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THE STUDIES ON THE RESULTS OF PERIODICAL STOPPING OF THE EXPLOITATION FRONT IN THE SEAMS OF MINERAL COAL WITH THE USE OF SURVEYING METHODS

BADANIA SKUTKÓW OKRESOWYCH ZATRZYMAŃ FRONTU EKSPLOATACJI W POKŁADACH WĘGLA KAMIENNEGO Z WYKORZYSTANIEM METOD GEODEZYJNYCH

Based on surveying in mines "Wesoła" and "Ziemowit" the influence of the breaks in exploitation fronts on vertical translocations and horizontal deformations of the area surface was made. A very quick manifestation of the results of stopping and restarting the exploitation front within 24 hours for subsidence and 48 hours for horizontal deformations and the high intensity of this impact were found. These results manifest with very big changes in the increases of traslocations and horizontal deformations per day. They diminish with the stopping of the front till 10–30% of maximum values and then, after its restarting grow to maximum values within 1–2 days. Significantly greater irregularity of the course of the process of the rock mass deformation was observed.

The results of the observations showed that discontinuous mining exploitation could unfavourably effect the buildings and the development of the area increasing the risk of damage. Presented in the paper results of the survey can be used as source material for the verification of existing views on this issue.

Key words: influence of exploitation, exploitation rate, stoppage of the exploitation front, land subsidence and deformation

Badania wpływu przestojów frontów ścianowych na przebieg przemieszczeń pionowych i deformacji powierzchni terenu zrealizowano w oparciu o pomiary geodezyjne przeprowadzone w dwóch rejonach eksploatacji pokładowego złoża węgla kamiennego. Pierwszy rejon wybrano nad eksploatacją ściany 104 (pokład 308) w obszarze górniczym kopalni „Wesoła", drugi natomiast — nad eksploatacją ściany 719 (pokład 207) w obszarze górniczym kopalni „Ziemowit". W obu przypadkach była to eksploatacja pierwszego pokładu prowadzona ścianowym systemem zawałowym z dużym postępem frontu osiągającym wartość do 12 m/dobę.

Badania prowadzono wykorzystując specjalnie zastabilizowane linie obserwacyjne: W1 (Kopalnia „Wesoła") i Z1 (Kopalnia „Ziemowit") — rys. 2 i 3. Współrzędne płaskie punktów obserwowanych

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wyznaczano przy zastosowaniu techniki satelitarnej GPS. Zakres pomiarów geodezyjnych obejmował wyznaczanie wysokości punktów oraz długości baz pomiarowych. Pomiary te wykonywano równocześnie tzw. metodą trzech statywów z wymuszonym centrowaniem z wykorzystaniem tachimetru elektronicznego. Obserwacje objęły cały okres wpływów górniczych, przy czym w okresie występowania najintensywniejszych wpływów pomiary realizowane były w cyklu dobowym (łącznie w obu rejonach przeprowadzono 77 serii pomiarowych).

Zrealizowany zakres pomiarów linii obserwacyjnych umożliwił wyznaczanie wartości podstawowych wskaźników deformacji oraz ich zmian szczególnie w okresach zatrzymań frontów eksploatacji i ponownych ich uruchomień. Już wstępna analiza wykazała, że skutki każdego z przestojów frontu eksploatacyjnego pod względem jakościowym okazały się zbliżone. Wskazuje to na podobną reakcję górotworu na nieciągłe prowadzenie frontów eksploatacji w obu rejonach badawczych.

W celu ilościowego opisu wpływu przestojów frontu eksploatacji na przebieg obniżeń terenu sporządzono wykresy obniżeń w czasie wybranych punktów linii obserwacyjnych (rys. 4 i 11). Wyraźnie widoczne są charakterystyczne „wypłaszczenia" wykresów po zatrzymaniu frontu eksploatacji złoża i ponowne przyspieszenie obniżeń po ponownym jego uruchomieniu. Efekt nierównomierności przebiegu obniżeń punktów w czasie najbardziej widoczny jest w analizie przyrostów obniżeń w jednodobowych interwałach czasu, na co pozwoliły przeprowadzone pomiary geodezyjne.

Celem przeprowadzenia dokładniejszej analizy wyżej opisanego efektu sporządzono wykresy przyrostów obniżeń w czasie (rys. 6, 7 i 16) dla trzech reprezentatywnych punktów linii W1 i Z1. Na tych wykresach obserwuje się podobny efekt spowolnienia procesu narastania obniżeń po upływie doby od zatrzymania frontu eksploatacji oraz jego przyspieszenia po upływie doby od ponownego rozpoczęcia urabiania. Wyniki wykonanych w tym okresie obserwacji bezspornie wykazały, że górotwór reaguje bardzo szybko na wszelkie zaburzenia w ciągłości eksploatacji, co nie potwierdziło wcześniejszych poglądów tygodniowego bądź nawet dłuższego czasu takiej reakcji. W aspekcie ilościowym zauważyć można, że zmiany przyrostów obniżeń punktów zależą zarówno od czasu trwania przerwy eksploatacyjnej, jak też od odległości krawędzi eksploatacji od obserwowanego punktu w trakcie przestoju. Dobowy przyrost obniżeń w rejonie I zmniejszał się maksymalne z wartości około 20 mm/dobę przy postępującym froncie do 3–5 mm/dobę po jego zatrzymaniu. Większe różnice obserwowano w rejonie II, w którym dobowy przyrost obniżeń po zatrzymaniu frontu eksploatacji, zmniejszał się maksymalne z wartości około 35 mm/dobę do 5–7 mm/dobę.

Analiza obserwowanych odkształceń poziomych w czasie (rys. 8 i 13) w obu rejonach badań prowadzi do spostrzeżenia, iż w efekcie zatrzymania i ponownego uruchomienia frontu eksploatacji, występują zaburzenia tych przebiegów polegające na zmianach dobowych przyrostów odkształceń baz pomiarowych. Dla dokładniejszej analizy tego zjawiska sporządzono dla wszystkich odcinków linii pomiarowych W1 i Z1 wykresy przyrostów odkształceń poziomych w czasie (przykładowo dla boku 1–2 rys. 9 i dla boku 212–213 rys. 14). Na wykresach obserwuje się efekt wahania przyrostów odkształceń poziomych w interwałach czasowych nie przekraczających 2–3 doby (czasami nawet jednej doby) od zatrzymania lub ponownego uruchomienia frontu eksploatacji. Zmiany polegają na tym, że każda baza pomiarowa, w czasie obejmującym przerwę eksploatacyjną oraz okres ponownego uruchamiania frontu eksploatacyjnego, podlega niewielkiemu ściskaniu lub rozciąganiu, niezależnie od tego, czy w tych okresach znajduje się w fazie odkształceń rozciągających czy ściskających.

Na podstawie analizy wartości zmian odkształceń poziomych można stwierdzić, że fluktuacje spowodowane przerwami eksploatacyjnymi nie zaburzają zasadniczo generalnego trendu zmian tego wskaźnika deformacji. Szczegółową analizę utrudniał fakt występowania niewielkich wartości dobowych przyrostów odkształceń poziomych, mieszczących się w większości przypadków w granicach dokładności ich rejestracji (m_ε = ±0,18 mm/m). Maksymalne wartości dobowych przyrostów odkształceń poziomych w rejonie I nie przekraczały $\Delta\varepsilon(I)$ = 0,65 mm/m/dobę, natomiast w rejonie II — $\Delta\varepsilon(II)$ = 0,5 mm/m/dobę.

Podsumowując przeprowadzone badania należy stwierdzić, że pozwoliły one po raz pierwszy na uzyskanie jednoznacznego obrazu wpływu przestojów ścianowych frontów eksploatacji na przebieg procesu deformacji powierzchni terenu. Generalnie należy stwierdzić, że nieregularne prowadzenie eksploatacji górniczej (w szczególności jej zatrzymania i ponowne uruchomienia) w dużo większym niż dotychczas przypuszczano stopniu zaburzają przebieg procesu deformacji górotworu i powierzchni terenu.

Po zatrzymaniu frontu eksploatacji zaobserwowano znaczny spadek dobowych przyrostów obniżeń (do 20% wartości maksymalnych). Efekt zatrzymania frontu ujawniał się już po jednej dobie od momentu zatrzymania eksploatacji i trwał 2–3 doby. Po ponownym uruchomieniu frontu eksploatacji również po okresie jednej doby następował szybki przyrost obniżeń dobowych i po 2–3 dniach osiągał wartości obserwowane przy ciągłym przebiegu frontu.

Reakcja na przestoje frontów eksploatacji w obserwowanych odkształceniach poziomych jest podobna do obserwowanych obniżeń, następuje ona jednak później, rozpoczyna się drugiego dnia od zatrzymania frontu i trwa około 3 doby. Natomiast reakcja na ponowne uruchomienie frontu trwała około 4 doby (do osiągnięcia maksymalnych przyrostów odkształceń poziomych dla pełnego biegu frontu).

Istotnym spostrzeżeniem jest wykazanie, że wpływ przestojów frontu eksploatacji występuje tym wyraźniej, im większa jest prędkość frontu eksploatacji.

Załączone w pracy tabele i wykresy stanowią ilościową dokumentację badanego procesu deformacji powierzchni terenu.

Słowa kluczowe: wpływ eksploatacji, prędkość eksploatacji, przestoje frontów, obniżenia i deformacje terenu

1. Introduction

With the growing advance (speed) of exploitation fronts both in Polish and world mining the question of the harmful influence of the dynamics of exploitation on the surface of the area appeared. The dynamic factors first of all include the increase of the speed of exploitation, its changes and the duration of breaks in exploitation.

