grygierek and Kalisz 2018; Deng et al. 2019; Jia et al. 2020; Orwat 2020; Orwat and Gromysz 2020; Cempiel et al. 2023) due to the lack of fully

---

✉ Corresponding Author: Piotr Strzałkowski; e-mail: piotr.strzalkowski@polsl.pl

[1] Silesian University of Technology, Faculty of Mining, Safety Engineering and Industrial Automation, Gliwice, Poland; ORCID iD: 0000-0003-3942-3935; e-mail: piotr.strzalkowski@polsl.pl

effective methods to protect structures against deformations of this type. Discontinuous linear deformations also cause an increase in the value of continuous deformations (Orwat 2023). In the case of sinkhole-type deformations, an effective method to eliminate the threat is to fill the voids in the rock mass with binding materials (Stryczek and Gonet 2000), eliminating the need to reinforce building structures. Monitoring the deformation state becomes crucial in this situation, as presented in the work (John 2021). Predicting surface-type discontinuous deformations is not always possible due to a significant random component, although several methods have been developed for their prediction (Chudek et al. 1988; Strzałkowski 2015), which may not fulfill their role in the case of the suffosion occurrence. However, there is a lack of methods for predicting linear discontinuous deformations, which occur relatively frequently in various places worldwide. Considering the above statements, it should be acknowledged that the issues related to these deformations are current and important. Therefore, it is worth considering the causes of linear discontinuous deformations and the possibilities of predicting their creation, at least to a limited extent. Literature studies indicate conditions that favor the occurrence of linear deformations as:

- Tectonic faults (Kratzsch 1983; Li et al. 2004; Ścigała 2013; Woo et al. 2013; Strzałkowski and Szafulera 2020),
- The structure of the rock mass, including the occurrence of loess (Peng et al. 2016; Lian et al. 2020),
- Horizontal tensile strain (Malinowska and Hejmanowski 2016; Strzałkowski and Ścigała 2017; Zhu et al. 2018; Deng et al. 2019; Ścigała and Szafulera 2020).

It should also be noted that the closure of mines through flooding may generate the formation of discontinuous linear deformations. The causes and effects of activating such deformations due to mine flooding, as observed in German conditions, have been analyzed in the study by Tajduś et al. (2023).

Therefore, the occurrence of these deformations is influenced by various factors, significantly complicating the possibility of their prediction. Two geological condition patterns can be distinguished in which these deformations occur: tectonically disturbed and undisturbed rock mass, as confirmed in the study (Wang et al. 2019). Regarding the impact of horizontal strain on the formation of such deformations, it should be related, in the author's opinion, to specific geological and mining conditions, including the interaction with a rock mass intersected by faults and undisturbed, as well as the type and thickness of loose overlying rocks. These conditions can be incorporated into numerical calculations (Malinowska et al. 2018). Convincing evidence for this is provided by the presented strain values at which the deformations occurred. In the Polish Lublin Coal Basin case, this value was 2.5 mm/m (Malinowska and Hejmanowski 2016), considering the thick layers of low-strength marls in the lithological profile. The study's authors (Zhu et al. 2018) reported a correlation between strain value and the height of ground steps. The range of strain values at which the steps occurred was observed between approximately 3.2 and 6 mm/m. Conversely, findings from studies (Strzałkowski and Ścigała 2017; Strzałkowski and Szafulera 2020) suggest that under the conditions of the Polish Upper Silesian Coal Basin, the values of horizontal strain at which ground steps occurred were notably higher. In the first study, they reached up to 10 mm/m in case of faults with small throws, while in the second study, they ranged between 6 and 9 mm/m for faults with throws measuring several meters.

This paper analyzes the causes of linear deformations using the Polish Upper Silesian Basin area as an example and proposes a method for determining the zones where they may occur.

The problem is important because despite ongoing decarbonization efforts (Gawlik and Mokrzycki 2019), intensive extraction of coking coal, which is listed as a critical raw material (Strzałkowski and Maruszczyk 2024), will continue.

1. Analysis of geological and mining conditions

1.1. Lithology and stratigraphy

The analyzed area is located in Poland, in the Upper Silesian Coal Basin. The location of the Basin is shown in Figure 1.

Fig. 1. The location of the Upper Silesian Coal Basin. Silesian Coal Basin – S, Lublin Coal Basin – L

Rys. 1. Lokalizacja Górnośląskiego Zagłębia Węglowego.
Górnośląskie Zagłębie Węglowe – S, Lubelskie Zagłębie Węglowe – L

The rock mass in the analyzed area consists of overburdened layers and productive Carboniferous rocks. The overburden layers include Quaternary and Tertiary formations. The Quaternary layers consist of clays, gravels, and sands with a total thickness of 45 m in borehole K3 – see Figure 2. Beneath the Quaternary layers is the Tertiary formation

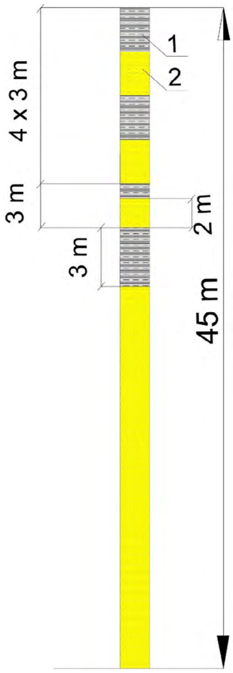

Fig. 2. Lithological profile of the Quaternary layers
1 – clay, 2 – sand

Rys. 2. Profil litologiczny czwartorzędu

composed of sands and clays. It is important to emphasize that loose rocks underlie the entire overlying sequence with a total thickness of 264 m.

