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STANISŁAW KNOTHE*

THE TIME OF APPEARANCE OF IMPACTS OF INTERRUPTED MINING ACTIVITIES ON THE SURFACE

CZAS WYSTĘPOWANIA NA POWIERZCHNI SKUTKÓW PRZESTOJÓW FRONTU EKSPLOATACJI I ICH INTENSYWNOŚĆ

The paper provides the results of research conducted in the coal mines "Wesoła" and "Ziemowit", exploring how the stopping of mining operations at weekends should impact on subsidence and surface deformations. Daily measurements of ground subsidence taken with the use of geodetic techniques and strain gauge readouts taken every three hours reveal that impacts of stopping and recommencing of mining activities are rapidly manifested on the surface. The surface response shows after 1 or 2 days and the impacts persist for 2–4 days. The intensity of the ground response is manifested as a significant reduction in the daily increase of ground deformation and subsidence after the mining operations are stopped, followed by a rapid increase of these parameters when mining operations are recommenced.

Key words: mining damages, interruption of mining operations, subsidence and surface deformations

Artykuł przedstawia, podobnie jak dwie prace poprzedzające, wyniki badań przeprowadzonych w kopalniach „Wesoła" i „Ziemowit" nad wpływem okresowych przestojów sobotnio-niedzielnych frontu ścianowego na intensywność zmian wartości przemieszczeń pionowych i odkształceń poziomych oraz ich przebieg w czasie. W artykule ograniczono się do analizy wyników pomiarów, które nie budziły wątpliwości, mianowicie do:

- pomiarów obniżeń *w* prowadzonych przez zespół pracowników Akademii Górniczo-Hutniczej metodami geodezyjnymi oraz
- pomiarów odkształceń poziomych ε prowadzonych, przy zastosowaniu tensometrów, przez zespół pracowników Instytutu Mechaniki Górotworu PAN, przy czym ograniczono się do wykorzystania wyników pomiarów dokonywanych w czasie, gdy obszar w którym zainstalowane były tensometry podlegał odkształceniom ściskającym.

Pomiary obniżeń prowadzone były w okresie intensywnych ruchów terenu co 24 godziny, natomiast pomiary odkształceń poziomych dokonywane były w sposób ciągły, z rejestracją wyników co

* INSTYTUT MECHANIKI GÓROTWORU, POLSKA AKADEMIA NAUK, 30-059 KRAKÓW, UL. REYMONTA 27

3 godziny. Bardzo duża dokładność pomiarów tensometrycznych pozwoliła na otrzymanie dokładnego obrazu przebiegu zmian bardzo małych wartości dobowych przyrostów odkształceń poziomych Δε [mm/m/dobę].

Usytuowanie linii pomiarowych, geodezyjnej i tensometrycznej w stosunku do pola ścianowego pokazują rysunki 1 i 2. Parametry ścian i warunki w jakich prowadzono eksploatację były w obu kopalniach bardzo podobne (tabl. 1).

Postępy dzienne frontów ścianowych, wartości dobowych przyrostów obniżeń Δ*w* [m/dobę], przebiegi wartości odkształceń poziomych ε oraz wartości ich dobowych przyrostów Δε [mm/m/dobę] (wartości dobowych przyrostów odkształceń poziomych zostały na rysunkach dziesięciokrotnie powiększone) pokazane zostały, przykładowo dla wybranych reperów niwelacyjnych oraz odpowiadających im tensometrów, na rysunkach 3, 4, 5 i 6.

Wyniki pomiarów przedstawione na tych rysunkach wykazują z dużą dokładnością, zwłaszcza w przypadku eksploatacji w kopalni „Wesoła" (rys. 3 i 4), nadzwyczaj regularne, okresowe występowanie na powierzchni skutków przestojów frontów z niewielkim opóźnieniem i dużą intensywnością.

Skutki zatrzymań frontu ścianowego ujawniają się już po około 24 godzinach spadkami wartości dobowych przyrostów obniżeń Δ*w*, które w trzecim dniu po zatrzymaniu frontu wynoszą już tylko 13–30% wartości największych w ostatnim dniu przed zatrzymaniem frontu. Po uruchomieniu frontu przyrosty Δ*w* zaczynają wzrastać, osiągając w czwartym dniu po uruchomieniu frontu wartość odpowiadającą ciągłej eksploatacji. Podobnie zmieniają się wartości dobowych przyrostów odkształceń poziomych Δε, przy czym okresy czasowe zachodzących zmian są nieco dłuższe, a względne zmiany wartości dobowych przyrostów odkształceń poziomych Δε stosunkowo większe niż w przypadku obniżeń.