Two first factors are described in very abundant literature. They were also widely discussed and documented in the research project no. 9 S60 1015 07, done by the team of Professor St. Knothe and Professor E. Popiołek from 1994 until 1997. The conclusions of these papers contribute much to the problem.

The influence of the breaks in mining exploitation on arising mining damage is known, but poorly documented. Among mining practitioners and scientists there is an opinion that a few days lasting breaks in exploitation fronts can be (depending on the rock mass and the speed of exploitation) more harmful for the buildings on the surface than a continuous exploitation, even if very intensive. With a big advance of exploitation fronts and stopping them for the weekends or holidays and then starting work again causes the increase of the acceleration in the deformation growth, compared with the exploitation with a constant speed. This causes the growth of stress in objects and the increase of damage on the surface of the area. The problem of harmfulness of the breaks in exploitation fronts became up-to-date because of the increased concentration of mining and increased exploitation speeds. This is a problem that appeared within the last few years and it is important, especially with growing responsibility for the protection of the mining area.

To define the impact of the breaks on the surface of the area it is necessary to assess the delays in the revealing of the influences of the breaks in exploitation front on the surface and how long the breaks already registered by the changes in translocations on the surface are. The views on this question varied in time. For example, it was said that the delay is several weeks, several days (Kowalski 1993, 1995) or less than ten days (Sroka 1999).

To obtain reliable data and justify controversial views, in 1999–2002 a research project was carried out, financed by the Polish State Committee of Scientific Research. Its purpose was to investigate the results of the breaks in exploitation, when the exploitation front moves very fast. Surveying and tensometric methods were applied in the research. This publication contains the information on the course of surveying methods, their results and the conclusions from data processing.

2. The existing views on the impact of non-continuous mining exploitation during so-called exploitation breaks

The problem of the influence of the speed and lack of continuity of the exploitation of the bed on the surface of the area and the buildings has not been satisfyingly solved so far. The research done so far in Poland and abroad generally show that it is optimal to exploit the bed with the constant speed, without making breaks. Objects on the surface are badly effected by too fast exploitation and discontinuities in time with irregular breaks and great changes in the progress of exploitation front. And yet, such a way of mining activates old workings and stimulates discontinuous deformations on the surface.

The measure of the impact of stopping and restarting exploitation fronts is the speed of changes of the deformation indexes i.e. discontinuity of the process of the formation of a dynamic subsidence trough. This statement is present in several papers by Polish and German authors (Sroka 1974, 1993; Knothe 1975, 1984; Dżegniuk, Sroka 1978; Sroka, Schober 1988, 1990; Hansel 1991).

The observed damage of the objects is connected with their small resistance on the disturbances in the regular course of the deformation process, especially with the accelerations of rock mass movements, which are greater in case of stopping the exploitation and its restarting, compared to the case of the continuous advance (Sroka 1974, 1993).

A linear reduction of the speed of exploitation front before longer breaks in exploitation and its linear growth after the renewing of mining are recommended (Sroka 1995; Knufinke 1996). In a basic phase the advance should be uniform, and maximal exploitation speed (as well as the acceptable length of breaks) should be individually determined, depending on the resistance of the objects (Knufinke 1996). If the exploitation is run with the breaks for Saturdays and Sundays — according to Kratzsch — for very sensitive objects the acceptable speed of the progress in the exploitation front should be 3 m/24 hrs and for other objects — 5 m/24 hrs (Kratzsch 1994).

Drzęźla, based on the approximate assessment of the influence of the changes in the speed of mining and exploitation breaks on the kinematics of the subsidence trough, draws similar conclusions. He states that changes in the speed of exploitation and breaks significantly multiply the growth of the deformation index for the surface of the area. Because of that, if the exploitation comes under a particularly important object, the continuity and uniformity of the progress in the exploitation front should be preserved.

At the same time the progress of mining under the object should be limited and changes in the progress should be gradual, in a certain distance in front of and behind the object (Drzęźla 1996). A relatively uniform progress of the exploitation front and the and reduction of the length of exploitation breaks can contribute to the minimisation of the harmful influence of the dynamics of exploitation on buildings (Hejmanowski et al. 1997).

Based on the presented above views one can conclude that a continuous exploitation with a proper constant speed can make an alternative for a costly procedure of securing the buildings.

The problem of the harmfulness of the exploitation breaks to the surface of the area and objects, has been reported for a long time in many German studies (Marbach 1939; Hofmann 1950; Nelson 1964, Lipmann 1974). In newer papers (Kratzsch 1990, 1994) it is stated that exploitation breaks stimulate subsidence troughs where maximal values of the deformation indexes are higher than in a finally shaped trough.

More exact studies in this area were done by Sroka (1999). As the conclusion, the author recommends a continuous exploitation at least in the area of the protected objects. This will protect these objects from periodical and undoubtedly harmful negative accelerations after stopping the mining front and positive accelerations after renewing the mining exploitation. These accelerations are bigger than the accelerations characteristic for the exploitation front progressing with a uniform speed. Sroka also notices that the influence of the breaks in exploitation on mining damage is as important as the influence of the exploitation speed.

As it results from practical experience, the damage of the objects depends on the level of a deformation index, the dynamics of exploitation and the duration of its influence. The analysed by Sroka examples of exploitation indicate that the highest number of the registered reports of mining damage takes place in the first two days of the week, i.e. after a weekend break in exploitation. Even greater number of reports took place after longer holiday breaks. One-day breaks usually did not cause changes in the number of complaints. As the example of the influence of the breaks in the high speed exploitation front one can take the exploitation of wall no. 206 in seam Mathilde of the mine Friedrich Heinrich, that was done with an enormous speed up to 30 m/24 hrs. On the subsidence curve of a selected point no. 20 situated on the surface of the area and stabilised over the centre of the wall (Fig. 1) the deformations caused by two two-days exploitation breaks are visible. A hypothetical undisturbed process of subsidence was presented by arrows. During the week before the first break the mean exploitation speed was 23 m/24 hrs (maximal 30 m/24 hrs), and in the following week 14 m/24 hrs. The introduction of continuous exploitation i.e. 6–7 days, significantly smoothened the process of the subsidence of this point.

The problem of the influence of a big progress in the exploitation front and breaks in exploitation on the surface of the area was also presented by Zych. In his article (Zych 2002) he presents a preliminary analysis of the results of surveys from the mine "Jankowice", made every day (in two measurement intervals), with a high progress of the exploitation front. He states that the breaks in exploitation caused the fall of

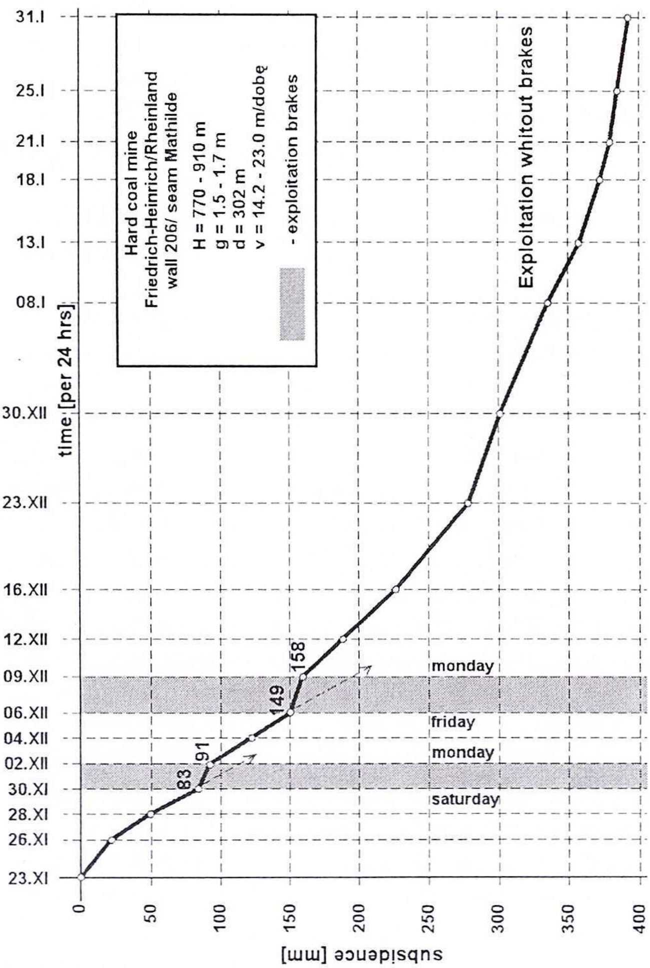

Fig. 1. The course of the subsidence of point no. 20 over the intensive exploitation of wall 206 in seam Mathilde, hard coal mine "Friedrich-Heinrich"

Rys. 1. Przebieg obniżeń punktu nr 20 nad intensywną eksploatacją ściany 206 w pokładzie Mathilde, KWK „Friedrich-Heinrich"

daily increases of subsidence points from the values up to 60 mm/24 hrs and above 100 mm/24 hrs to the values below 20 mm/24 hrs.

The existing views have been based on not very abundant field studies carried out only by surveying methods. This did not allow a full characteristic of this, very irregular in time, process. In the further part of this article the description of a substantial process based on authors' studies done by surveying methods and in the region two hard coal mines will be presented. Parallel research with the use of tensometric methods are the subject of a separate publication.