The Carboniferous strata below the overburden layers represent the "Orzeskie" layers, composed of alternating layers of clayey shales and sandstones, including coal seams from the "300" group. Below them, there are the "Rudzkie" layers (built similarly to the "Orzeskie" layers) with coal seams from the "400" group. The considered area's surface elevation is approximately 270 m above sea level.

1.2. Tectonics

In the vicinity of the property, the Fault "P I" runs approximately north-south. It throws the layers vertically by a height of 60–80 m towards the west. The outcrop of this fault on the Carboniferous roof occurs about 280 m east of the area under consideration. Additionally, there are faults with minor throw heights (1.5–3 m) and varying orientations.

1.3. Observed linear discontinuous deformations

A series of linear discontinuous deformations were observed in the study area as ground steps with heights up to about 20 cm. These deformations traversed the terrain of the southern plot marked in Figure 3. The course of the deformations is marked with red lines. Two of these deformations reached the north wall of the building and likely affected the building itself, causing cracks in its load-bearing walls. Photographs documenting the course of deformations and damage to the walls are also shown in Figure 3, with arrows indicating which deformations they refer to. While discontinuous linear deformations are not uncommon nowadays, micro-sinkholes with oval shapes and diameters of up to about 0.5 m and depths of up to several tens of centimeters were observed along their course.

Fig. 3. View of discontinuous linear deformations formed in years 2015–2021

Rys. 3. Widok deformacji nieciągłych liniowych powstałych w latach 2015–2021

1.4. Mining extraction carried out

In the region where the deformations occurred, intensive mining operations have been conducted since the 1980s until the present. The extracted seams were situated at depths ranging from approximately 440 m to about 960 m. The mining was carried out using a longwall system with roof caving. Basic information about the geological and mining conditions of the ongoing extraction is provided in Table 1.

The location of the extracted panels in relation to the deformations is shown in Figure 4.

Table 1. Basic information of geological-mining conditions

Tabela 1. Podstawowe informacje o warunkach geologiczno-górniczych

Coal seam	Panel	The begin	The end	H, m	g, m
340/2	W-1	01.12.1986	01.11.1987	440	1.25
340/2	W-2	01.12.1987	30.08.1988	460	1.40
340/2	W-3	15.06.1990	11.12.1991	450	1.25
345/1	W-1	01.12.1984	30.03.1985	560	1.80
345/1	W-2	01.07.1985	30.03.1986	580	1.80
346/1	W-12	20.06.1987	11.03.1988	600	1.50
346/1	W-13	01.09.1986	30.03.1987	590	1.50
346/1	W-2	01.07.1981	30.04.1982	580	1.50
346/1	W-3	01.01.1982	17.12.1982	600	1.50
347/1	W-1	01.02.1988	31.12.1988	635	1.20
347/1	W-2	01.10.1989	30.06.1990	630	1.25
347/1	W-3	01.10.1991	30.06.1992	640	1.20
355/1	W-1	01.07.1990	31.12.1990	815	1.90
355/1	W-2	01.07.1991	11.12.1991	800	1.90
357/1	W-10	01.02.2007	01.10.2007	790	1.90
357/1	W-2	01.08.1995	21.02.1996	815	2.00
357/1	W-4	01.02.1993	11.12.1993	830	2.20
357/1	W-5	01.01.2002	11.09.2002	800	1.85
357/1	W-6	01.07.2003	30.04.2004	820	1.90
357/1	W-9	01.08.2006	21.12.2006	825	2.10
360/1	W-1	01.12.1998	30.06.1999	870	1.65
360/1	W-2	01.12.1997	30.11.1998	890	1.70
360/1	W-3	01.10.2004	01.09.2005	870	1.90
360/1	W-4	01.07.2006	30.06.2007	890	2.00
360/1	W-7	01.12.2010	30.04.2011	870	2.00
361	W-1	01.04.2002	17.01.2003	910	1.85
361	W-2	01.07.2003	11.12.2003	900	2.00
361	W-3	01.06.2009	30.04.2012	885	2.50
361	W-4	01.12.2012	01.07.2015	915	2.50
361	W-5	15.09.2015	30.01.2017	945	2.50
361	W-6	01.10.2017	30.05.2018	970	2.50
362/1	W-1a	15.07.2017	30.03.2019	900	2.40
362/1	W-2	01.07.2019	30.09.2022	930	2.50
362/1	W-3	01.02.2022	30.09.2022	965	2.50

H – depth of extraction, g – thickness of coal seam.

