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The link between an experiment and mathematics is measurement – it translates experiment results into the language of mathematics.
[Galileo]

ANALYSIS OF THE IMPACT OF THE COAL BED INCLINATION AND THE DIRECTION OF EXPLOITATION ON SURFACE DEFORMATION

KSZTAŁTOWANIE SIĘ DEFORMACJI POWIERZCHNI Z UWZGLĘDNIENIEM WPŁYWU NACHYLENIA POKŁADU I KIERUNKU PROWADZENIA EKSPLOATACJI

The article presents deformation indexes for three examples, for which the quantitative relations of extreme values were described, including the influence of a coal bed dip and a direction of exploitation. The conclusion regards the mining prevention on minimizing longwall deformation. New experience allows improving methods of theoretical description of deformation, which is the aim of the research continuing at the Central Mining Institute.

Keywords: mining exploitation, measured surface deformation, dip of the seam, direction of longwall face, mining prevention

W artykule zostały przedstawione czynniki, które w istotny sposób wpływają na rozkład i wielkość ustalonych (asymptotycznych) deformacji powierzchni dla niecek obniżeniowych. W tym celu wykorzystano wyniki obserwacji z trzech rejonów Górnośląskiego Zagłębia Węglowego, gdzie typowym sposobem wybierania kopaliny jest system ścianowy z zawałem stropu, pojedynczym frontem eksploatacyjnym. Dla każdego przykładu scharakteryzowano warunki górniczo-geologiczne, zakres obserwacji geodezyjnych oraz przeprowadzono analizę rozkładu wskaźników deformacji wzdłuż linii pomiarowych nad polem eksploatacji i w rejonie krawędzi. Ponadto porównano obliczone i zmierzone wskaźniki deformacji (obniżenia, nachylenia, krzywizny pionowe i odkształcenia poziome), przy czym prognozę wsteczną przeprowadzono dla wcześniej wyznaczonych (na podstawie pomiarów) wartości parametrów teorii Knothego-Budryka.

Pierwszy przykład (Rys. 1) dotyczy niepełnej niecki obniżeniowej, która powstała nad górotworem wielokrotnie zdeformowanym. Na jej asymetryczny kształt wpłynęły następujące czynniki: nachylenie warstw karbońskich, kierunek eksploatacji, eksploatacja wielokrotna (liczne krawędzie pól eksploatacyjnych) oraz występowanie calizny pokładu w kierunku północnym od krawędzi ściany (filar graniczny). Z wykresów wskaźników deformacji przedstawionych na rys. 2-5 oraz danych zawartych w tabeli 2

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wynika, że określone pomiarami wartości ekstremalne wskaźników i ich rozkłady znacznie różnią się w skrzydle północnym i południowym. Niecka od strony wzniosu i krawędzi startowej ściany jest bardziej stroma niż od strony upadu. Nachylenia są dwukrotnie większe (o 100%), odkształcenia poziome 1,79 razy (o 79%), a krzywizny 3,17 razy (o 217%) większe. Z porównania wyznaczonych parametrów teorii Knothego-Budryka oraz rozkładu zaobserwowanych i obliczonych wskaźników deformacji (Rys. 2-5) można stwierdzić, że wartości parametrów różnią się w istotny sposób:

- współczynnik eksploatacyjny *a* jest większy w skrzydle południowym o 43% niż w północnym,
- parametr górotworu (tg*β*) dla skrzydła północnego jest większy o 100% niż w skrzydle południowym,
- obliczone deformacje (tzw. reprognoza) dobrze aproksymują deformacje pomierzone.

Drugi przykład (Rys. 6) dotyczy niepełnych niecek obniżeniowych, które wykształciły się na powierzchni w wyniku prowadzenia eksploatacji pokładu z podziałem na dwie warstwy.

Z analizy wyników pomiarów (tabela 4) i wykresów ustalonych wskaźników deformacji dla każdej z warstw (Rys. 7-10) wynika, że:

- kształty niecek są w przybliżeniu symetryczne,
- największe obniżenia dla drugiej (dolnej) warstwy są większe o 16%, niż dla warstwy pierwszej (górnej);
- największe nachylenia (średnie dla dwóch skrzydeł niecki) dla warstwy dolnej (drugiej z kolei) są większe o 64% niż dla warstwy pierwszej (górnej);
- odkształcenia poziome o charakterze rozciągania (dodatnie, średnie dla dwóch skrzydeł niecki) spowodowane eksploatacją drugiej warstwy (dolnej) są większe o 81%, niż dla warstwy pierwszej (górnej);
- odkształcenia poziome o charakterze ściskania (ujemne) spowodowane eksploatacją drugiej warstwy (dolnej) są analogiczne, jak dla warstwy pierwszej (górnej);
- jakościowo krzywizny dla obydwu warstw są podobne, ilościowo dla warstwy drugiej są większe niż dla pierwszej;
- denna część niecki powstała po wybraniu warstwy dolnej jest o około 50 m przesunięta w stosunku do niecki spowodowanej eksploatacją warstwy górnej, przesunięcie to ma związek z nachyleniem pokładu, jak i kierunkiem eksploatacji ścian;
- obliczone wskaźniki deformacji (tzw. reprognoza) dobrze aproksymują proces deformacji.

Trzeci przykład (Rys. 11) dotyczy także niepełnej niecki obniżeniowej (pomimo płaskiego dna niecki), która ujawniła się na powierzchni nad polem pojedynczej ściany, której front eksploatacyjny był w przybliżeniu zgodny z kierunkiem rozciągłości pokładu. Z analizy pomiarów wskaźników deformacji (Rys. 12-15) wynika, że:

- nachylenia w rejonie skrzydła północnego (krawędź startowa) wynoszą do 9,7 mm/m, a w rejonie krawędzi końcowej do 6,4 mm/m;
- krzywizny w rejonie skrzydła północnego (krawędź startowa) wynoszą do 0,13 km^{-1} (promień krzywizny – 7,7 km), a w rejonie skrzydła południowego (krawędź końcowa) do 0,028 km^{-1} (promień krzywizny – 35,7 km), natomiast w rejonie dna niecki do –0,063 km^{-1} (promień krzywizny – 15,9 km);
- niecka od strony krawędzi startowej jest bardziej stroma niż od strony południowej, nachylenia są większe o 52%, a odkształcenia poziome o 5%.