3. The characteristic of the study area

The surveying methods of the studies on the deformation of the surface of the area were applied in two mines of Upper Silesia. The first region was selected over the exploitation of wall 104 (seam 308) in the mining area of "Wesoła" (region I), while the other region — over the exploitation of wall 719 (seam 207) in the mining area of "Ziemowit" (region II).

These regions were selected because of the conditions they fulfilled both in terms of measurements as well as exploitation. In both regions the exploitation of first coal seam in the field of a large exploitation surface was carried out. The lack of objects on the surface allowed the use of a system of wall caving with a high progress of the exploitation front. A favourable forest management of the surface over the exploitation allowed making measurements without additional restrictions resulting from the area management related to the existence of buildings.

3.1. Geological and mining conditions in region I (mine "Wesoła")

In region I the mining exploitation was carried out in wall 104, seam 308. The exploitation field is located in the south–western part of the mining area of "Wesoła". In this region a loose overlay is built of Quaternary formations 10 m thick, formed as sand and clay, Tertiary formations about 105 m thick formed as silts, and Triassic formations 15 m thick, formed as marls and limestone. The Carboniferous formations were found up to the depth of 1000 m (to seam 342).

The thickness of seam 308, in the region of the exploited wall 104 ranges between 2.6 m and 3.0 m. In the roof of the seam there are silt shale of the thickness of 0.8–4.7 m. It was locally found that also directly in the roof of the seam, sandstone occurs. In the sole of the seam a 3.2–6.4 m thick layer of silt shale occurs. The inclination of the seam ranges on average from 0° to 6°.

The exploitation of wall 104 started on 19^{th} April 2001 (Fig. 2). The exploitation was run with the wall collapse system on the average depth of about 405 m. The length of the wall of the coasting was 1170 m, on the whole exploited section was constant — 240 m. The exploitation was run on the whole thickness of the seam 2.6–3.0 m (on average 2.9 m). The exploitation was run five days a week. The surveying was done in the period from the occurrence of first influence on 27^{th} September 2001, when the front was 270 m distance from the observation line.

In the analysed period, apart from weekend breaks, owing to the Board of the Mine, a 3 days test break was made. There were also a few holiday breaks and technological breaks. These breaks took place in the following periods: 28^{th} April-3^{rd} May 2001, 14–17^{th} June 2001, 14–16^{th} July 2001, 15^{th} August 2001 and 28–29^{th} August 2001.

Average advance of the exploitation front per 24 hrs was during the observations i.e. until 27^{th} September 2001 — 4.9 m/24 hrs. Regarding only working days, the average advance of the front was 7.4 m/24 hrs. Maximal exploitation advance was 10 m/24 hrs.

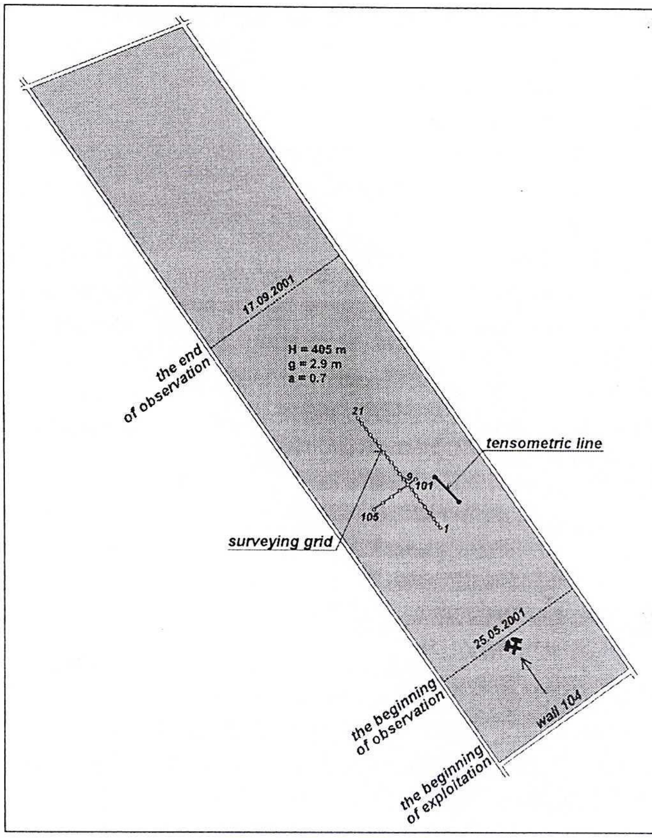

Fig. 2. The exploitation of wall 104, hard coal mine "Wesoła"

Rys. 2. Eksploatacja ściany 104, KWK „Wesoła"

When the front of wall 104 advanced to the observation line i.e. from 2nd July 2001 until 8th August 2001 basic surveying was made, organised in the cycle of 24 hrs. Average daily advance of the front was 5.5 m/24 hrs then; while without exploitation breaks it was 7.8 m/24 hrs. Maximal advance was that time 9 m/24 hrs.

3.2. Geological and mining conditions in region II (mine "Ziemowit")

In region II mining exploitation was run in the wall 719, seam 207. The exploitation field is located in central-west part of the Mining Area "Lędziny I". In this region loose overlay consists of Quaternary formations, thick from 10 m to 25 m, formed as sands, locally with silt, sandy clays and Tertiary formations 10 m to 210 m thick, formed in a silt face and Triassic formations 10 m to 50 m thick represented by limestone and marl formations of Red Sandstone.

Seam 207, in the discussed regions situated on the depth from 330 to 480 m and its thickness ranges from 2.6 to 3.2 m (on average 2.9 m). Locally in the areas of the damage of the roof of the seam the thickness is reduced to 1,0 m. The direct roof of the seam 207 is formed from the layer of silt shale up to 4,0 m thick. The main roof — between seam 206 and 207 is built of different sandstones of medium and coarse granularity with local insertions of siltstone.

The exploitation of wall 719 started 8th January 2001 (Fig. 3). The exploitation was run with the collapse of the roof on the depth 440 m at the beginning of the wall, reducing the depth to 350 m at its end. The length of the wall of the coasting was 1750 m, in the section 0 to 309 m it was 249.5 m then it diminished to 235.5 m in the further part of the coasting. The height or the exploitation port ranged 2.7–3.1 m, on average 3.0 m. The exploitation was run 5 days a week in a three-shift system.

Exploitation of the wall 719 started on 8th January 2001. Surveying was made from 30th July 2001 to 4th January 2002, i.e. when the exploitation effected the points of the observation line. In this period, apart from weekend exploitation breaks there were several holiday and technological breaks such as: 3–5th August 2001, 16th August 2001, 17th October 2001, 2–4th November 2001, 5th December 2001, 25–27th December 2001 and 1–2nd January 2002.

Average daily advance of the exploitation front in the whole period of the studies was only 2.6 m/24hrs. Regarding only working days it was 3.9 m/24 hrs. The maximal daily advance of the exploitation front was 6.7 m/24 hrs.

In detail the exploitation of wall 719 was studied in the time when the front passed the observation line i.e. from 20th September 2001 until 21st November 2001. Average daily progress of the front was that time 2.8m/24 hrs, after excluding exploitation breaks — on average 4.1 m/24 hrs. Maximal advance was 6.3 m/24 hrs that time.

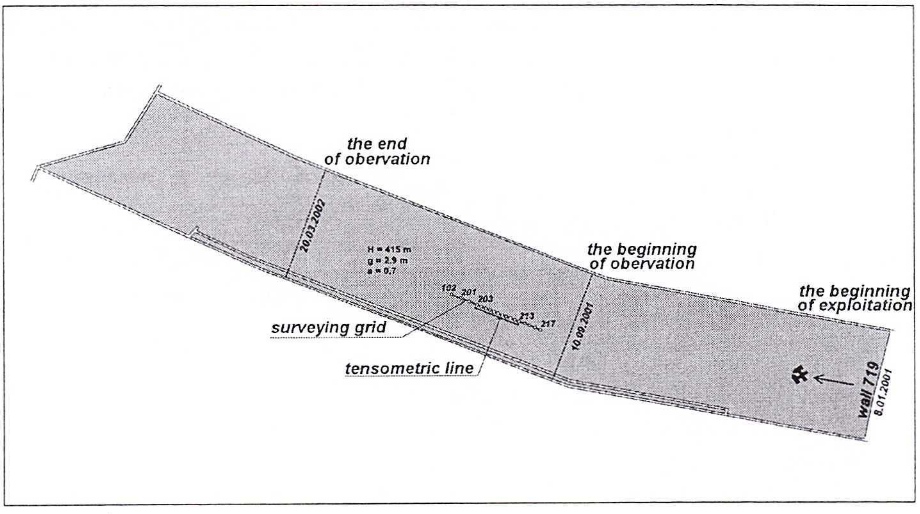

Fig. 3. The exploitation of wall 719, hard coal mine "Ziemowit"

Rys. 3. Eksploatacja ściany 719, KWK „Ziemowit"

4. The course of surveying observations

The studies on the surface deformation under the influence of intensive exploitation of the hard coal seams were, in both regions, carried out based on specially stabilised observation lines. In region I (mine "Wesoła") the observation line W1 was established, ad in region II (mine "Ziemowit") the line was Z1.

4.1. Surveying measurements in region I (mine "Wesoła")

The measurement line W1 of the length of 195 m, consisting of 21 stabilised surface points in the distance of about 10.0 m, was running over the axis of the wall no. 104 in seam 308 (Fig. 2). The first point of the line (point no. 1) was in the distance of 320 m from the beginning of the wall. To assess possible additional influence of the earlier exploited, parallel wall no. 103, through point no. 9 of line W1, an auxiliary transverse measurement line no. P2 was established. Its length was 75 m. The line consisted of 5 points stabilised in the distance of about 15.0 m and point no. 9 on line P1. All the points of the measurement lines were permanently stabilised in the ground. It was four months before the first measurement. This procedure eliminated the additional influence of stabilisation on the picture of the deformation process.