Podobnie, choć nieco mniej regularnie i wyraźnie, zjawisko przebiegało w kopalni „Ziemowit" (rys. 5 i 6), co przypuszczalnie należy przypisać dwukrotnie mniejszym niż w kopalni „Wesoła" i nieregularnym postępom frontu ścianowego oraz nieco odmiennym własnościom górotworu.

Słowa kluczowe: szkody górnicze, przestoje frontu, obniżenia i deformacje powierzchni

1. Introduction

The present study and two earlier works (Popiołek, Ostrowski, Sapata, Wójcik 2003) and (Gustkiewicz, Kanciruk, Stanisławski 2003) present the selected results of research work on the impacts of downtime in the mining operations on the ground surface, basing on results of field tests. The measurements were taken by two research teams: from the AGH University of Science and Technology (coordinated by Prof. Popiołek) and from the Strata Mechanics Research Institute of the Polish Academy of Sciences (coordinated by Prof. Gustkiewicz). Measurements were taken in two coal mines, as a part of the research programme supported by the State Committee for Scientific Research (KBN).

The issues relating to the impacts of mining operations stoppage have been extensively studied for more than ten years by those investigating the mining impacts. They have focused on the intensity of ground deformations and the time after which those impacts are revealed. New studies on mining impacts supported by more precise and more frequent measurements being completed, a more accurate and detailed explanation of the problem might be now available.

There is no doubt that a thorough study of the problem requires well-proven data from many more mining operations covering a variety of conditions, supported by most accurate and frequent measurements.

Such data were collected by the teams of research workers from the AGH University of Science and Technology and from the Strata Mechanics Research Institute in the coal mines “Wesoła” and “Ziemowit”. In those two cases mining operations were conducted in regions undisturbed by previous mining activities and in similar conditions (see Table 1), the only difference lay in the rate of the face advance. In the coal mine “Wesoła” the rate was two times greater than that in the mine “Ziemowit”.

TABLE 1

Parameters and conditions of mining operations

TABLICA 1

Parametry i warunki, w jakich prowadzono eksploatację górniczą

	Coal mine “Wesoła”	Coal mine “Ziemowit”
Seam designation	308	207
Longwall	104	719
Seam thickness	2.6–3.0 m; average 2.9 m	2.7–3.1 m; average 3.0 m
Depth	Average 405 m	350–440 m
Longwall length	240 m	235–250 m
Wall range	1170 m	1750 m
Average rate of advance*	7.8 m per day	4.1 m per day
Overburden		
# Quaternary rocks	Sand, clay; 10 m	Sand, clay; 10–25 m
# Tertiary rocks	Silts 105 m	Silts 105 m
# Triassic rocks	Marl, limestone; 15 m	Marl, limestone; 10–50 m

* The average value for the whole period of measurements.

Two observation lines were set up on the surface, above the mining operations: a geodesic line for measuring ground deformations and subsidence with the use of geodetic survey techniques and a line of strain gauges. The first measurements were conducted by the research team from the AGH University of Science and Technology; the latter — by the research team from the Strata Mechanics Research Institute. They used 8 strain gauges, with the base line 8 m long. The locations of the observation lines are indicated in Fig. 1 and 2.

The data on field conditions, rock mass properties, the applied mining methods and survey techniques as well as the employed measuring techniques, equipment and measurement precision are omitted here as these were presented in detail in the previous two papers.

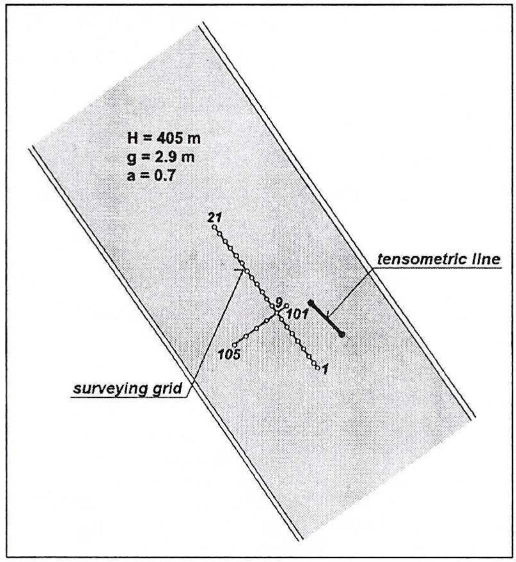


Fig. 1. The orientation of observation lines above the panel 104 in the coal mine "Wesoła"