Przedstawione przykłady potwierdzają, choć w różnym stopniu, wpływ nachylenia pokładu i kierunku prowadzenia eksploatacji na kształtowanie się (opis) deformacji powierzchni. Ma to szczególne znaczenie pomimo małych nachyleń pokładów (do 10°), ale dużej głębokości eksploatacji. Wyznaczone parametry teorii Knothego-Budryka są zróżnicowane. Współczynnik eksploatacyjny *a* dla analizowanych przykładów znajduje się w przedziale od 0,68 do 0,97, a parametr górotworu tg*β* od 1,6 do 4,6. Przyjmując do prognoz właściwe wartości parametrów teorii Knothego-Budryka, przy właściwym rozpoznaniu warunków geologicznych, można uzyskać dobrą zgodność między zmierzonymi i teoretycznymi wartościami wskaźników deformacji powierzchni.

Z pierwszego i trzeciego przykładu wynika istotny wpływ kierunku prowadzenia eksploatacji na kształtowanie się ekstremalnych, ustalonych wskaźników deformacji. Średnio nachylenia, które wystąpiły na powierzchni w rejonie krawędzi startowej ścian eksploatacyjnych są większe o 75%, a odkształcenia poziome o charakterze rozciągania (z przykładu 1) o 80% od wartości zaobserwowanych w rejonie krawędzi końcowej. Korzystniej jest dochodzić frontem ściany do chronionego obiektu, niż rozpoczynać eksploatację w jego rejonie (Kwiatek i in., 1997; Mielimąka, 2009).

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Drugi przykład przedstawia wpływ kolejności i kierunku eksploatacji oraz nachylenia pokładu na rozkład i wartości ekstremalne wskaźników deformacji. Przy wybieraniu drugiej, kolejnej warstwy w kierunku przeciwnym do upadu pokładu, występują większe deformacje powierzchni. Z tego przykładu można wnioskować, że z punktu widzenia kształtowania się deformacji powierzchni, korzystniej jest eksploatować w kierunku zgodnym z kierunkiem nachylenia (upadu) pokładu, rozpoczynając eksploatację od strony wzniosu. Jest to zauważalne zwłaszcza w wartościach współczynnika (*k*) odchylenia wpływów eksploatacji z uwagi na nachylenie pokładu.

Zgromadzone doświadczenia pozwolą doskonalić sposoby prognozowania deformacji powierzchni, co jest celem badań prowadzonych w Głównym Instytucie Górnictwa.

Słowa kluczowe: eksploatacja górnicza, pomierzone deformacje powierzchni, nachylenie pokładu, kierunek eksploatacji, profilaktyka górnicza

1. Introduction

The aim of the article is to present indicators of longwall deformation caused by underground exploitation with caving (three examples – study cases). The research covers incomplete and established troughs – asymptotic from three regions of Upper Silesian Coal Basin, where a typical system of hard coal extraction is longwall mining with caving and single exploitation front.

The article demonstrates the impact of the following factors: large number of operations in rock mass, a coal bed dip and an operation direction, on the formation of surface deformation. The research are based on geodetic measurements.

The results of measurements of longwall deformation caused by mining operation conducted in various geological and mining conditions, as well as their analysis and interpretation were performed in order to show the factors affecting the formation. The analysis of the measurement results in more reliable projections, consistent with the results of existing experience, even if the results deviate from the current projections. In order to achieve this goal, the repeatable and unique unit, resulting from individual circumstances, was separated from presented experiments.

2. Ist example: deformation of the rock mass repeatedly deformed

The first example of observed longwall deformation refers to the subsidence trough, which shape is affected by the number of (earlier) exploitations, Carboniferous layers inclination and direction of operation. The trough was formed above the longwall 24 in the bottom layer of the coal bed 510 with caving, fig. 1

Basic data characterizing the geological and mining conditions for the longwall 24 are presented in the table 1.

The table 1 and figure 1 show that mining operation was carried out above the longwall 24 in ten seams, including in the top layer of the seam 510 and the bottom layer of the seam 509 – 10 m under the seam 510.

Subsidence trough was occurred on surface between November 2003 and November 2005. The measuring line was located approximately along the longitudinal axis of the panel. The distance between measuring points amounts to 45 m; in the south part of the measurement line – 25 m (points 977-982).

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TABLE 1

Basic data characterizing the geological and mining conditions for the longwall 24

Data's name or type	Value or description of data characterizing exploitation
Panel width	280 – 300 m
Panel length	800 m
Exploitation depth	760 m (north) – 840 m (south)
Overburden	Quaternary – 30 m Triassic – 130 m
Angle and direction of seam dip	6°, south
Extracted layer height	2.25 m
Time operation	December 2013 – December 2014
Direction of the longwall face	North – South
Old workings in seam 510	in bottom layer with caving (2001), in bottom layer with backfilling (1987-1988) in top layer with caving (1997-1999)
Old workings over seam 510	in seams 406/4, 407, 408/2, 411, 412, 414, 419, 501, 507 with caving and backfilling (1939-1985) in top layer of seam 509 with caving (1987-1989) in bottom layer of seam 509 with caving (1991-1995)
Old workings beneath seam 510	N/A