The altitudes of the points of the lines were defined by the method of trigonometric levelling, while the altitude reference to the points situated outside of the zone of predicted influence in each measurement series was run by the method of geometric levelling. The lengths of the sides of the line, making the base for the determination of horizontal deformations and the inclinations of the area, were measured by an electronic remote sensor.

The first series of measurements was made several weeks before the starting the exploitation of the wall no. 104. Based on this the distribution of the points on the line was determined and the initial values were obtained (altitudes of the points and lengths of the stations) for further observations.

The initiation of the process of surface deformation in the area of the region of the observation line W1 was measured by several measurement series when the exploitation front was approaching. The results of the measurements carried out on 25th May 2001 and 19, 26 and 29th June 2001 allowed the decision on the start with 2nd July 2001 an intensive registration of the progressing deformation process. The linear measurements, performed in 24-hrs cycle lasted until 8th August 2001.

Trigonometric levelling and the measurement of the lengths of the sides on the line were made simultaneously with a so-called method of three tripods with forced centring. A total station Geodimeter 650 was used. The altitude reference of the line was done by the method geometric levelling with the use of electronic code precise leveller Zeiss DiNi 12 and two folded — four metres long rods. The data were automatically registered.

The accuracy of the definition of the altitude of the observation points of the line was mainly connected with the accuracy of the measurement of the aim axis of the instrument (±0.5 mm) and the altitude of the aim point (±0.5 mm) over the points of the line. The error of the definition of the point of the line in the station was ±0.7 mm (influence of the measurement error of the vertical angle for short sides was negligible). The accuracy of the determination of the altitude of the points o the line was diminishing with the progressing measurements, according to the law of transferring errors and ranged from ±0.8 mm for the first point of the line (the value connected with the accuracy of reference) to about ±3.5 mm for the ending point.

The lengths of the sides were measured with the mean error ±1.3 mm, which resulted from the standard of the remote sensor (1 + 1 ppm) and the accepted centring error (±0.5 mm) with an optical plumb.

4.2. Surveying measurements in region II (mine "Ziemowit")

The measurement line Z1 202 m long, consisting of 18 points was running over the axis of the wall no. 719 in seam 207 (Fig. 3). The first point of the line (point no. 217) was in the distance of 750 m from the beginning of the wall. Parallel translocation of the line from the wall axis towards the exploited earlier wall 718 was about 40 m. Because of the field conditions — the measurement bases were not equal. At the beginning the line points were in the distance of 12.5 m, in the centre — 10.0 m, and in the end — 20.0 m. All the points of the measurement line were permanently stabilised in the ground two months before the first measurement.

The initial series of measurements was made several weeks before the revealing of the influence of wall exploitation in the region of the observation line. Based on this the location of the points of the line was defined as well as the initial data for later data processing and analysis.

The measurements of the altitude of the points of the line and the length of the measurement stations were carried out by a similar method an instruments as in region I (mine "Wesoła")

To define the flat co-ordinates of the observation points on the line of both lines a satellite GPS technique was applied. Flat co-ordinates of the points of the line were determined through surveying sequence, with bilateral reference in a locally accepted reference system, with the use of the network of GPS points. The accuracy of determining the co-ordinates of the linear points was very high. The mean error of the location of the points on the line referring to the accepted system of co-ordinates does not exceed ±5 mm.

The beginning of the deformation process on the surface in the region of observation line Z1 was observed with the use of several measurement series while the exploitation front was approaching the wall. The results of measurements made on 10th and 17th September 2001 enabled us to decide to start on 20th September 2001 an intensive registration of the progressing deformation process. The measurements of the line were carried out in 24 hours cycle (every second week) ad lasted until 21st November 2001.

For surveying measurements in region II were made similarly to region I, the obtained accuracy turned out to be similar to the ones in region I.

4.3. The processing of the results of surveying

The surveying network to study the process of the deformation of the surface of the area was designed and established in such a way so that the determination of maximal daily values of the increase of vertical translocations and maximal daily values of the increase of deformation indexes, characterising the formed subsidence trough could be possible.

Surveying measurements carried out on observation lines made possible to determine — apart from subsidence and horizontal deformations — the inclinations (important for tall objects) ad the curvature of the area.

In several series of surveying measurements made on observation lines, the lengths of the sides of the line and the altitude of its points was registered. The altitude of the linear points was determined with the levelling directly after the measurement in the field with the application of internal software of the leveller.

The measurement data were processed directly after each measurement series, combining them in appropriate tables. This allowed consequent following the development of the subsidence trough and the growing values of deformation indexes, at the same time making on-line control of the correctness of the measurements (detecting possible fundamental errors). The data registration in the field was automatic in a digital form in the operational memory of the total station and on the card PCMCIA of the leveller, and then the data were directly transmitted on hard discs of stationary computers. Saved in text files were imported by a special computer program made by A. Wójcik, M.Sc., Eng. (data from the total station), or directly (data from the leveller) to the calculation charts of a standard program Excel (pack OFFICE 97, Microsoft), where they were properly segregated and put in order.

For graphic processing a computer program Grapher 3.0 (from software pack of Golden Software) getting data to make graphs directly from properly prepared Excel files.

The full set of the results of surveying from regions I and II with the calculated deformation indexes is in the Archive of the Chair of the Protection of Mining Areas, University of Mining and Metallurgy in Cracow.

5. The analysis of the results of surveying

5.1. The results of the observations from region I (mine "Wesoła")

5.1.1. Area subsidence and its change in time

During intensive influence of exploitation under the line W1, 34 measurement series were made. Daily measurement cycle allowed accurate determination of the course of the subsidence of the points on the line in time (the period from 29th June to 8th August 2001. The course of the subsidence of individual points of line W1 in time was presented in Fig. 4. This figure shows the course of every second observed point; the graphs from the remaining points are similar. At the beginning every point, while the exploitation front was approaching, suffered small subsidence. When the front went under the point — the subsidence reaches an intensive phase, and then, with time the subsidence growth is diminishing and the point reaches maximal subsidence. The results of the last — 42nd measurement series (not included into the figure, because of a large time span) show that each point reaches practically the same final subsidence. In the phase of the most intensive subsidence growth, the graphs for the respective points do not overlap, which is the result of the other distance of each point from the moving exploitation front.

The formation of a subsidence trough during the deformation process (so-called dynamic trough) is shown in Fig. 5, where one can clearly see a continuously progressing surface deformation. Subsequent measurement series present subsidence of individual points on line W1 during the deformation wave. Initially the surface of the area is positively curved (convex), then with the time (and the approach of exploitation front) mildly goes into a negative curvature (concave), finally (after passing of the deformation wave) is getting flatter again (the result of 42nd measurement series).

The measurements showed that in the region of line W1 the area subsided on average by 1.070 m (the biggest final subsidence 1.087 m was scored in point no. 14). Final subsidence of all the points of the observation line range within the limits from 1.043 to 1.086 m and show a slight scatter around the mean value ($\sigma = \pm 0.016$ m). The maximal subsidence is lower than predicted by preliminary forecasts. This indicates stiffer and more condense than assumed structure of the rock mass.

In the graphs of subsidence points (Fig. 4) it is clearly visible that the repetitive disturbances occur during the breaks in the exploitation front. After stopping the exploitation front, the subsidence rapidly becomes slower. For better illustration of this phenomenon a series of graphs showing a daily growths of the subsidence of individual points during the most intensive impact of exploitation was made. As an example the charts for point no. 1 and 2 were presented in Fig. 6 and 7. They confirm a significant decrease of the daily growth of the subsidence of the point after stopping the exploitation front, even from the value of 20 mm/24 hrs with the advancing front to 3–5 mm/24 hrs two days after stopping it. This phenomenon was observed during all the six examined