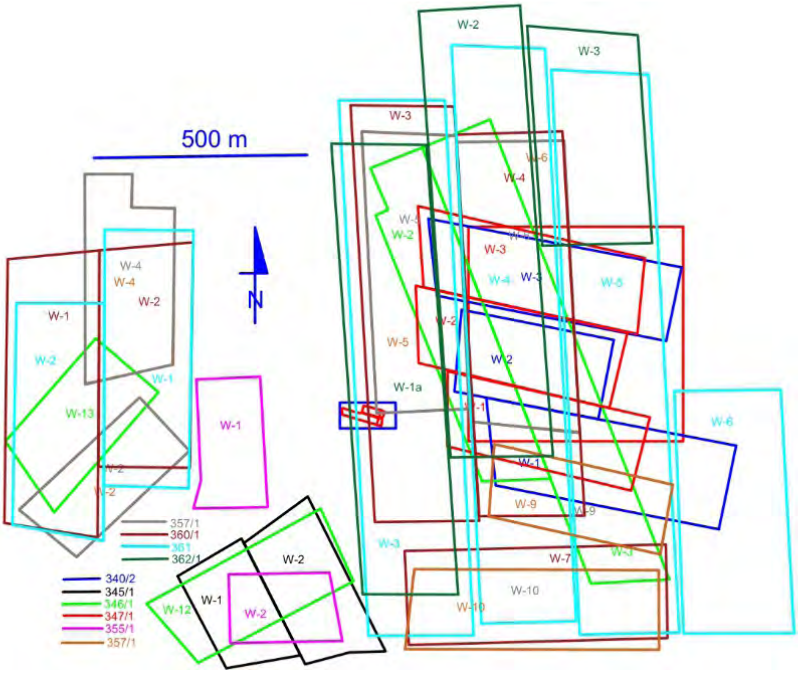

Fig. 4. Location of the extracted panels in relation to the deformations zone

Rys. 4. Lokalizacja wyeksploatowanych ścian w stosunku do strefy deformacji

2. The method of analysis used

The Budryk-Kothe theory (Kratzsch 1983; Knothe 1984) was used to calculate the values of the deformation indices caused by the mining operation. The calculations were done using the DEFK-Win computer software developed by R. Ścigala (2013).

According to Knothe model, subsidence of any point located on the surface, with coordinates $A(s,q)$, can be expressed by the formula (Knothe 1984):

$$w(s,q) = \frac{w_{\max}}{r^2} \int_{a1-s}^{b-s} e^{\frac{-\pi\eta 2}{r^2}} d\xi \int_{c-q}^{d-q} e^{\frac{-\pi\eta 2}{r^2}} d\eta \qquad (1)$$

↳ $w_{\max} = -ag$,

a – coefficient of roof control,

g – thickness of the extracted coal seam,

r – the radius of main influence range. This parameter is used interchangeably with the parameter tan β, where β is the angle of main influence range.

Both of these parameters are correlated.

$$\tan\beta = \frac{H}{r} \tag{2}$$

Formulas for individual deformation indices are obtained through the appropriate differentiation of formula (1).

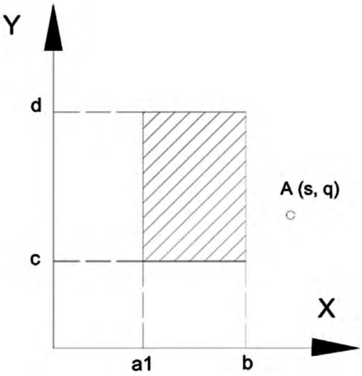

Fig. 5. Diagram for the formula (1)

Rys. 5. Schemat do wzoru (1)

3. Calculation results and their analysis

Using DEFK-Win software, calculations were performed for the values of the following deformation indices: subsidence – w, maximum tilt – $T_{\max}$, and maximum horizontal strain – $E_{\max}$. The calculations were carried out in a grid of points covering the area in the deformation region. The following parameter values of the Budryk-Knothe model were taken for the calculations:

- Coefficient of roof control $a = 0.8$,
- Tangent of the angle of main influence range $\tan\beta = 2$,
- Coefficient of proportionality of horizontal displacements to tilt $B = 0.32\ r$,

The results of calculations in the form of contour lines of the values of the above deformation indices are shown in Figures 6–8.