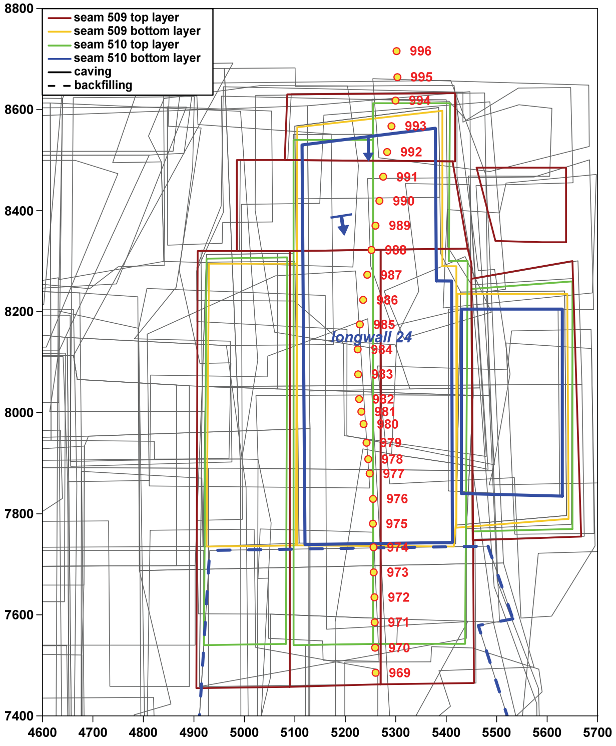

Fig. 1. Longwall 24 outline in the bottom layer of seam 510, mining operations' outline and observation line location

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Charts of measured deformation indicators: subsidence – Fig. 2, tilt – Fig. 3, curvatures – Fig. 4 and horizontal deformation – Fig. 5. The table 2 summarizes the extreme values of deformation.

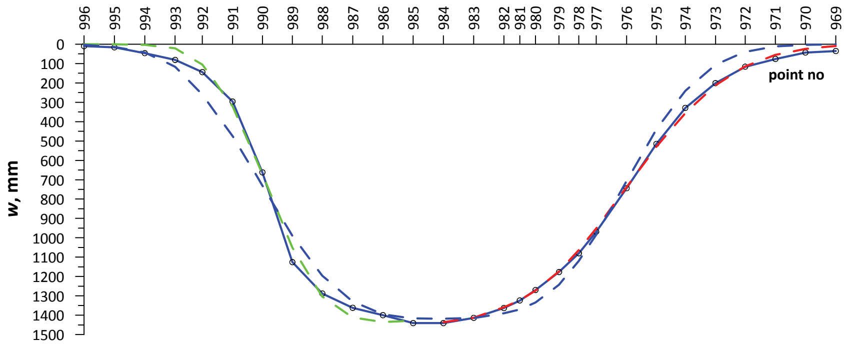

Fig. 2. Observed (solid line) and calculated (dashed lines) subsidence along the measurement line: blue – the entire trough, green – north side, red – south side

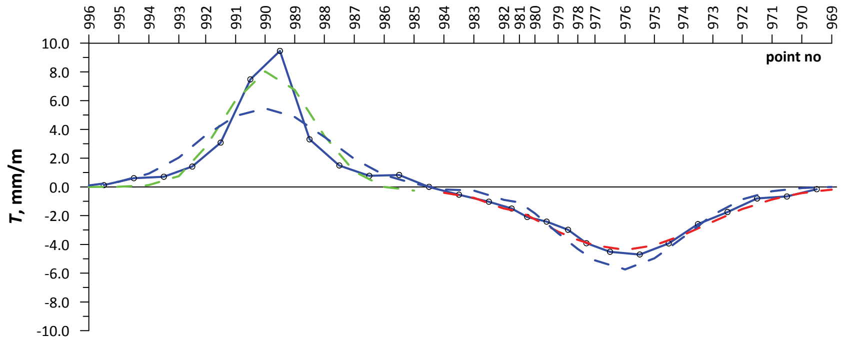

Fig. 3. Observed (solid line) and calculated (dashed lines) tilt along the measurement line: blue – the entire trough, green – north side, red – south side

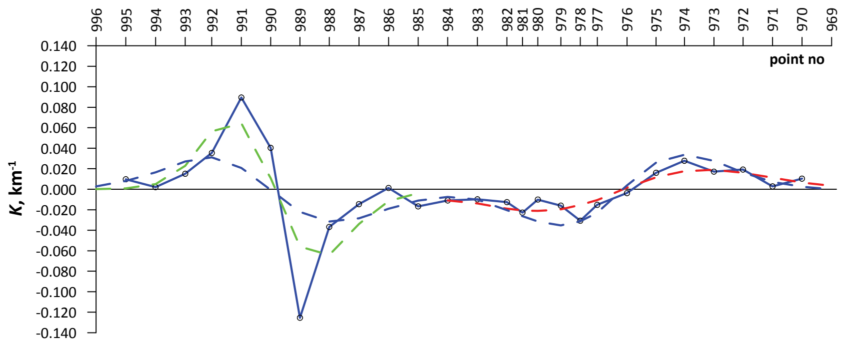

Fig. 4. Observed (solid line) and calculated (dashed lines) curvatures along the measurement line: blue – the entire trough, green – north side, red – south side

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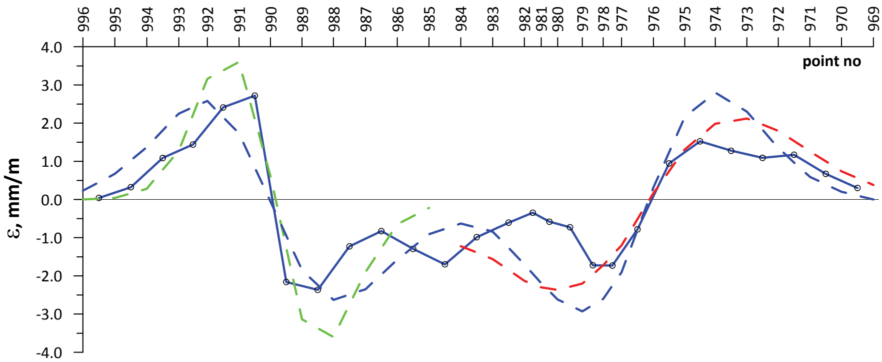