Rys. 1. Usytuowanie linii pomiarowych nad polem ściany 104 w KWK „Wesoła"

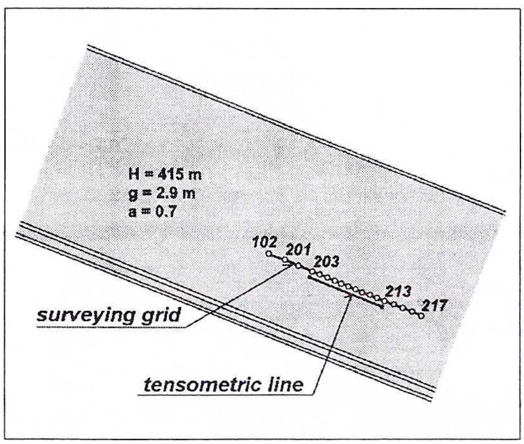


Fig. 2. The orientation of observation lines above the panel 719 in the coal mine "Ziemowit"

Rys. 2. Usytuowanie linii pomiarowych nad polem ściany 719 w KWK „Ziemowit"

Geodetic surveys of subsidence and measurements of horizontal deformations were taken daily (every 24 hours), at the period of most intense rock mass motion. Measurements of horizontal deformations with the use of strain gauges were taken every 3 hours and the results were automatically recorded.

The analysis of measurement results clearly shows that geodetic measurements of subsidence and, though with certain reservations, also measurements of horizontal deformations with the use of strain gauges best illustrate ground motion disturbances due to periodic stopping of longwall mining. Measurements using strain gauges are reliable in those periods of time when the area where strain gauges are fixed is subject to compressive strain. In the periods where tensile strain was predominant the strain gauges were no longer reliable, maybe because of the way they were secured in place and also due to the presence of water in the area. On the other hand, the results of geodetic measurements of horizontal deformations failed to give a clear picture of the impacts produced when mining operations were stopped as the measurements were not precise enough to determine the daily increments of horizontal deformations due to mining activities in the coal mines "Wesoła" and "Ziemowit".

The issues related to precision and reliability of measurements being duly considered, the analysis of the impacts of interrupted mining operations on ground subsidence and deformations takes into account the following parameters:

- subsidence (vertical deformation) determined with the use of geodetic surveys,
- horizontal deformations measured with strain gauges

which appeared when ground motions were most intense. The period during which the interruptions of mining operations manifested themselves most clearly covered the time when the working face moved from underneath the measurement point to the distance 0.5–0.9 of the radius r of the main impact zone.

Daily measurements yielded the daily increments of subsidence Δw and horizontal deformation $\Delta\varepsilon$. Their variations are shown in the form of time patterns in Fig. 3, 4, 5, providing the graphs of daily variations of subsidence Δw m/24 hours of a specified benchmark (geodetic position) and of daily variations of horizontal deformation $\Delta\varepsilon$ mm/m/24 hours measured with a strain gauge positioned at the same distance from the working face as the benchmark.

2. Results of measurements taken in the coal mine "Wesoła"

Results of measurements taken in the coal mine "Wesoła", graphed in Fig. 3, 4, show the daily increments of horizontal deformation $\Delta\varepsilon$ registered by two strain gauges in extreme positions (no. 1 and 8), at the distance 40 m from one another, as well as daily increments of subsidence Δw of the corresponding benchmarks. Measurements reveal that:

- there is rapid rock mass (surface) response to stopping and recommencing of longwall mining after a weekend break,
- daily increments of subsidence and horizontal deformations are considerable,
- these effects are repeated each time the mining operations are thus interrupted.

The impacts upon the rock mass are revealed after 1–3 days (sometimes even after 4 days) from the moment mining activities were stopped or recommenced and persist for 3–5 days. When horizontal deformations are considered these periods are slightly longer.