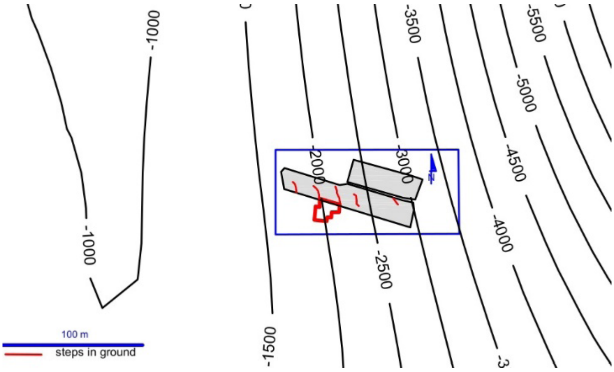

Fig. 6. Contour lines of calculated surface subsidence, mm

Rys. 6. Izolinie obliczonych obniżeń powierzchni, mm

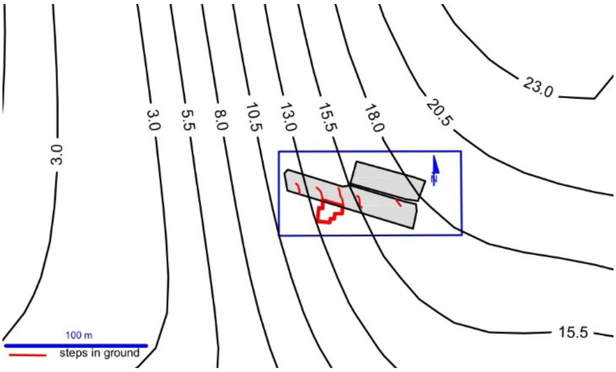

Fig. 7. Contour lines of calculated maximum tilt, mm/m

Rys. 7. Izolinie obliczonych nachyleń maksymalnych, mm/m

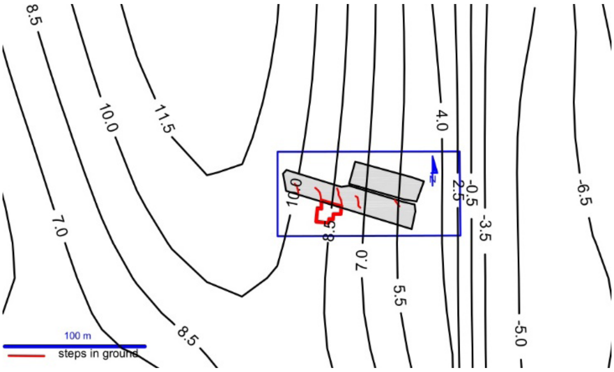

Fig. 8. Contour lines of calculated maximum horizontal strain, mm/m

Rys. 8. Izolinie obliczonych odkształceń poziomych maksymalnych, mm/m

Based on Figure 6, we can conclude that the zone where discontinuous deformation occurred was subjected to subsidence of varying values. In the western part, the subsidence was about 1.5 m, while in the eastern part, they exceeded the value of 3.5 m. Within the discontinuous deformation zone, subsidence ranged from about 1.8 m to about 3 m.

The values of maximum tilt ranged from about 10.5 mm/m to about 20 mm/m (see Figure 7). Within the deformation zone, the maximum tilts took on values ranging from about 12 mm/m to about 17 mm/m. The tilt contour lines ran in an NW-SE direction, aligning with the direction of the ground steps. It is also worth noting that in the region where discontinuous deformations occurred, there were vertically overlapping edges of mining fields conducted in seams: 357/1, 360/1, 361, 362/1. The positions of these edges resulted in increased values of maximum terrain tilt.

In the considered zone of discontinuous deformation, the maximum horizontal strain had positive values (extension) and ranged from about 5 mm/m to about 10 mm/m (see Figure 8). The direction of the contour lines did not align with the direction of the discontinuous deformations.

The presented material shows that it is possible to indicate the areas at risk of discontinuous linear deformations roughly. In the analyzed case, it can be assumed that they occurred in zones where horizontal strain exceeded approximately 5 mm/m. The results of the analyses presented in the work (Zhu et al. 2018) prove that it is possible to find a relationship between the height of the ground step and the values of horizontal strain. However, selecting reliable data for statistical analysis is difficult. Firstly, tectonically disturbed and undisturbed rock mass cases should be distinguished and considered separately. Areas of fault outcrops on the

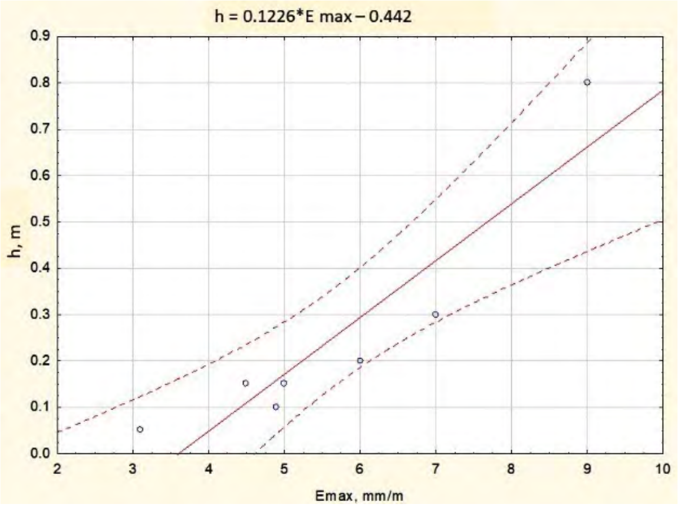

Fig. 9. The relationship between the high of step in ground and the values of horizontal tensile strain

Rys. 9. Zależność pomiędzy wysokością stopnia terenowego i wartością odkształceń poziomych maksymalnych rozciągających roof Carboniferous layers can be considered at particular risk. Therefore, it is advisable to limit the analysis to cases of tectonically undisturbed rock mass. Secondly, the moment of deformation occurrence and the temporary value of strain at the considered place and time should be precisely determined when conducting statistical analyses. For the purposes of this study, several reliable cases of the ground steps occurrence in tectonically undisturbed rock mass, with known values of horizontal strain, were selected. The relationship between the height of the steps and the strain values was approximated by a linear function using the Statistica program. Figure 9 shows the data for calculations and the linear function approximating them with the confidence intervals of 0.95. As can be seen, deformations occurred already at strain values over 3 mm/m. Concerning the presented case study, it can be concluded that the height of the ground step, or even its occurrence, is also influenced by other statistically significant factors apart from the horizontal strain values. One can consider, for example, the mechanical properties of the rock mass, the thickness of the extracted seam, the thickness of the overburden of loose rocks, and the speed of the advancing extraction front. Numerous cases demonstrate that these deformations do not occur at horizontal strain values of about 6 mm/m and greater. This issue requires further detailed research and analysis. However, initially, studies should be limited to the conditions of the specific area.