Fig. 5. Observed (solid line) and calculated (dashed lines) horizontal deformations along the measurement line: blue – the entire trough, green – north side, red – south side

TABLE 2

Summary of the extreme observed rates of deformation along the measurement line

Deformation indicator/ location	**Measured value**	**Location of deformation**
Subsidence, mm	1441	trough bottom
Tilt on the north side of the trough, mm/m	9.34	initial edge, lift side
Tilt on the south side of the trough, mm/m	4.67	end edge, dip side
Convex curvature (radius, km) on the north side of the trough, km^{-1}	+0.092 (10.9)	initial edge, lift side
Convex curvature (radius, km) on the south side of the trough, km^{-1}	+0.029 (34.5)	end edge, dip side
Concave curvature (radius, km), km^{-1}	–0.122 (–8.2)	trough bottom
Tensile horizontal deformation, on the north slope of the trough, mm/m	+2.72	initial edge, lift side
Tensile horizontal deformation, on the south slope of the trough, mm/m	+1.52	end edge, dip side
Compressive horizontal deformation, mm/m	-2.32	trough bottom

The charts of deformation indicators shown in figures 2-5 and the data in the table 1 show that determined by measurements extreme values of indicators and their distribution differs in the north side and the south one. The trough from the lift side and initial edge of the longwall is steeper than from the dip side. The tilt are twice greater (by 100%), the horizontal deformation is greater by 1.79 times (79%), and the curvature by 3.17 times (by 217%). This difference was caused due to the coal bed dip and north operating edge being initial edge. Additional factors are the exploitation history (times) and the occurrence of undisturbed coal bed in the north part of the trough (border pillar), and the edge of the exploitation in bottom layer of the seam 510 with backfilling (fig. 1) from the south panel.

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The parameters of Knothe-Budryk theory (Knothe, 1984) were determined separately for the cognitive purposes, for the north and south sides, and for the entire trough:

- for the north side:
  - subsidence factor $a = 0.68$;
  - rockmass parameter $tg\beta = 4.6$;
  - edge correction: from the north $p = 90$ m, from the east and west $p = 0$;
  - standard fit deviation $\sigma = 36.8$ mm.
- for the south side:
  - subsidence factor $a = 0.97$;
  - rockmass parameter $tg\beta = 2.3$;
  - edge correction: from the south $p = 140$ m, from the east and west $p = 0$;
  - standard fit deviation $\sigma = 13.8$ mm.

Additionally, the following parameters based on the entire trough were determined:

- subsidence factor $a = 0.79$;
- rockmass parameter $tg\beta = 3.1$;
- edge correction: from the north $p = 80$ m, from the south $p = 140$ m, from the east and west $p = 0$;
- standard fit deviation $\sigma = 69.08$ mm.

Designated proportionality coefficient of horizontal displacement is $B = 0.32\ r$, where r – is the radius of main influences.

Compared parameters of the theory show that:

- designated for subsidence trough sides parameters differ significantly, subsidence factor is increased by 43% for the south side, and the rockmass parameter ($tg\beta$) is increased by 100% for the north side,
- subsidence factor determined for the entire trough ($a = 0.79$) is approximately equal to the average value of the sides of trough ($a = 0.825$), the difference is about 4%,
- rockmass parameter values differ by 11%, which are respectively $tg\beta = 3.45$ (average value for the trough sides) and $tg\beta = 3.1$ (for the entire trough).

Based on the parameters calculated according to the theory, the figures 2-5 present calculated rates of deformation along the measurement line (dashed lines): blue – the entire trough, green – north side, red – south side. Comparison of the measured deformation indexes shows that theoretical deformation may be treated as close to the average value.

3. IInd example, the deformation measurement results for two exploitation directions

The second example refers to the shaping process of surface deformation caused by exploitation of the panels in the inclined seam 502 in two layers operated in two opposite directions, Fig. 6. The longwall 225 was operated from north to south in the top layer (N-S), and the longwall 225/II from south to north (S-N) in the bottom layer. The survey observations were taken along the measurement line (points 1-43). The average distance between points equals 25 m.

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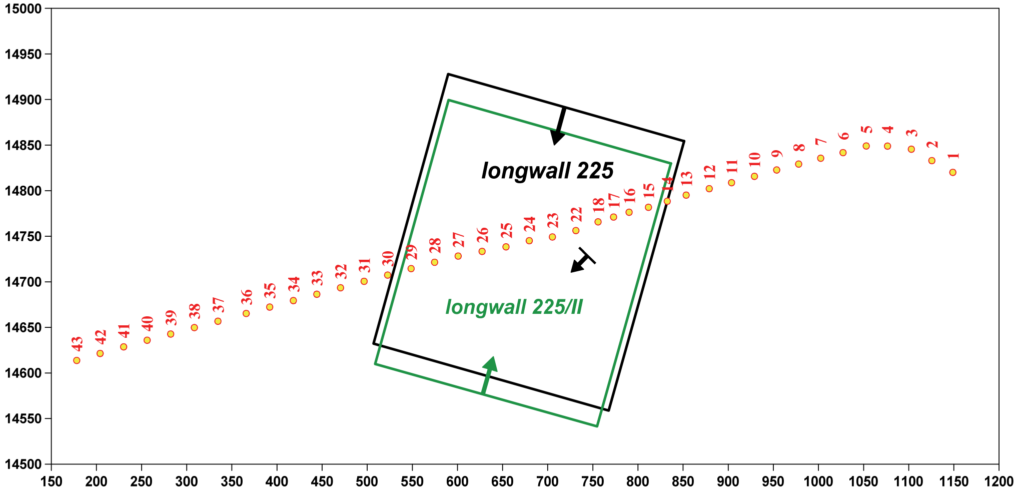

Fig. 6. Longwall 225 outline (top layer) and 225/II (bottom layer) in the seam 502 and the measurement line location

Basic data characterizing the geological and mining conditions for the longwall 225 and 225/II are presented in the table 3.