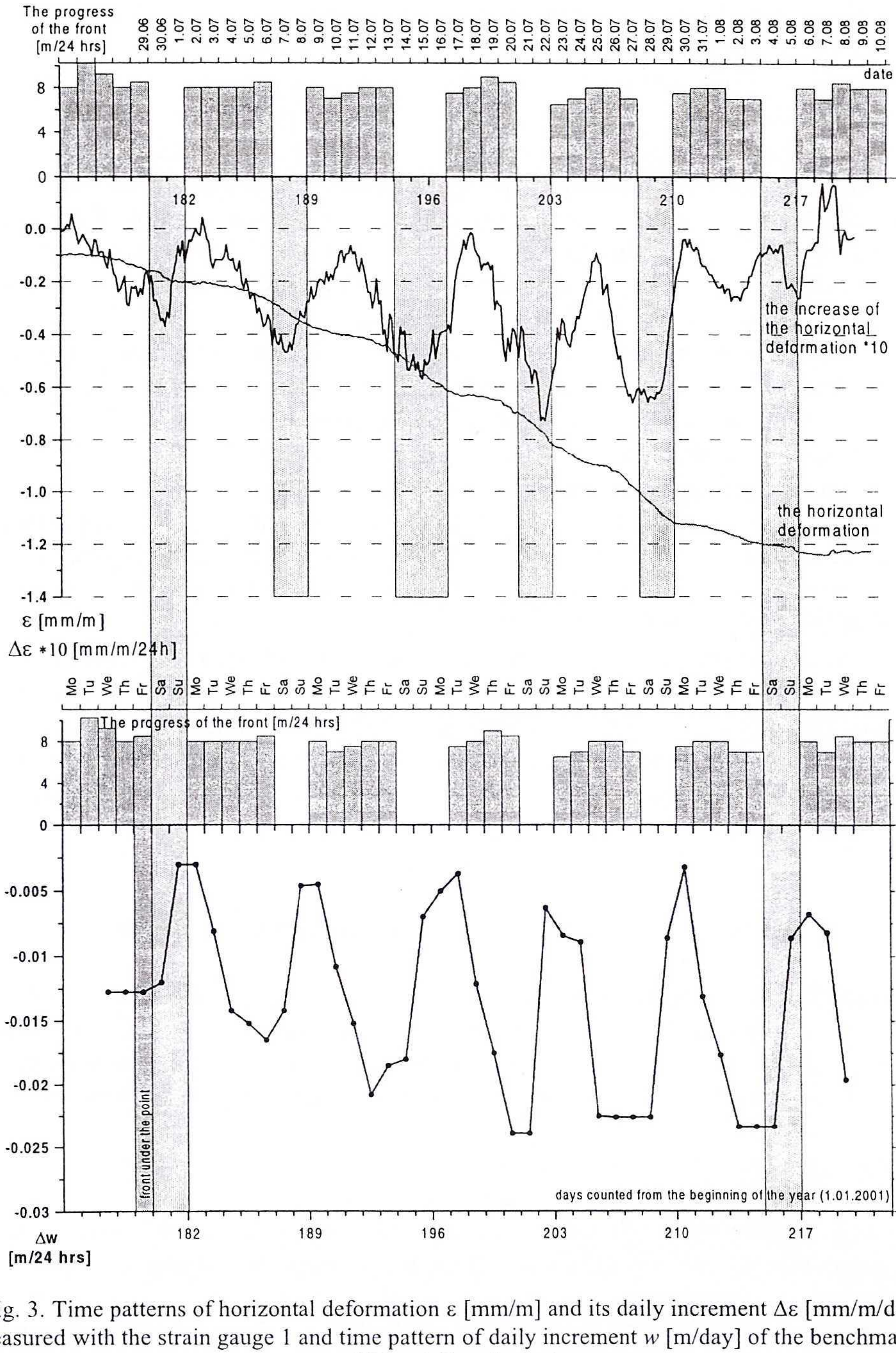


Fig. 3. Time patterns of horizontal deformation ε [mm/m] and its daily increment Δε [mm/m/day] measured with the strain gauge 1 and time pattern of daily increment *w* [m/day] of the benchmark 4 ("Wesoła" coal mine)

Rys. 3. Przebieg odkształceń poziomych ε [mm/m] i ich dobowych przyrostów Δε [mm/m/d] zmierzonych tensometrem nr 1 oraz przebieg dobowych przyrostów Δ*w* [m/d] punktu nr 4 w kopalni „Wesoła"