4. Proposal for utilizing the analysis results

From the presented analyses, it can be concluded that the primary cause of the occurring deformations is the increased values of horizontal tensile strain, which corresponds to the study's findings (Strzałkowski and Ścigała 2017). This observation can be utilized to identify areas at risk of such deformations. Of course, in the case of mining in multiple seams up to a common boundary, the situation is straightforward, and areas at risk can be determined in advance. The situation is different when dealing with a less regular distribution of extracted mining fields. Such a scenario is presented for the mining operation, the data of which is provided in Table 2.

The location of the extracted and planned extraction mining fields is shown in Figure 10. The figure also depicts contour lines for maximum tilt and maximum horizontal strain. The calculations were performed assuming the same parameter values as before. Areas of horizontal strain with values greater than +6 mm/m (extension) are marked in red. It was assumed that under the considered conditions, these are areas at risk of discontinuous linear deformations arising. The area where strain exceeds +9 mm/m is also highlighted. It can be assumed that the first area is at risk of the formation of linear discontinuous deformations, while the second area is at risk of experiencing deformations of greater magnitude and with an increased probability. The direction of deformation may be related to the direction of the contour lines for maximum tilt.

Mining should be conducted using the principles of sustainable development. So, similar calculations were performed for the same scope of mining. This time, it was assumed that

Table 2. Basic information about condition of planned mining extraction

Tabela 2. Podstawowe informacje o warunkach projektowanej eksploatacji

Coal seam	Panel	The begin	The end	H, m	g, m
4132	1	01.12.2023	01.07.2024	490	2.00
4132	2	01.07.2027	01.01.2028	580	2.30
4132	3	01.10.2027	01.04.2028	530	2.10
4132	4	01.10.2013	01.04.2014	575	2.10
4132	5	01.04.2025	01.10.2025	485	2.10
4141	6	01.01.2030	12.11.2030	610	2.10
4142	7	01.03.2030	19.02.2031	535	2.10
4142	8	01.12.2029	28.02.2030	575	2.10
416	12	20.12.2029	01.10.2030	645	2.70
416	13	01.07.2027	01.04.2028	560	2.10
416	9	01.04.2032	01.02.2033	645	2.70

the mining would be conducted with the roof caving alongside goaves backfilling using fine fraction waste (e.g., fly ash). Therefore, a smaller value of the roof control coefficient a = 0.6 was used for the calculations. The values of the other Budryk-Knothe model parameters remained unchanged. Contour lines for maximum tilt and maximum horizontal strain are presented in Figure 11. In this figure, areas where horizontal deformations exceeded 6 mm/m

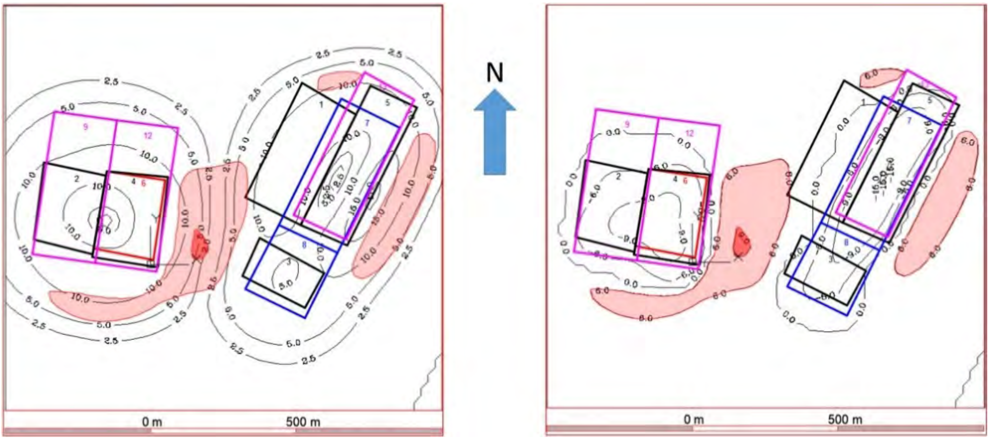

Fig. 10. Location of mining panels and contour lines: tilt on the left, mm/m, and maximum horizontal strain on the right, mm/m. Extraction carried out with roof caving

Rys. 10. Rozmieszczenie wyrobisk ścianowych i izolnie: nachyleń maksymalnych po stronie lewej, mm/m oraz odkształceń poziomych maksymalnych po stronie prawej, mm/m. Eksploatacja z zawałem stropu

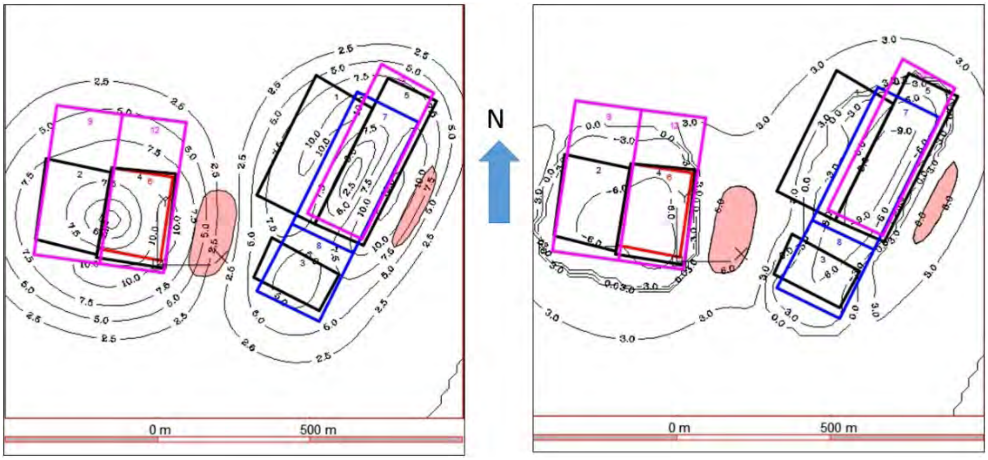

Fig. 11. Location of mining fields and contour lines: tilt on the left, mm/m, and maximum horizontal strain on the right, mm/m. Extraction carried out with roof caving alongside goaves backfilling