TABLE 3

Basic data characterizing the geological and mining conditions for the longwall 225 and 225/II

Data's name or type	Longwall 225 (top layer):	Longwall 225/II (bottom layer):
Panel width	260 m	
Panel length	300 m	
Exploitation depth	500 (north) – 540 m (south)	
Angle and direction of seam dip	10°, south-west	
Overburden	Quaternary – up to 10 m	
Extracted layer height	2.10	
Time operation	3 November 2008 – 26 March 2009	22 July 2010 – 12 December 2010
Direction of the longwall face	North – South	South – North
Old workings in seam 502	N/A	
Old workings over seam 502	N/A	225
Old workings beneath seam 502	in seam 504 with backfilling (1961-1962) in seam 507 with backfilling (1963-1966) in seam 510 with backfilling (1982-1983)	

Figures 7-10 show graphs of final – set indicators of deformation for each layer: subsidence, tilt, vertical curvatures, and horizontal deformations.

The table 4 shows the extreme values of deformation indexes. Due to large fluctuations in the curvature values their comparison was not conducted.

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TABLE 4

Summary of the extreme observed rates of deformation along the measurement line

Type of deformation		Subsidence, mm	Tilt, mm/m	Horizontal deformation, mm/m	
				max	min
longwall 225	east side	612	3.00	0.68	–2.88
	west side		–2.97	1.30	
longwall 225/II	east side	708	4.84	1.40*	–2.93
	west side		–4.90	2.19	

* – an average for adjacent sections 15-16 and 16-17

The analysis of the measurement results presented in the table 4 shows that:

– the greatest subsidence for the bottom layer (the second) is higher by 16% than for the top layer (the first), the slopes of troughs are substantially symmetrical,
– for the lower layer (the second) tilt (average values for two slopes of the trough) is larger by 64% than for the top layer (the first),
– tensile horizontal deformation (average values for two slopes of the trough), due to the operation of the bottom layer (the second), is larger by 81% than for the top layer (the first),
– compressive horizontal deformation due to operation of the bottom layer (the second) is the same as for the top layer (the first).

The quality of curvatures for both layers is similar (Fig. 9); the quantity for the second layer is greater than for the first one. Figure 7 shows that the bottom part of the trough formed after the lower layer was exploited is moved by about 50 m in relation to the trough caused by the operation of the upper layer. This is related to the coal bed inclination and the direction of longwalls operation. Furthermore, the order and direction of the exploitation and seam inclination influence the extreme tilt values and horizontal compressive deformation, which differ significantly.

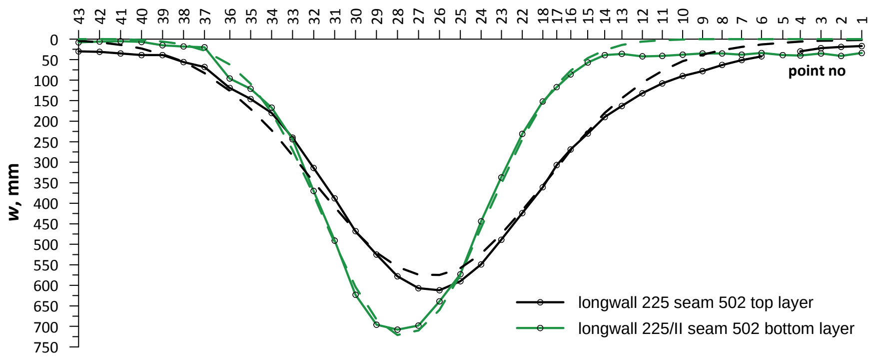

Fig. 7. Measured (solid lines) and calculated (dashed lines) subsidence caused by operation in the top layer (longwall 225) and in the bottom layer (longwall 225/II) of the seam 502

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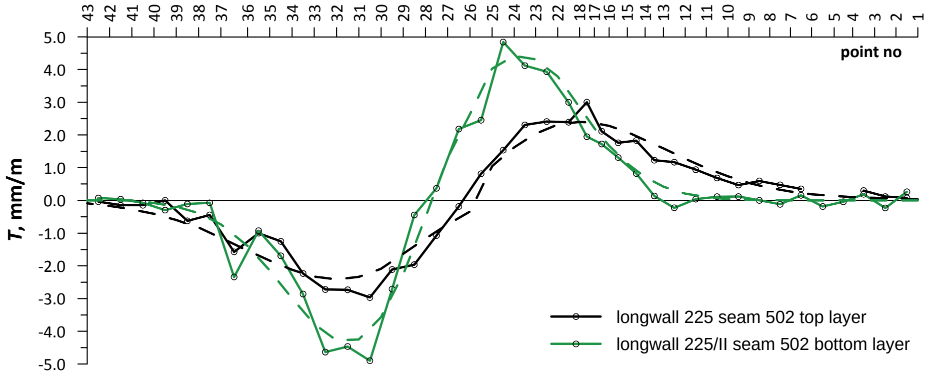

Fig. 8. Measured (solid lines) and calculated (dashed lines) tilt caused by operation in the top layer (longwall 225) and in the bottom layer (longwall 225/II) of the seam 502