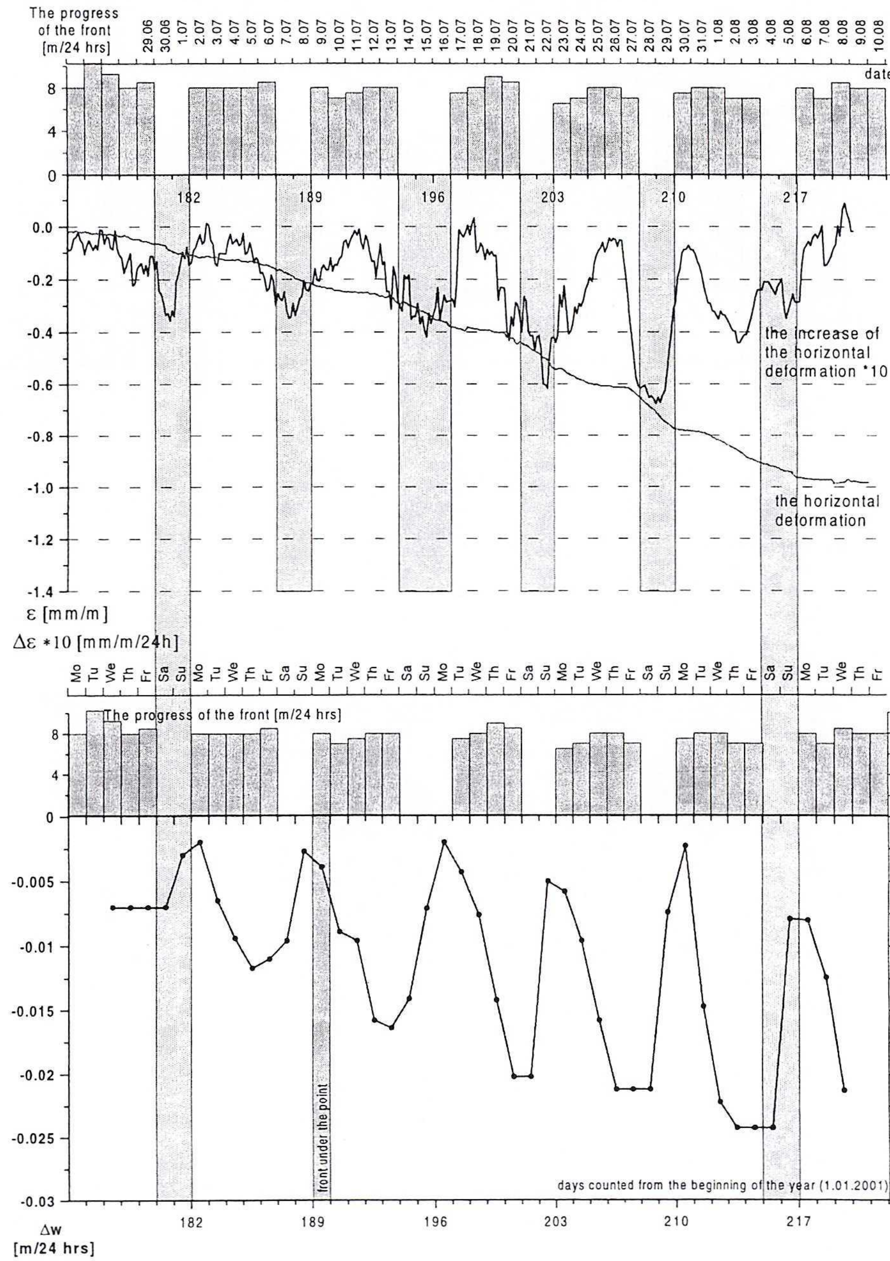


Fig. 4. Time patterns of horizontal deformation ε [mm/m] and its daily increment Δε [mm/m/day] measured with the strain gauge 8 and time pattern of daily increment Δw [m/day] of the benchmark 9 ("Wesoła" coal mine)

Rys. 4. Przebieg odkształceń poziomych ε [mm/m] i ich dobowych przyrostów Δε [mm/m/dobę] zmierzonych tensometrem nr 8 oraz przebieg dobowych przyrostów Δw [m/d] punktu nr 9 w kopalni „Wesoła"