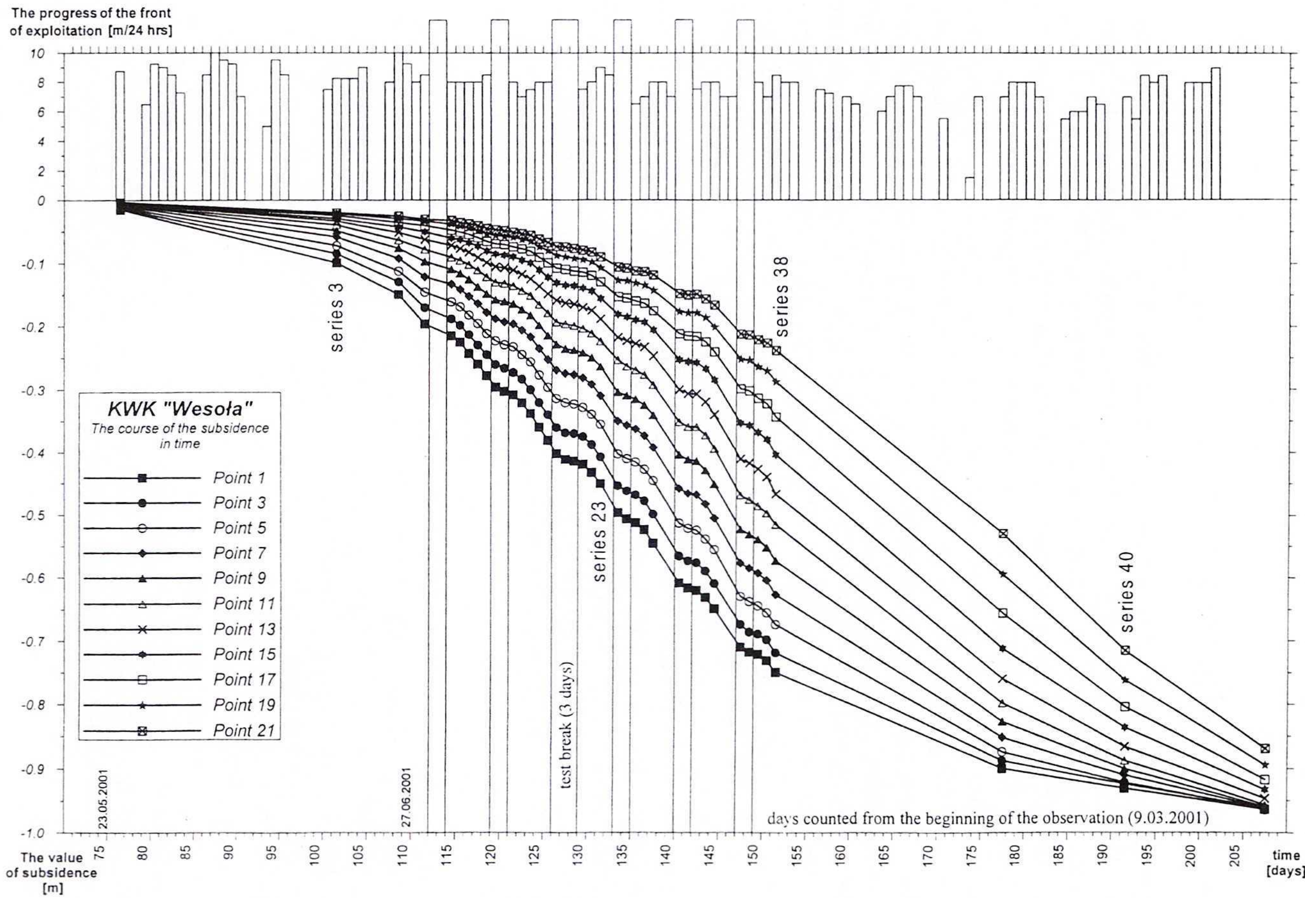

Fig. 4. The course of the subsidence of the points of the observation line W1 in time, hard coal mine "Wesoła"

Rys. 4. Przebieg obniżeń punktów linii obserwacyjnej W1 w czasie, KWK „Wesoła"

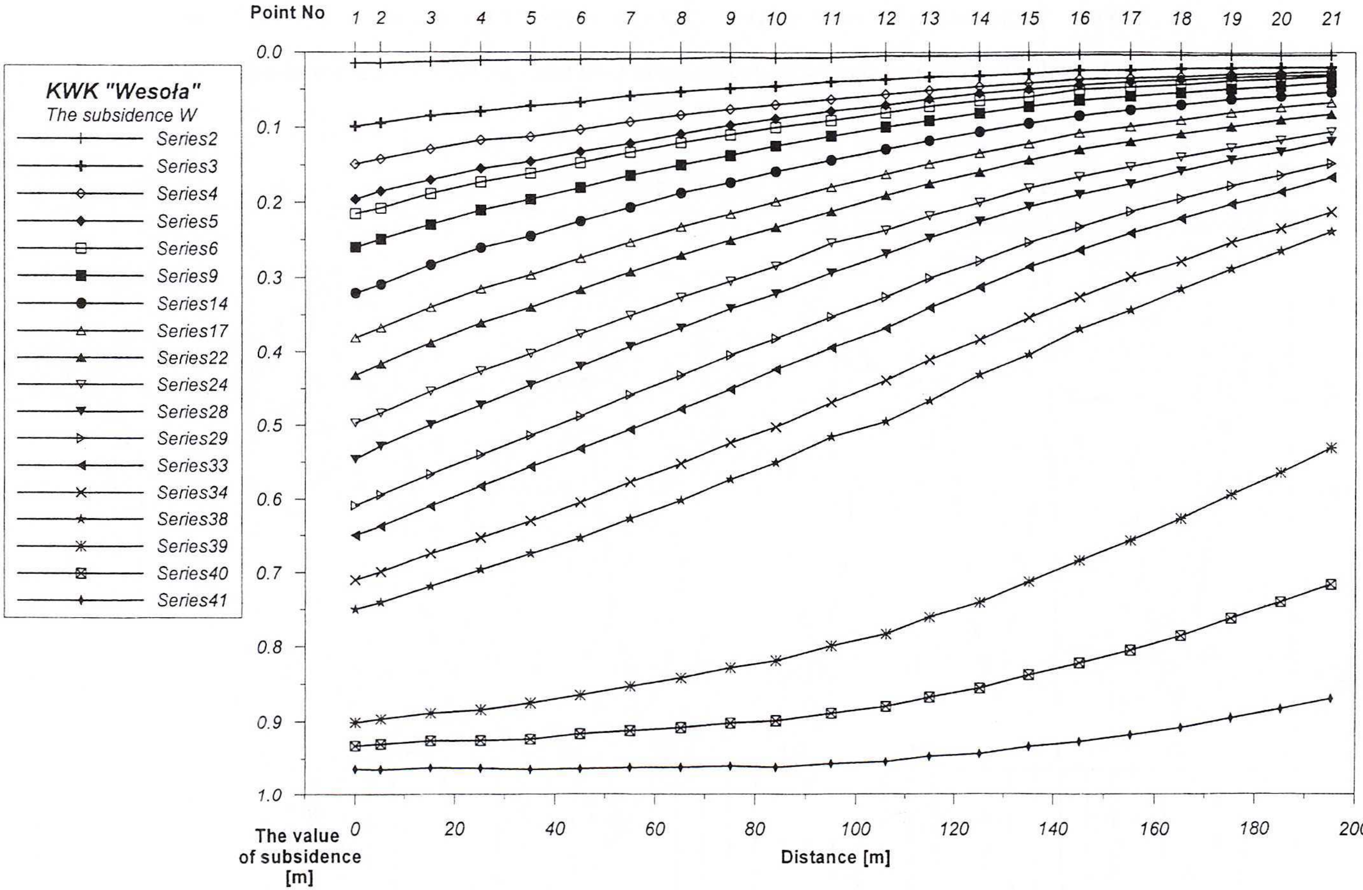

Fig. 5. The development of the dynamic subsidence trough alongside the observation line W1, hard coal mine "Wesoła"

Rys. 5. Rozwój dynamicznej niecki obniżeniowej wzdłuż linii obserwacyjnej W1, KWK „Wesoła"

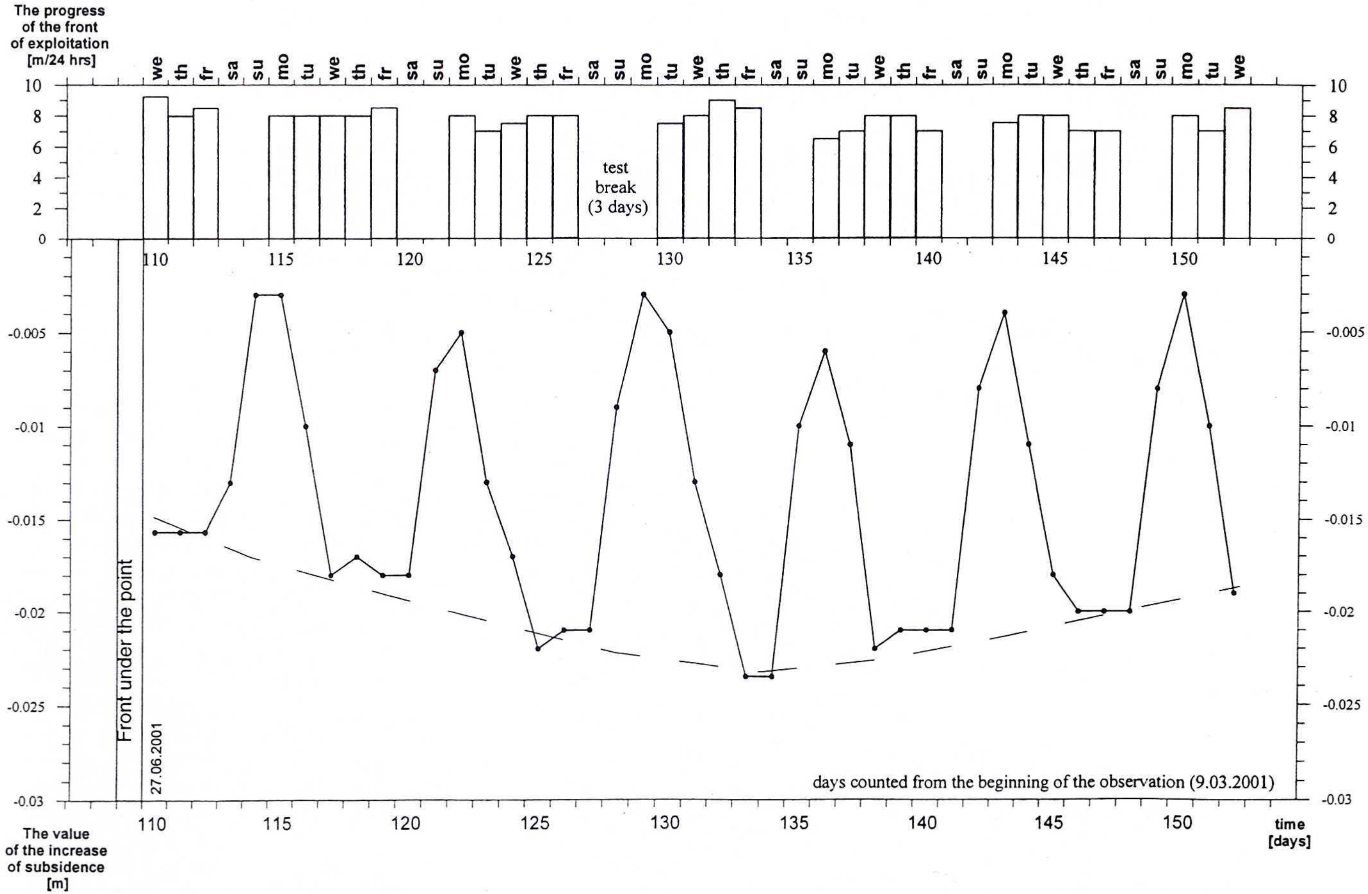

Fig. 6. The course of the increase of point no. 1 in time (observation line W1), hard coal mine "Wesoła"