Rys. 11. Rozmieszczenie wyrobisk ścianowych i izolnie: nachyleń maksymalnych po stronie lewej, mm/m oraz odkształceń poziomych maksymalnych po stronie prawej, mm/m. Eksploatacja z doszczelnianym zawałem stropu

are marked in red. As seen in the figures, areas with these strain values occupied a smaller surface area compared to mining without backfilling. There were also no deformations with values around 9 mm/m. Therefore, the degree of risk of terrain deformation occurrence can be reduced in a straightforward manner by implementing backfilling during mining.

The forecast made in this way is, of course, incomplete because the dimensions of the deformations were not determined. However, they are challenging to specify due to the significant randomness of the phenomenon. Therefore, with information about previously occurring deformations in the area, the expected value can be determined based on statistical analyses.

Summary and conclusions

The conducted analyses of the causes of the described discontinuous deformations (ground steps), along with a review of the literature, allow for the following statements and conclusions to be presented:

1. The occurrence of discontinuous linear deformations depends on various geological and mining factors. These include the presence of tectonic faults, mechanical properties of the rock mass, the thickness of loose rocks in the overburden, and mining to a common boundary in multiple seams. However, one of the decisive factors is the value of horizontal tensile strain. Determining the critical value of horizontal tensile strain should be specific to the geological and mining conditions, and, above all,

it should be conducted separately for the disturbed rock mass with tectonic faults and the undisturbed one. Based on the presented example, it can be observed that even the occurrence of faults with small throws can lead to the phenomenon of suffusion on the discontinuity surfaces. In the analyzed case, this resulted in the formation of micro-sinkholes, which may pose a particular threat to buildings.

2. The direction of the linear deformation was consistent with the direction of the course of contour lines of maximum tilt.
3. Partial forecast of the occurrence of linear deformation can be based on identifying areas where tensile horizontal strain will exceed certain values. Determining the values characterizing the dimensions of deformations is difficult. They can be approximately estimated based on statistical analyses from the forecast area.
4. It is crucial to conduct underground mining operations sustainably, i.e., considering minimizing its impact on the surface. Reducing the degree of risk of discontinuous linear deformation should be achieved by minimizing the value of horizontal strain, including avoiding extraction in multiple seams to a shared boundary.

The Author have no conflict of interest to declare.

REFERENCES

Chudek et al. 1988 – Chudek, M., Janusz, W. and Zych, J. 1988. Study on diagnosis and prognosis of the formation of discontinuous deformation due to underground mining. *Zeszyty Naukowe Politechniki Śląskiej*, seria Górnictwo 141(165), Gliwice (*in Polish*).

Cempiel et al. 2023 – Cempiel, E., Strzałkowski, P., Ścigała, R. and Bryt-Nitarska, I. 2023. Assessment of damage causes of monumental objects located in mining areas – case study. *Archives of Mining Sciences* 68(2), pp. 187–205, DOI: 10.24425/ams.2023.146175.

Deng et al. 2019 – Deng, Y., Chen, C., Xia, K., Pang, H., Sun, Ch., Yang, K. and Zheng, X. 2019. Investigation on the distribution characteristics of ground cracks in the Chengchao Iron Mine, China. *Environmental Earth Sciences* 78, DOI: 10.1007/s12665-019-8268-2.

Gawlik, L. and Mokrzycki, E. 2019. Changes in the structure of electricity generation in Poland in view of the EU climate package. *Energies* 12(17), DOI: 10.3390/en12173323.

Grygierek, M. and Kalisz, P. 2018. Influence of mining operations on road pavement and sewer system-selected case studies. *Journal of Sustainable Mining* 17(2), pp. 56–67, DOI: 10.1016/j.jsm.2018.04.001.

Jia et al. 2020 – Jia, Z., Lu, Q., Peng, J., Qiao, J., Wang F., Wang, S. and Zhao, J. 2020. Analysis and comparison of two types of ground fissures in Dali County in the Weihe Basin, China. *Environmental Earth Sciences* 79, DOI: 10.1007/s12665-019-8783-1.

John, A. 2021. Monitoring of Ground Movements Due to Mine Water Rise Using Satellite-Based Radar Interferometry – A Comprehensive Case Study for Low Movement Rates in the German Mining Area Lugau/Oelsnitz. *Mining* 1(1), pp. 35–58, DOI: https://doi.org/10.3390/mining1010004

Kowalski, A. 2015. *Surface deformations in the Upper Silesian Coal Basin* (*Deformacje Powierzchni w Górnośląskim Zagłębiu Węglowym*). Katowice: GIG (*in Polish*).