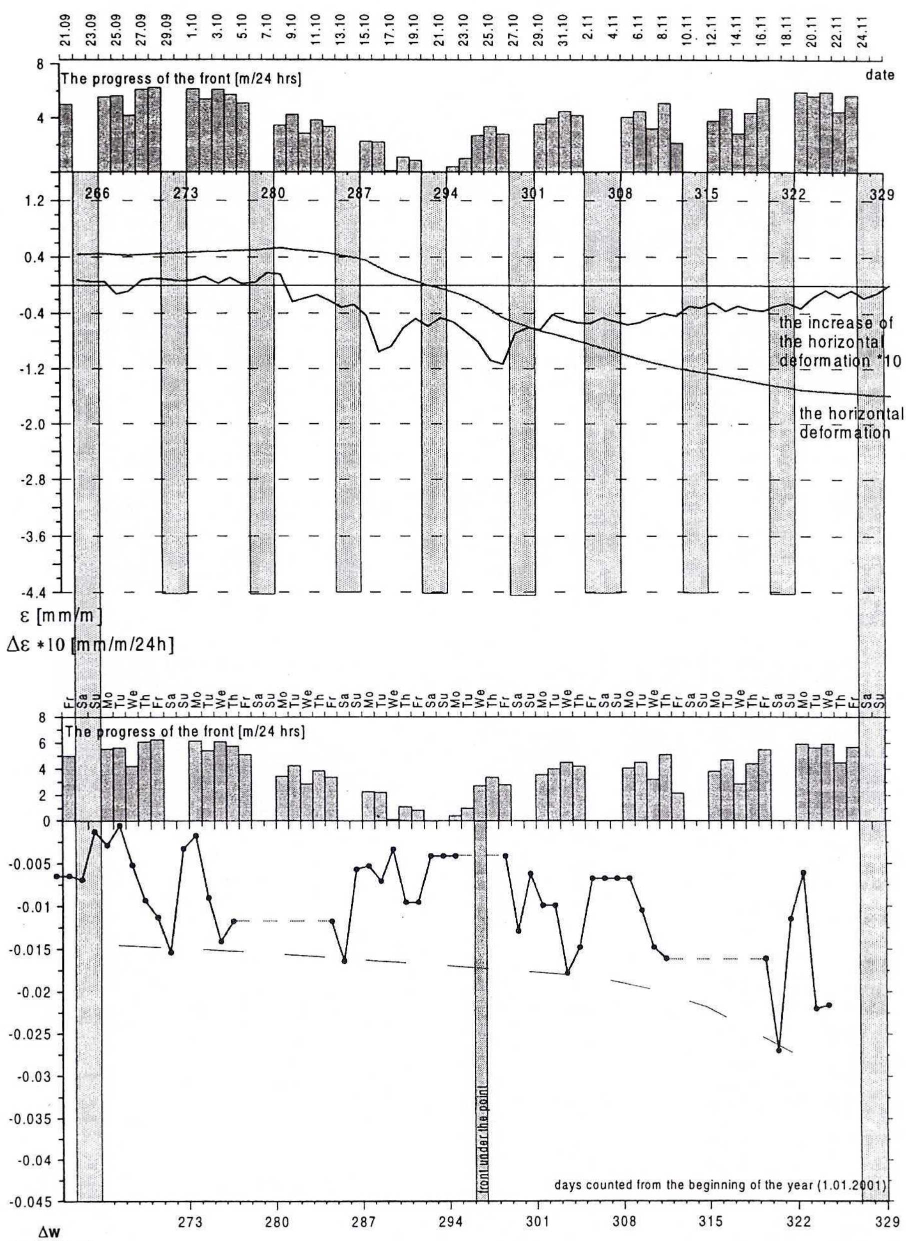


Fig. 5. Time patterns of horizontal deformation ε [mm/m] and its daily increment Δε [mm/m/day] measured with the strain gauge 5 and time pattern of daily increment Δ*w* [m/day] of the benchmark 206 ("Ziemowit" coal mine)

Rys. 5. Przebieg odkształceń poziomych ε [mm/m] i ich dobowych przyrostów Δε [mm/m/dobę] zmierzonych tensometrem nr 5 oraz przebieg dobowych przyrostów Δ*w* [m/d] punktu nr 206 w kopalni „Ziemowit"

Fig. 3 providing the results of measurements of the benchmark 4 with the use of the strain gauge 1 shows that the value of daily increment of subsidence Δw begins to decrease about 24 hours after the working face is stopped and after 48 hours, i.e. on the third day will reach its minimal value amounting to 13–30 % of the maximal value registered on the last working day (Friday). When mining activities are recommenced, the subsidence increment Δw begins to increase after nearly 24 hours. This process continues for about 3 days (72 hours); afterwards (on the fourth day) the subsidence increment reaches the value registered when mining activities are continued uninterrupted.