Rys. 6. Przebieg przyrostów obniżeń punktu nr 1 w czasie (linia obserwacyjna Wl), KWK „Wesoła"

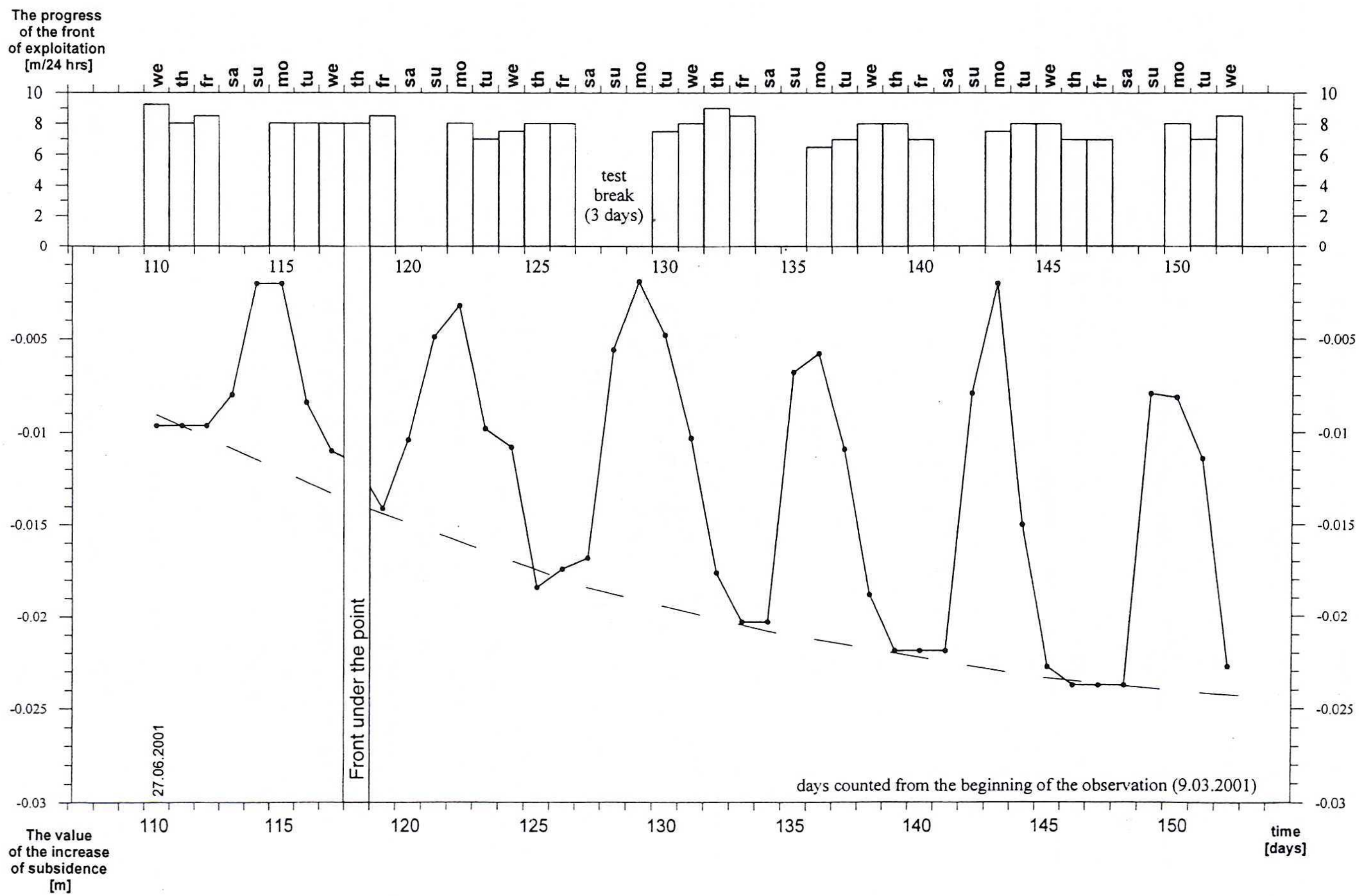

Fig. 7. The course of the increase of point no. 7 in time (observation line W1), hard coal mine "Wesoła"

Rys. 7. Przebieg przyrostów obniżeń punktu nr 7 w czasie (linia obserwacyjna Wl), KWK „Wesoła" exploitation breaks in all the points of the observation line. After 2–3 days from restarting the exploitation of the wall the subsidence growth again reaches maximal values.

To illustrate the differences between maximal increases of subsidence of the points of the observation line Table 1 was made.

TABLE 1

Maximal daily growth of the subsidence of the observation points in line W1

TABLICA 1

Maksymalne dobowe przyrosty obniżeń punktów linii obserwacyjnej W1

Number point	dw_{max} [mm/24 hrs]	Number point	dw_{max} [mm/24 hrs]	Number point	dw_{max} [mm/24 hrs]
1	23.5	8	24.7	15	24.4
2	23.4	9	24.2	16	20.6
3	23.3	10	26.2	17	21.1
4	23.9	11	24.8	18	19.0
5	24.8	12	26.0	19	17.1
6	24.4	13	27.7	20	16.3
7	23.7	14	23.7	21	15.4

5.1.2. Horizontal deformations and their course in time

The graphs of the course of horizontal deformations in time for the selected sides in the observation line are presented in Fig. 8. The graphs confirm the known course of the deformation process: accumulation of deformations growing with the approaching exploitation front to the measurement section, the occurrence of compressive deformations after passing the front under a studied section and close to zero final values of horizontal deformation, which however do not reach zero, which is the result of so-called post-exploitation inventories after the passing of the exploitation front.

Temporary extreme stretching deformations reached the value $\varepsilon_{extr}(+) = +1{,}03$ mm/m (on the section 16–19), and compressing deformations: $\varepsilon_{extr\ śr}(-) = -1{,}75$ mm/m (on the section 14 –15). Mean value of e extreme, temporary values of stretching deformations was $\varepsilon_{extr\ śr}(+) = +\ 0{,}64$ mm/m (scatter $\sigma_{\varepsilon+} = \pm 0{,}20$ mm/m), while in respective compressing deformations: $\varepsilon_{extr\ śr}(-) = -1{,}23$ mm/m (scatter $\sigma_{\varepsilon-} = \pm 0{,}34$ mm/m).

From the graphs in Fig. 8 it can be concluded that after halting the exploitation front and then restarting mining — rapid fluctuations of this deformation index occur. The graphs of daily increases of deformations "$\Delta\varepsilon$" (e.g. for side 1–2) show the fluctuations of these increases in short time intervals (Fig. 9). In Tables 2 and 3 maximal values of daily increases of horizontal deformations on line W1 are shown.