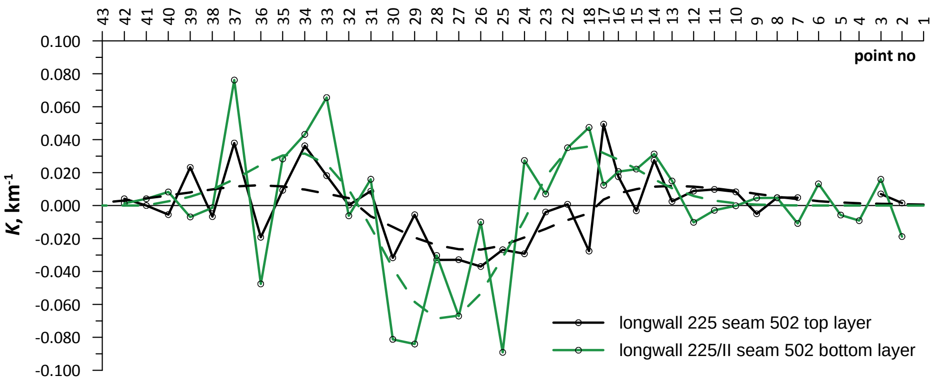

Fig. 9. Measured (solid lines) and calculated (dashed lines) curvatures caused by operation in the top layer (longwall 225) and in the bottom layer (longwall 225/II) of the seam 502

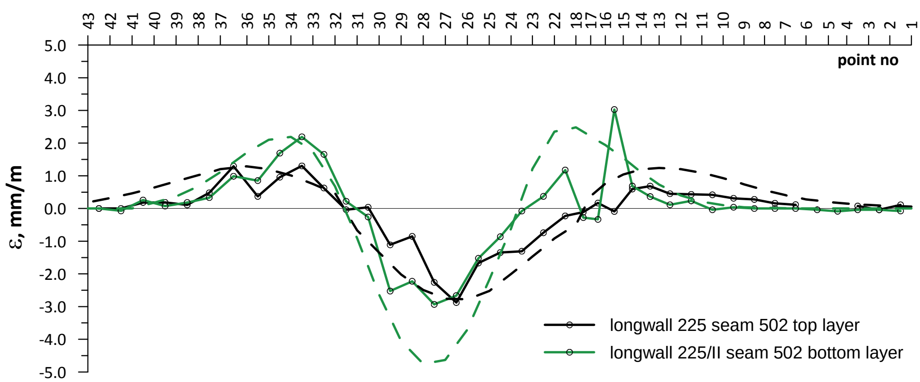

Fig. 10. Measured (solid lines) and calculated (dashed lines) horizontal deformations caused by operation in the top layer (longwall 225) and in the bottom layer (longwall 225/II) of the seam 502

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Determined parameters of the theory along the measuring line:
- for the first layer (the top):
  - subsidence factor $a = 0.73$;
  - rockmass parameter tg$\beta = 1.6$;
  - edge correction $p = 30$ m;
  - coefficient of variation (deviation) due to the inclination of Carboniferous strata $k = 0.7$;
  - standard fit deviation $\sigma = 33.5$ mm.
- for the second layer (the bottom):
  - subsidence factor $a = 0.82$;
  - rockmass parameter tgβ =2.45;
  - edge correction $p = 45$ m;
  - coefficient of variation (deviation) due to the inclination of Carboniferous strata $k = 1.2$;
  - standard fit deviation $\sigma = 13.8$ mm.

A comparative analysis of the designated parameters shows that:
- subsidence factor for the second layer is greater than the first layer by 12%,
- rockmass factor for the second layer is greater than the first layer by 53%,
- operation periphery for the second layer is greater than the first layer by 50%,
- the coefficient of deviation (offset influences) for the second layer is greater than the first layer by 71%.

A comparison for the distribution of calculated and measured deformation indexes (figures 7-10) shows that using correct parameters of the Knothe-Budryk theory let reliable and well describe the deformation process.

4. IIIrd example, the influence of the operation direction on longwall deformation

The third example is analysed according to surface deformation caused by the operation with caving in the top layer of seam 510, with a single longwall 534 (fig. 11). The direction of operation was approximately similar to the direction of the seam strike. Moreover, an incomplete trough formed on the surface.

Basic data characterizing geological and mining conditions for the longwall 534 are presented in the table 5.

The analysis of the geodetic observations (figures 12-15) shows that:
- the extension of the panel width influences on the distribution of subsidence in a bottom part of the trough (between 1975-1984), the greatest subsidence is 1.59 m (point 1982);
- the tilt in the north slope of the trough (initial edge) amounts to 9.7 mm/m, and in the end edge amounts to 6.4 mm/m;
- the values of curvatures towards the north slope of the trough (starting edge) are up to 0.13 km^{-1} (radius 7.7 km), and in the area of the south slope of the trough (end edge) are up to 0.028 km^{-1} (radius 35.7 km), while in the area of the trough bottom they amount to –0.063 km^{-1} (15.9 km);
- tensile horizontal deformation over the north edge of the longwall amounts to 1.31 mm/m, over the south one amounts to 1.24 mm/m; significant changes in the horizontal

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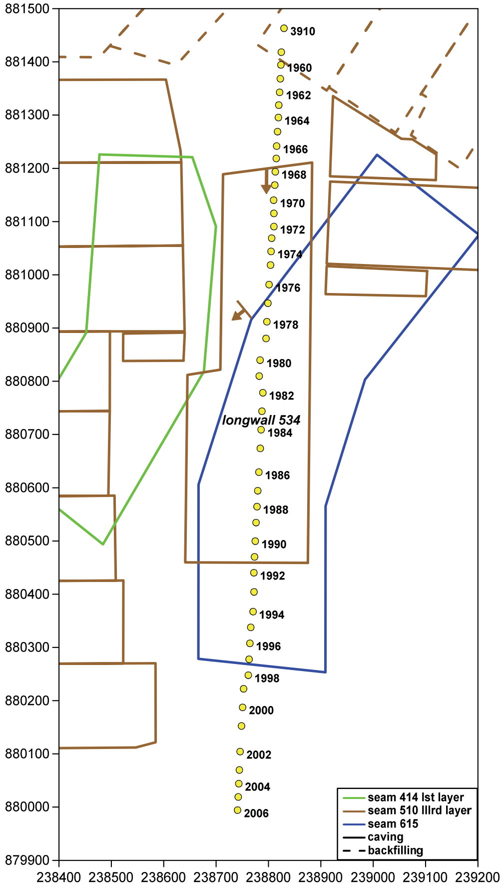