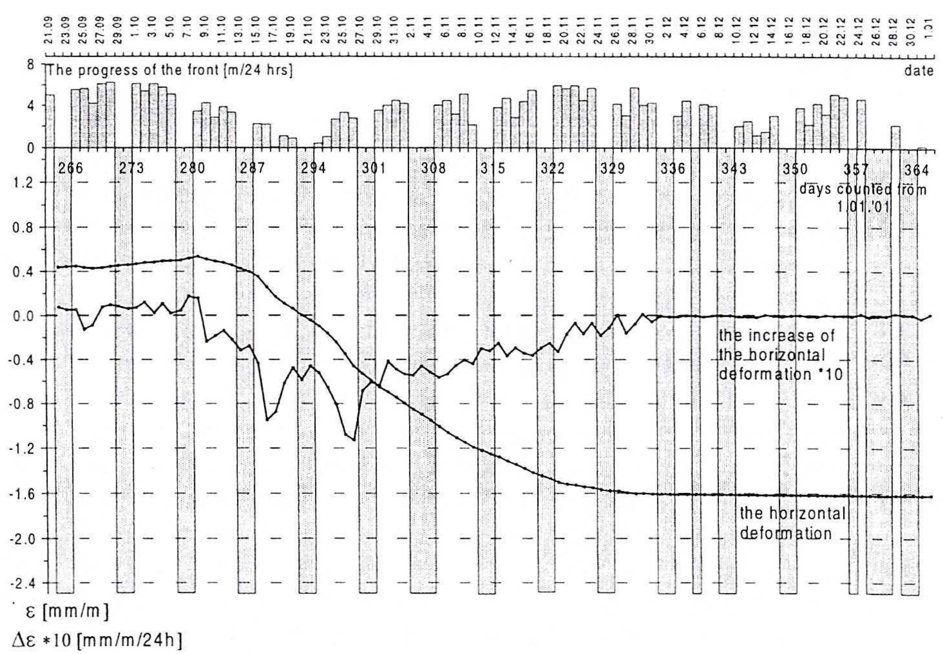
As far as daily increments of horizontal deformation are concerned, the response time will be longer. When the working face is stopped, the value of increment begin to decrease after 36–48 hours and on the fifth or sometimes fourth day (after about 72 hours) it reaches its minimum equal to 3–17 % of the maximal value registered the day before the mining activities were interrupted. When mining activities are started anew, the impacts manifest themselves after 48–72 hours and $\Delta\varepsilon$ continues to rise until the seventh day — which is the day when mining operations are interrupted again. The values of the daily increment of horizontal deformation $\Delta\varepsilon$ would therefore not reach the value registered when mining activities are continued uninterrupted and the $\Delta\varepsilon$ variation pattern has a saw-tooth profile. Thus obtained variation pattern $\Delta\varepsilon$ is obtained for the predetermined effective work time to downtime ratio (i.e. when mining operations are stopped).

3. Results of measurements taken in the coal mine "Ziemowit"

Measurements taken in the coal mine "Ziemowit" did not give such a full and clear picture as those taken in "Wesoła" mine. Fig. 5 shows the selected daily increments of subsidence Δw registered in the benchmark 206 and daily increments of horizontal deformations measured with the nearest strain gauge (no. 5).

Though subsidence measurements were taken at intervals, the impacts of stopping and starting the longwall mining were clearly seen. The subsidence variation patterns, however, seem less regular than those obtained in the coal mine "Wesoła" due to significant fluctuations in the daily rates of face advance.

The influence of interrupted mining operations on the daily increment of horizontal deformations is less marked and irregular. The pattern of daily variations of $\Delta\varepsilon$ increments in the coal mine "Wesoła" in the period of most intense ground motions was almost exactly repeated every week, which is also confirmed by readouts from all strain gauges while there are some major differences between the time patterns of $\Delta\varepsilon$ obtained in the coal mine "Ziemowit". As an example, take a close look at time patterns of $\Delta\varepsilon$ (Fig. 6) registered by two strain gauges 5 and 7 located at the distance of 20 m from one another. The time patterns of registered by other strain gauges in the coal mine "Ziemowit" display certain differences, too. Furthermore, only the impacts of 2–3 subsequent interruptions occurring at different times are clearly indicated.