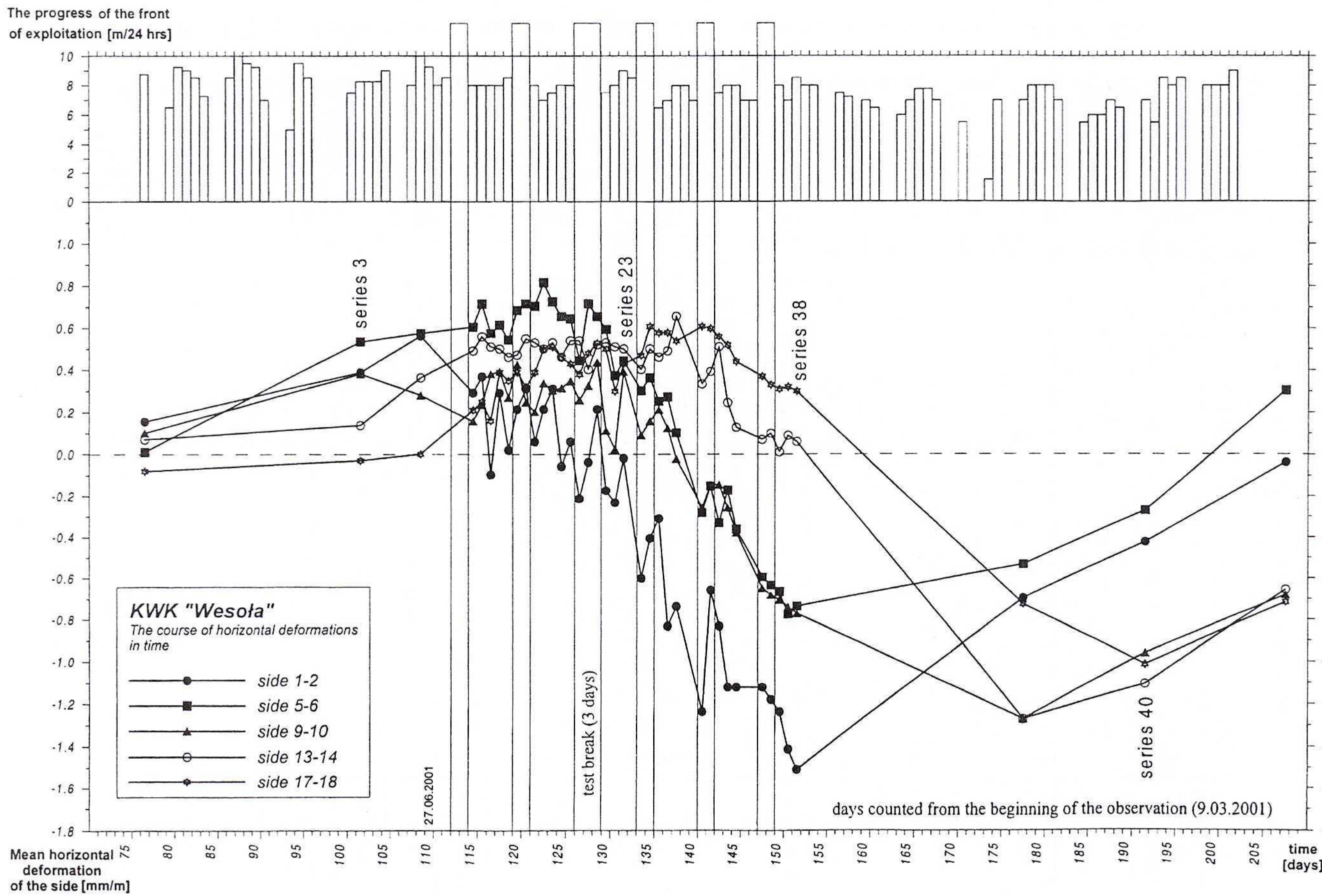

Fig. 8. The course of horizontal deformations of the selected sides of the observation line W1 in time, hard coal mine "Wesoła"

Rys. 8. Przebieg odkształceń poziomych wybranych boków linii obserwacyjnej W1 w czasie, KWK „Wesoła"

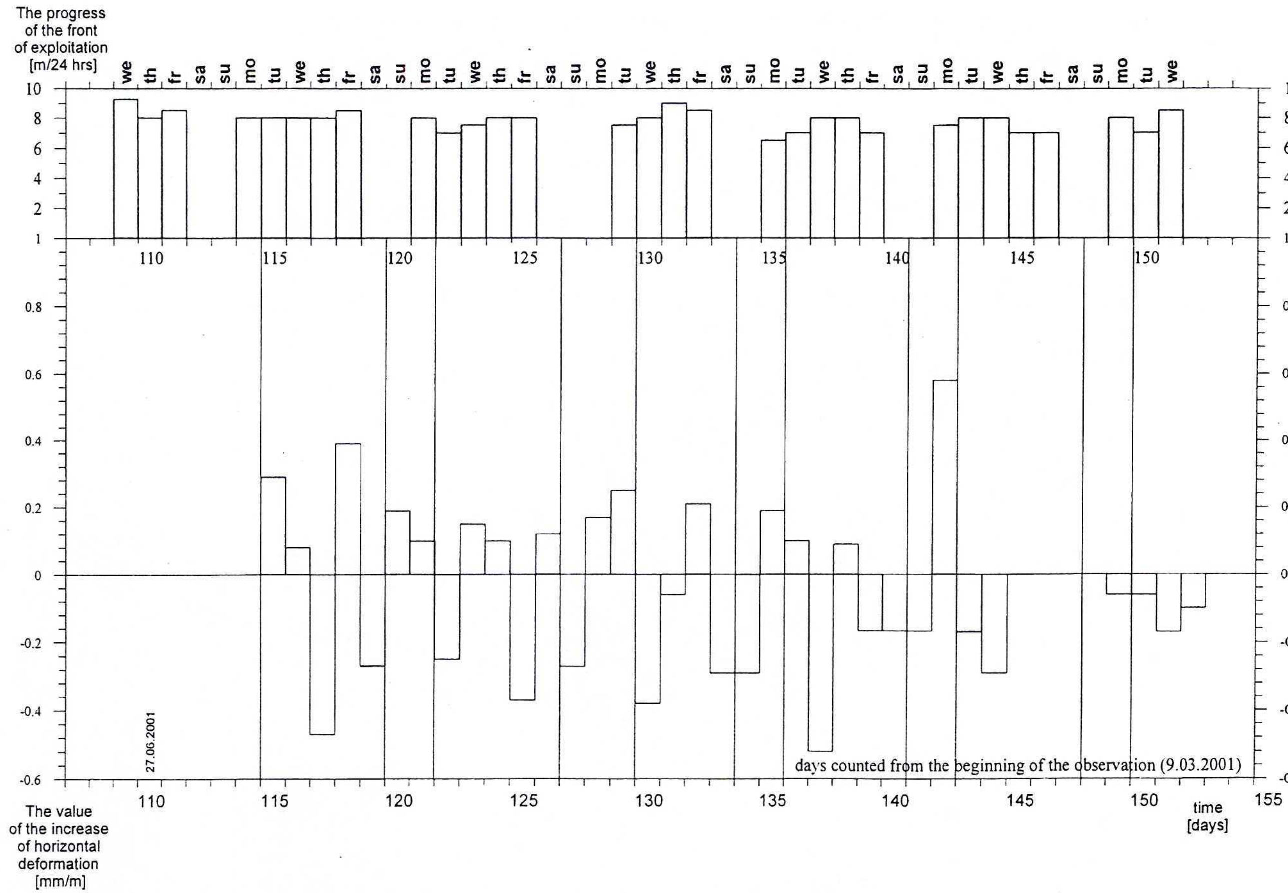

Fig. 9. The increase of horizontal deformations on side 1–2 in time, hard coal mine (observation line W1) "Wesoła"

Rys. 9. Przyrost odkształceń poziomych na boku 1–2 w czasie (linia obserwacyjna W1), KWK „Wesoła"

TABLE 2

Maximal daily increases of horizontal stretching deformations on the sides of the observation line W1

TABLICA 2

Maksymalne dobowe przyrosty odkształceń poziomych rozciągających na bokach linii obserwacyjnej W1

Side	$d\varepsilon_{max}$ (+) [mm/m/d]	Side	$d\varepsilon_{max}$ (+) [mm/m/d]	Side	$d\varepsilon_{max}$ (+) [mm/m/d]
1–2	—	8–9	+0.21	15–16	+0.21
2–3	+0.33	9–10	+0.37	16–17	+0.17
3–4	+0.22	10–11	+0.15	17–18	+0.23
4–5	+0.12	11–12	+0.17	18–19	+0.16
5–6	+0.28	12–13	+0.26	19–20	+0.26
6–7	+0.28	13–14	+0.17	20–21	+0.20
7–8	+0.24	14–15	+0.23		

TABLE 3

Maximal daily increases of horizontal compressing deformations on the sides of the observation line W1

TABLICA 3

Maksymalne dobowe przyrosty odkształceń poziomych ściskających na bokach linii obserwacyjnej W1

Side	$d\varepsilon_{max}$ (+) [mm/m/d]	Side	$d\varepsilon_{max}$ (+) [mm/m/d]	Side	$d\varepsilon_{max}$ (+) [mm/m/d]
1–2	—	8–9	–0.43	15–16	–0.22
2–3	–0.23	9–10	–0.33	16–17	–0.24
3–4	–0.36	10–11	–0.16	17–18	–0.20
4–5	–0.23	11–12	–0.17	18–19	–0.11
5–6	–0.22	12–13	–0.26	19–20	–0.19
6–7	–0.27	13–14	–0.26	20–21	–0.23
7–8	–0.31	14–15	–0.26		