Fig. 11. Longwall 534 outline in the III[rd] layer of the seam 510, and measurement line location

deformation of sections 1999 and 2006 can be interpreted as a result of damaged points or discontinuities;

– an extreme value of the horizontal compressive deformation over the panel is –4.53 mm/m (base 1982-1983), while the average of the three bases is –3.2 mm/m;
– the trough from the initial edge is steeper than from the end edge, tilt values are higher by 52%, and the horizontal deformation is greater by 5%.

Values of designated parameters of the Knothe-Budryk theory for all points of the measurement line are shown below:

– subsidence factor $a = 0.84$;
– rockmass parameter tgβ =1.6;
– edge correction: from the north p = 30 m, from the south p = 135 m, from the east and west $p = 0$;
– coefficient of variation (deviation) due to the inclination of Carboniferous strata $k = 0.7$;
– standard fit deviation $\sigma = 61.5$ mm.

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TABLE 5

Basic data characterizing the geological and mining conditions for the longwall 534

Data's name or type	Value or description of data characterizing exploitation
Panel width	175 – 235 m
Panel length	745 m
Exploitation depth	400 – 450 m
Angle and direction of seam dip	4-8 °, south-west
Overburden	Triassic – 180 m
Extracted layer height	3.0 m
Time operation	June 2006 – March 2007
Direction of the longwall face	North – South
Old workings in seam 510	I[st] layer with caving (1984-1987, 1997) and with backfilling (1968-1971), II[nd] layer with caving (1979-1984, 1994) and with backfilling (1971-1973), III[rd] layer with caving (1974-1982, 1994) and with backfilling (1977-1978, 1991-1992)
Old workings over seam 510	in seam 412 with backfilling (1983-1985), in seam 414/1 with caving (longwall 213, 2005-2006), in seam 419 with caving (1929-1935), in seam 501 with backfilling (1955-1956, 1993-1994), in seam 504 with backfilling (1974-1977)
Old workings beneath seam 510	in seam 615 with caving (longwall 405, 2005-2006)

Calculated (for designated parameters) deformation rates are shown in figures 12-15.

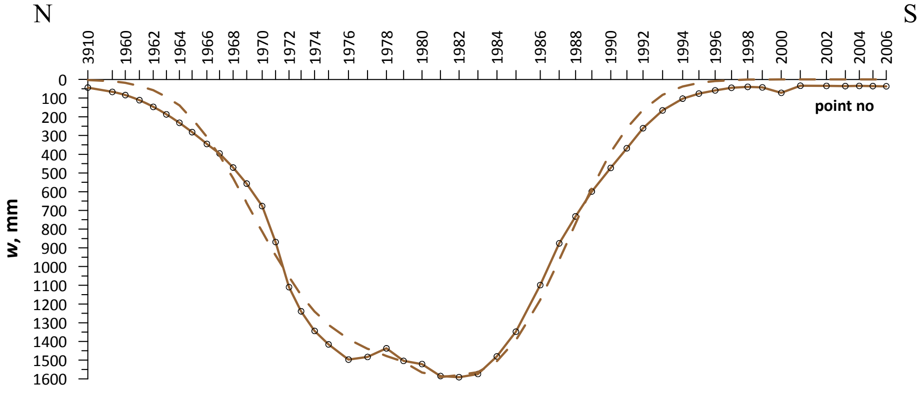

Fig. 12. Measured (solid line) and calculated (dashed line) subsidence due to the operation of the longwall 534 in III[rd] layer of the seam 510

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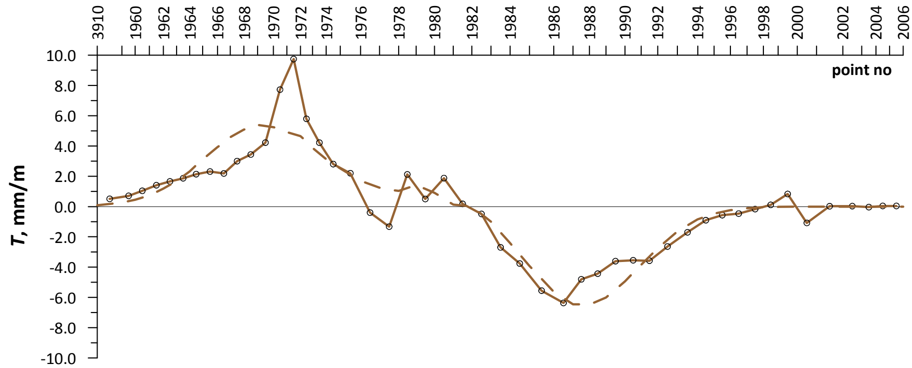

Fig. 13. Measured (solid line) and calculated (dashed line) tilt due to the operation of the longwall 534 in III[rd] layer of the seam 510