Kowalski, A. 2020. *Surface deformations in mining areas of hard coal mines* (*Deformacje Powierzchni Na Terenach Górniczych Kopalń Węgla Kamiennego*). Katowice: GIG (*in Polish*).

Knothe, S. 1984. *Forecasting the Impacts of Mining Exploitation* (*Prognozowanie Wpływów Eksploatacji Górniczej*). Katowice: Wyd. Śląsk (*in Polish*).

Kratzsch, H. 1983. Mining Subsidence Engineering. *Geological Magazine* 121(4), DOI: 10.1017/S0016756800029393.

Li et al. 2004 – Li, X., Wang, S.J., Liu, T.Y. and Ma, F.S. 2004. Engineering geology, ground surface movement and fissures induced by underground mining in the Jinchuan Nickel Mine. *Engineering Geology* 76(1–2), pp. 93–107, DOI: 10.1016/j.enggeo.2004.06.008.

Lian et al. 2020 – Lian, X., Hu, H., Li, T., Hu, D. 2020. Main geological and mining factors affecting ground cracks induced by underground coal mining in Shanxi Province, China. *International Journal of Coal Science & Technology* 7, pp. 362–370, DOI: 10.1007/s40789-020-00308-1.

Malinowska, A.A. and Hejmanowski, R. 2016. The impact of deep underground coal mining on Earth fissure occurrence. *Acta Geodynamica et Geomaterialia* 13(4), pp. 321–330, DOI: 10.13168/AGG.2016.0014

Malinowska et al. 2018 – Malinowska, A.A., Misa, R. and Tajduś, K. 2018. Geomechanical modeling of subsidence related strains causing earth fissures. *Acta Geodynamica et Geomaterialia* 15(2), pp. 197–204, DOI: 10.13168/AGG.2018.0015.

Orwat, J. 2020. Causes analysis of occurrence of the terrain surface discontinuous deformations of a linear type. Journal of Physics: Conference Series 1426, *International Conference on Applied Sciences* 9–11 May 2019, Hunedoara, Romania, DOI: 10.1088/1742-6596/1426/1/012016.

Orwat, J. and Gromysz, K. 2021. O ccurrence consequences of mining terrain surface discontinuous linear deformations in a residential building. Journal of Physics: Conference Series 1781, *International Conference on Applied Sciences* (ICAS 2020) 20–22 May 2020, Hunedoara, Romania, DOI: 10.1088/1742-6596/1781/1/012013.

Orwat, J. 2023. Influence of Discontinuous Linear Deformation on the Values of Continuous Deformations of a Mining Area and a Building Induced by an Exploitation of Hard Coal Seam. *Applied Sciences* 13(6), DOI: 10.3390/app13063549.

Peng et al. 2016 – Peng, J.B., Qiao, J.W., Leng, Y.Q., Wang, F. and Xue, S. 2016. Distribution and mechanism of the ground fissures in Wei River Basin, the origin of the Silk Road. *Environmental Earth Sciences* 75(8), pp. 1–12, DOI: 10.1007/s12665-016-5527-3.

Strzałkowski, P. 2015. Mathematical Model of Forecasting the Formation of Sinkhole Using Salustowicz's Theory. *Archives of Mining Science* 60(1) , pp. 63–71, DOI: 10.1515/amsc-2015-0005.

Strzałkowski, P. 2017. Proposal of predicting formation of sinkholes with an exemplary application. *Journal of Mining Science* 53(1), pp. 53–58, DOI: 10.1134/S1062739117011835.

Strzałkowski, P. and Szafulera, K. 2020. Occurrence of linear discontinuous deformations in Upper Silesia (Poland) in conditions of intensive mining extraction – case study. *Energies* 13(8), pp. 1–16, DOI: 10.3390/en13081897.

Strzałkowski, P. and Ścigała, R. 2017. The causes of mining induced ground steps occurrence – case study from Upper Silesia in Poland. *Acta Geodynamica et Geomaterialia* 14(3), pp. 305–312, DOI: 10.13168/AGG.2017.0013.

Strzałkowski, P. and Maruszczyk, M. 2024. Hard as a necessary energy resources in Poland. *Archives of Mining Sciences* 69(1), pp. 187–205, DOI: 10.24425/ams.2024.149827.

Stryczek, S. and Gonet, A. 2000. *Geoengineering* (*Geoinżynieria*). *Studia, Rozprawy, Monografie* 71. Kraków: IGSMiE PAN.

Szojda, L. 2019. *Structural aspects of securing buildings in mining areas* (*Aspekty konstrukcyjne zabezpieczania budynków na terenach górniczych*). Gliwice: Pol.Śl. (*in Polish*).

Szojda, L. and Wandzik, G. 2019. *Nieciągłe deformacje terenu – prognozowanie oraz konsekwencje ich występowania dla budynków*. [W:] Kaszyńska M, (red.). Awarie budowlane: Zapobieganie, diagnostyka, naprawy, rekonstrukcje. Monografia: 513–516. (Kaszyńska M.). Discontinuous terrain deformations – forecasting and consequences of their occurrence for building structures

Ścigała, R. 2013. The identification of parameters of theories used for prognoses of post mining deformations by means of present software. *Archives of Mining Sciences* 58(4), pp. 1347–1357, DOI: 10.2478/amsc-2013-0093.