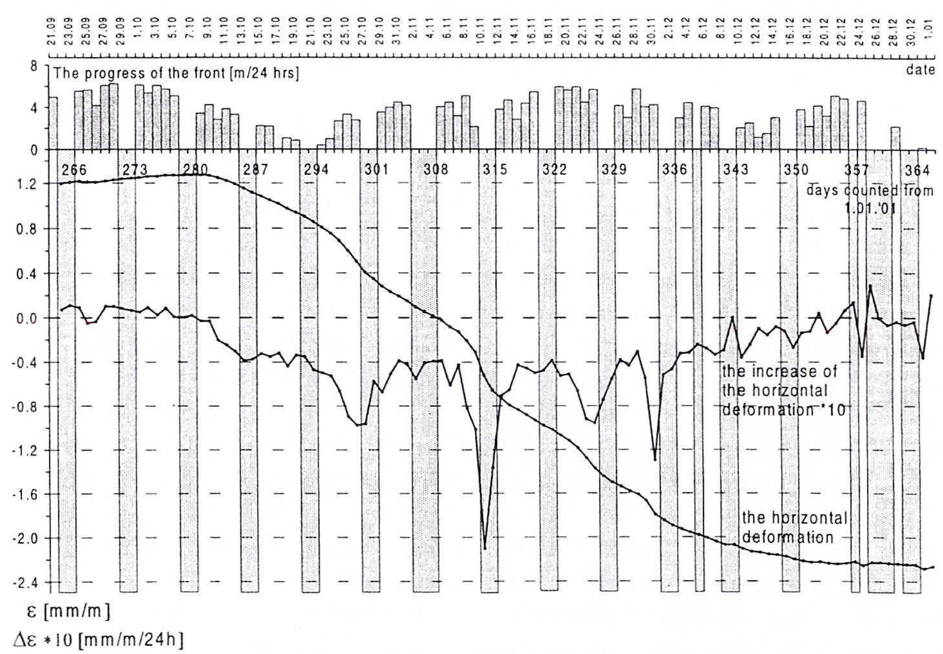


Fig 6. Time patterns of horizontal deformation ε [mm/m] and its daily increment Δε [mm/m/day] measured with the strain gauge 5 (upper section) and 7 (lower section) in the coal mine "Ziemowit"

Rys. 6. Przebieg odkształceń poziomych ε [mm/m] i ich dobowych przyrostów Δε [mm/m/dobę] zmierzonych tensometrem nr 5 (u góry) i nr 7 (u dołu) w kopalni „Ziemowit"

The differences between time patterns of $\Delta\varepsilon$ in the coal mine "Ziemowit" might be accounted for by decidedly slower and irregular rate of face advance and quite different geological conditions, hence the impacts were appearing on the surface as a discontinuous process. Nevertheless, the measurements of daily increments of subsidence Δw and horizontal deformations $\Delta\varepsilon$ confirm the adequacy of earlier results in terms of time and intensity of ground motion in response to interruptions of mining operations even though the data obtained in the coal mine "Wesoła" display less regularity.

Conclusions

Most precise daily surveys of surface subsidence and measurements of horizontal ground deformations taken with strain gauges supported by automatic recording of results every 3 hours enabled us to determine the daily increments of subsidence and horizontal ground deformations. Such precise and extensive measurements were done for the first time. The results led to the following conclusions:

1. The impacts of interrupted longwall mining (when mining activities are stopped and recommenced again) very quickly appear on the surface(after 24–48 hours),though in the coal mine "Wesoła" they are slightly delayed, and persist for 2–4 days.

2. These impacts manifest themselves as significant changes of velocity (and acceleration) of ground subsidence and horizontal deformation. In the case of regular, periodic interruptions (on Saturdays and Sundays) that might means periodic changes repeatedly affecting the area.

3. The impacts appear to be more intense when the rates of face advance in the mine are higher.

4. When the rates of face advance are higher and mining operations have to be interrupted, the surface structures are exposed to greater ground subsidence and deformations than during uninterrupted mining activities. Moreover, these negative impacts are repeated many times.

5. In order to establish how other factors, such as the rate of advance, properties of the rock mass, the extent of previous mining activities, should contribute to the impacts of interrupted mining activities, extensive data would have be collected on mining activities in various conditions.

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