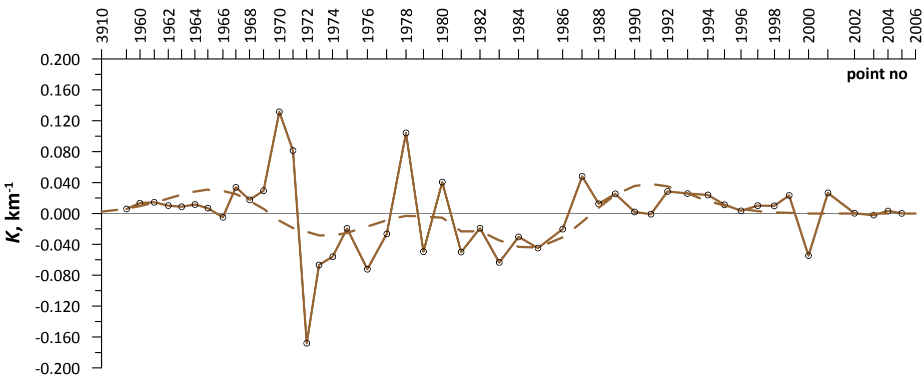

Fig. 14. Measured (solid line) and calculated (dashed line) curvatures due to the operation of the longwall 534 in III[rd] layer of the seam 510

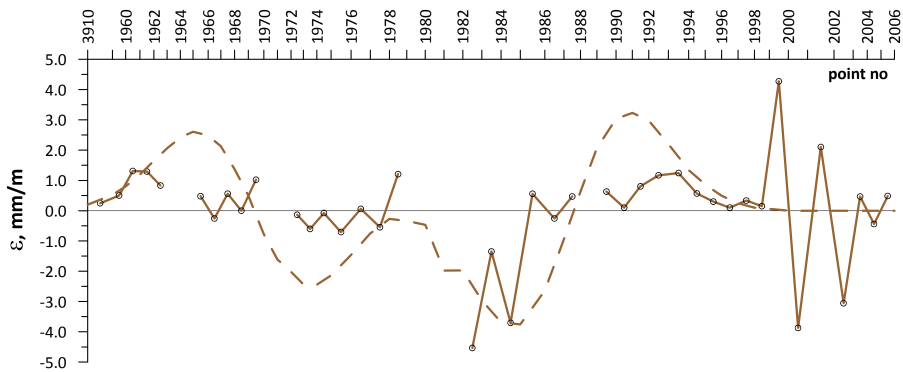

Fig. 15. Measured (solid line) and calculated (dashed line) horizontal deformations due to the operation of the longwall 534 in III[rd] layer of the seam 510

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5. An analysis of measurement results and gained experience

These examples confirm, to a varying degree, the influence of coal bed inclination and the direction of exploitation on the distribution of longwall deformation indicators. The presented factors should be researched separately. Impact assessment of the coal bed inclination should diagnose properly the distribution of deformation for the operation of the horizontal coal bed. Such process of cognition is possible in theory or by study on numerical equivalent models, in practice it is almost impossible to achieve.

The first and third examples reveal a significant effect of mining operation direction on the development of extreme deformation indicators. An average tilt that occurred on the surface over exploited longwalls' initial edges is greater by 75%, and the tensile horizontal deformation (from the 1st example) is also greater by 80% than the value observed over the end edge of the panel. A more effective method is to reach the protected area through the front of the longwall than to start mining exploitation in its area (Kwiatek et al., 1997; Mielimąka, 2009).

The second example presents the impact of the order and direction of the operation and the inclination of the coal bed on the distribution and extreme values of deformation indexes. The deformation is increased when the mining exploitation of the second layer takes place in the opposite direction to the coal bed dip. It can be concluded that considering the development of the longwall deformation, it is preferably to operate the longwall in the direction of the coal bed inclination, starting from the lift side. It is visibly reflected in the values of the variation coefficient of mining exploitation influence due to seam dip.

The theoretical references describe the influence of the coal bed inclination on the distribution of longwall deformation, by dividing panels into elementary fields (stripes of corrected height acc. to the inclination), parallel to the coal bed strike, which are calculated for the partial subsidence. Each of the partial distribution is symmetric, and the asymmetry is achieved only as a result of summation (integration) of all distributions. Concurrence is, however, approximate (Hejmanowski & Kwinta, 2010, Kwiatek et al., 1997). It seems that the theoretical description of the inclination effect on the formation of Carboniferous strata deformation can be improved by varying the parameter r in the Knothe-Budryk theory for directions of dip and strike coal seam. Moreover, Bals earlier had distinguished boundary angles γ of operation influences for the lift, dip and strike of seam. The nature of the deformation process causes that the boundary angle γ can be identified with the angle of main influences (Bals, 1931-1932).

Asymmetry phenomenon in the trough deformation, due to the operation direction, can probably explained by horizontal deformation history (on surface) and vertical (in the rock mass) in the area of the initial and end edge of the panel. The influence of mining operation direction on the distribution of deformation was the subject of research by Mielimąka (2009), who has proposed the changes in the algorithms of calculation to be taken into account in terms of these directions.

Designated parameters of the Knothe-Budryk theory for the analysed examples are varied, subsidence factor is ranged from 0.68 to 0.97, and the rockmass parameter tgβ is ranged from 1.6 to 4.6, which confirms necessity to properly select the parameters to the deformation projections.

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6. Conclusion

Collected and documented examples of the distribution of deformation indicators confirmed the observations concerning the impact of the operation direction and the coal bed inclination on the formation of longwall deformation. Significant is a necessity to consider seam inclination in the deformation projections, even in the case of low value (up to 10°) but exploited at great depths. Previously the seams with small inclination could be classified as horizontal.

New documented knowledge on the surface deformation processes shall help to improve methods for deformation projection, which is the aim of the research has conducted at the Central Mining Institute.

Examples of calculated and measured deformation indexes confirm the possibility to project deformation using Knothe-Budryk theory, throughout a good selection of parameters of the theory and a proper investigation of geological and mining data.

A number of recommendations for mining prevention methods reducing deformation indicators arise from the analysed examples:

– it is more efficient to conduct the operation by the longwall front to reach the protected area,
– in the case of inclined coal bed it is more effective to start and carry out the exploitation with caving from the lift, than from the dip side of coal seam.

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