Ścigała, R. 2013. *The influence of deposit tectonics on the distribution of deformations in the mining area* (*Wpływ tektoniki złoża na rozkład deformacji terenu górniczego*). Gliwice: Pol.Śl. (*in Polish*).

Ścigała, R. and Szafulera, K. 2020. Linear discontinuous deformations created on the surface as an effect of underground mining and local geological conditions-case study. *Bulletin of Engineering Geology and the Environment* 79, DOI: 10.1007/s10064-019-01681-1.

Tajduś et al. 2023 – Tajduś, K., Sroka, A., Dudek, M., Misa, R., Hager, S. and Rusek, J. 2023. Effect of the entire coal basin flooding on the land surface deformation. *Archives of Mining Sciences* 3(68), pp. 375–392, DOI: 110.24425/ams.2023.146857.

Wang et al. 2019 – Wang, F., Peng, J., Lu, Q., Cheng, Y., Meng, Z. and Qiao, J. 2019. Mechanism of Fuping ground fissure in the Weihe Basin of northwest China: fault and rainfall. *Environmental Earth Sciences* 78, DOI: 10.1007/s12665-019-8421-y.

Whittaker, B.W. and Redish, D.J. 1989. Subsidence – Occurrence, Prediction and Control. *Developments in Geotechnical Engineering* 56, DOI: 10.1016/0148-9062(90)95372-8.

Woo et al. 2013 – Woo, K., Eberhardt, E., Elmo, D. and Stead, D. 2013. Empirical investigation and characterization of surface subsidence related to block cave mining. *International Journal of Rock Mechanics and Mining Sciences* 61, pp. 31–42. DOI: 10.1016/j.ijrmms.2013.01.015.

Zhu et al. 2018 – Zhu, H., He, F. and Fan, Y. 2018. Development mechanism of mining-induced ground fissure for shallow burial coal seam in the mountains area of southwestern China: a case study. *Acta Geodynamica et Geomaterialia* 15(4), pp. 329–362, DOI: 10.13168/AGG.2018.0026.

RESOURCE MANAGEMENT IN CONDITIONS OF OCCURRENCE OF LINEAR DISCONTINUOUS DEFORMATIONS

Keywords

mining extraction influences, mining deformations, steps in ground

Abstract

The work explores the conditions for the formation of discontinuous linear deformations, which most often take the form of ground steps. These deformations pose a significant threat to building structures, which are extremely difficult to protect from such damage. The frequent occurrence of this type of deformation and the threat it poses to public safety make the issue of predicting them both current and significant. Deformations often occur as a result of intense mining extraction. The paper presents geological and mining conditions that favor the formation of these deformations. The influence of horizontal tensile strain on the occurrence of discontinuous linear deformations is highlighted. Based on the presented case study and the author's previous work, a conclusion has been drawn about a strain limit under the given conditions at which ground steps may occur. The paper also highlights the potential for discontinuous surface deformation (sinkholes) due to the suffosion phenomenon in the zone where these linear deformations occur.

The paper proposes a method for predicting the location of zones where ground steps may occur due to planned underground mining operations. Despite ongoing decarbonization efforts, intensive extraction of coking coal, which is listed as a critical raw material, will occur. However, such extraction should be conducted in a manner that prioritizes its sustainable impact on the surface. Taking the above into account, an example of conducting underground extraction is provided in a way that minimizes the threat of linear discontinuous deformations.

GOSPODARKA ZŁOŻEM W WARUNKACH WYSTĘPOWANIA DEFORMACJI NIECIĄGŁYCH LINIOWYCH

Słowa kluczowe

oddziaływanie eksploatacji górniczej, deformacje, stopnie terenowe

Streszczenie

Praca dotyczy warunków powstawania deformacji nieciągłych liniowych, które przybierają najczęściej formę stopni terenowych. Deformacje te stanowią duże zagrożenie dla obiektów budowlanych, które niezwykle trudno jest zabezpieczyć przed uszkodzeniami. Częste występowanie tego typu deformacji oraz stwarzanie przez nie zagrożenia dla bezpieczeństwa publicznego powodują, że problematyka ich przewidywania jest aktualna i istotna. Deformacje występują często wskutek prowadzenia intensywnej eksploatacji górniczej. W pracy przedstawiono warunki geologiczno-górnicze sprzyjające powstawaniu tych deformacji. Wskazano na wpływ odkształceń poziomych rozciągających na występowanie deformacji nieciągłych liniowych. Na podstawie przedstawionego studium przypadku i wcześniejszej pracy autora wyciągnięto wniosek o istnieniu w danych warunkach granicznej wartości odkształceń, przy której wystąpić mogą stopnie terenowe. Wskazano również na możliwość występowania deformacji nieciągłych powierzchniowych wskutek występowania zjawiska sufozji w rejonie deformacji nieciągłych liniowych.

W artykule zaproponowano sposób przewidywania obszarów występowania tych deformacji, które może wywołać projektowana eksploatacja górnicza. Pomimo postępującej dekarbonizacji prowadzona będzie intensywna eksploatacja węgla kamiennego koksującego, który znajduje się na liście surowców krytycznych. Eksploatacja ta powinna się jednak odbywać na zasadzie zrównoważonego oddziaływania na powierzchnię. Biorąc pod uwagę powyższe, przedstawiono przykład prowadzenia eksploatacji w sposób pozwalający na minimalizację zagrożenia terenu deformacjami nieciągłymi liniowymi.