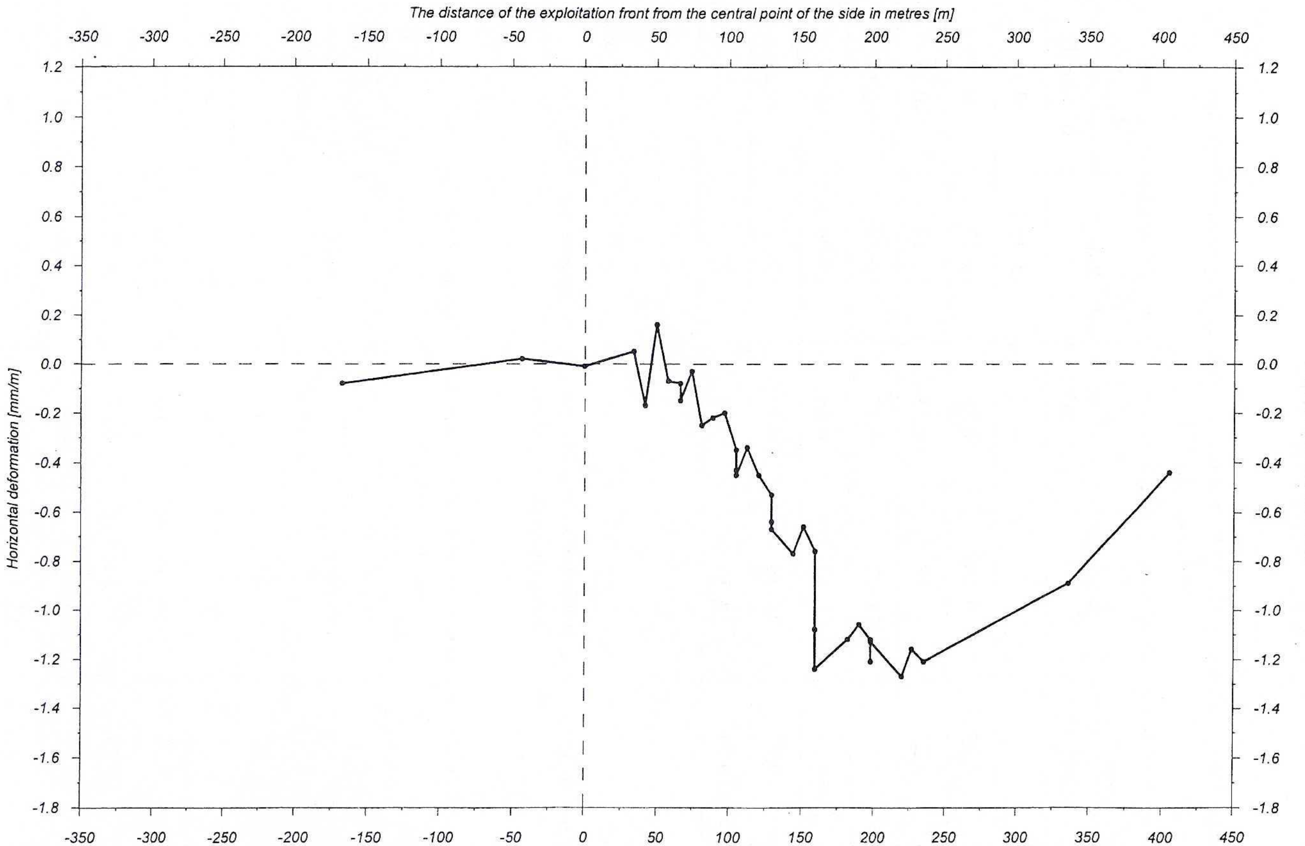

Fig. 10. The graph of the changes in horizontal deformations of side 2–3 in time, as the function of the distance between the exploitation front and the central point of the side. Observation line W1 in time, hard coal mine "Wesoła"

Rys. 10. Wykres zmian odkształceń poziomych boku 2–3 w czasie w funkcji odległości frontu eksploatacji od punktu środka boku. Linia obserwacyjna W1 — KWK „Wesoła"

The biggest daily increase of stretching deformations was $d\varepsilon_{max}$ (+) = +0,37 mm/m/24 hrs (on section 9–10). Mean value of maximal daily increases of stretching was $d\varepsilon_{\acute{s}r\ max}$ (+) = = +0,24 mm/m/24 hrs, while the biggest daily increase of compressing deformations was $d\varepsilon_{max}$ (–) = –0,43 mm/m/24 hrs (on section 8–9). Mean value of maximal daily increases of compressions was $d\varepsilon_{\acute{s}r\ max}$ (–) = –0,26 mm/m/24 hrs.

The phenomenon of the delay in the manifestation of the influence in the aspect of horizontal deformations was presented in the graphs of the changes of horizontal deformations in the function of the distance of the exploitation front from a given measurement section (e.g. for side 2–3 — Fig. 10). From the graphs it is seen that the change of the stretches on the compression that the change of stretching was in the moment, when the exploitation front goes away from a given measurement section on the distance of about 100 m to about 150 m. This means that in the moment when the exploitation front moved under a given section, it was subdued to stretching.

A non-typical effect registered by the measurements is the course of horizontal deformations in section 2–3, which was deformed only under the influence of compressive forces. Probably this section was within a uniform rock block, separated from the rest of the rock mass by dilatations. This can also be confirmed by the graph of the changes of this section in the function of the distance from the exploitation front.

The section of the auxiliary perpendicular measurement line P1, according to the theoretical model was subdued only to compressing deformations. The extreme, final horizontal deformation was ε_{extr} (–) = –4.58 mm/m. It occurred on section 101 — 9 on the slope of the profile of the trough. In section 9–102, located in the bottom part of the profile of the trough — final horizontal deformation was ε_{extr} (–) = –3.06 mm/m. This proves the fact that in the cross section the subsidence trough had no flat profile.

5.2. The results of the observations from region II (mine "Ziemowit")

5.2.1. Area subsidence and their course in time

On line Z1, 43 measurement series, while between 29th September 2001 and 21st November 2001 (from series no. 4 to series no. 39) the measurements were done in 24 hrs cycles. In Fig. 11 the graphs of changing the subsidence of 9 selected points of line Z1 are presented. The last, 43rd measurement series showed asymptotic state of the subsidence of all the points of the line. Fig. 12 shows the formation of subsidence during the progress of the front of exploitation under the measurement line. Maximal subsidence was w_{max} = 1.422 m and occurred in point no. 205. Mean maximal subsidence of all the points of the measurement line was $w_{max\ \acute{s}r}$ = 1.389 m. The scatter of maximal subsidence values around the mean was σ_w = 0.031 m).

The character of the changes of subsidence in time (Fig. 11) shows a distinct influence of breaks in front of exploitation on the process of the increase of subsidence. This manifests in the repetitive disturbances in the increase of subsidence at the time of stopping the exploitation, break and restarting the front. Additional confirmation of this

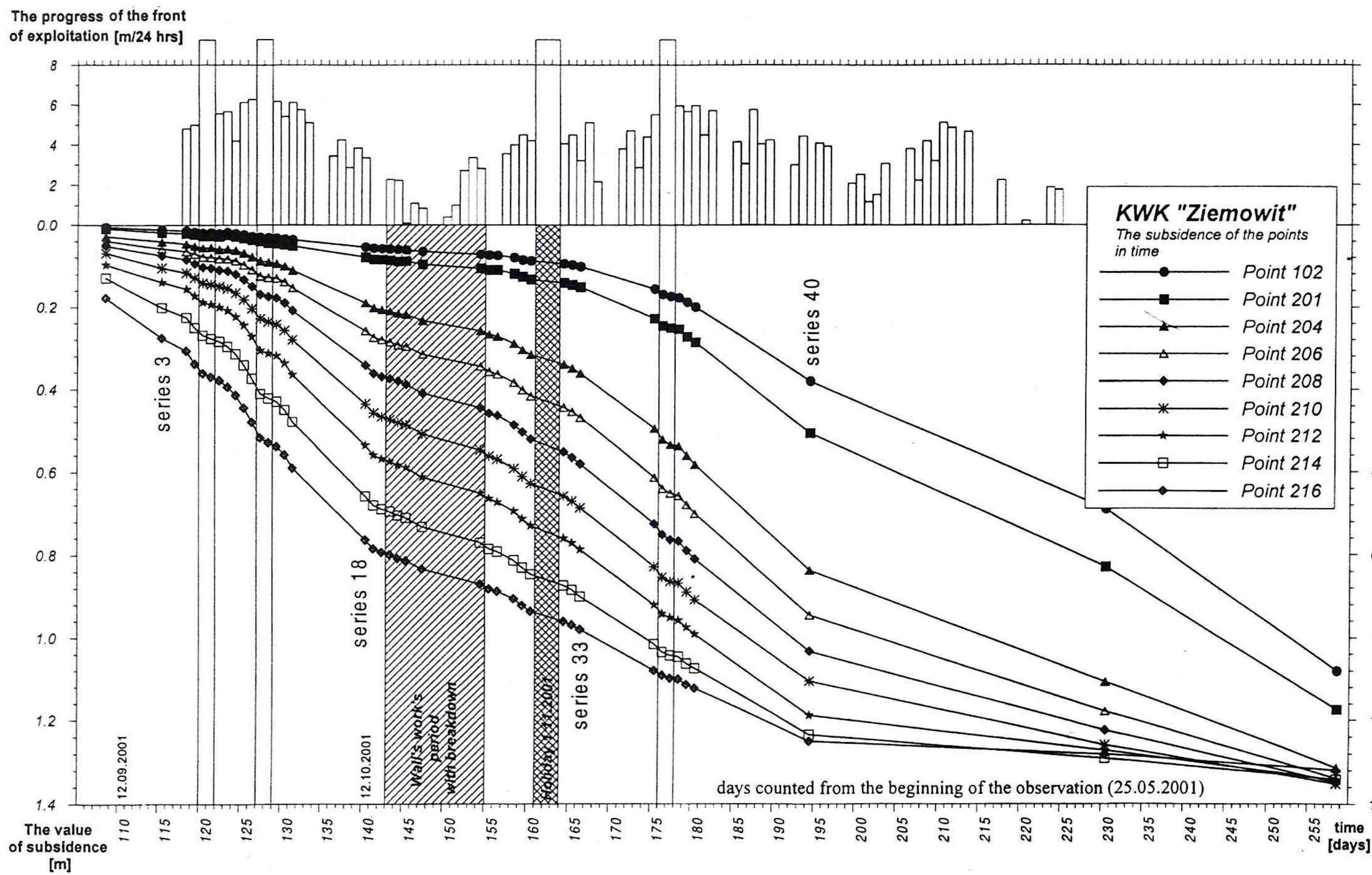

Fig. 11. The course of the subsidence of the points of the observation line Z1 in time, hard coal mine "Ziemowit"

Rys. 11. Przebieg obniżeń punktów linii obserwacyjnej Z1 w czasie, KWK „Ziemowit"

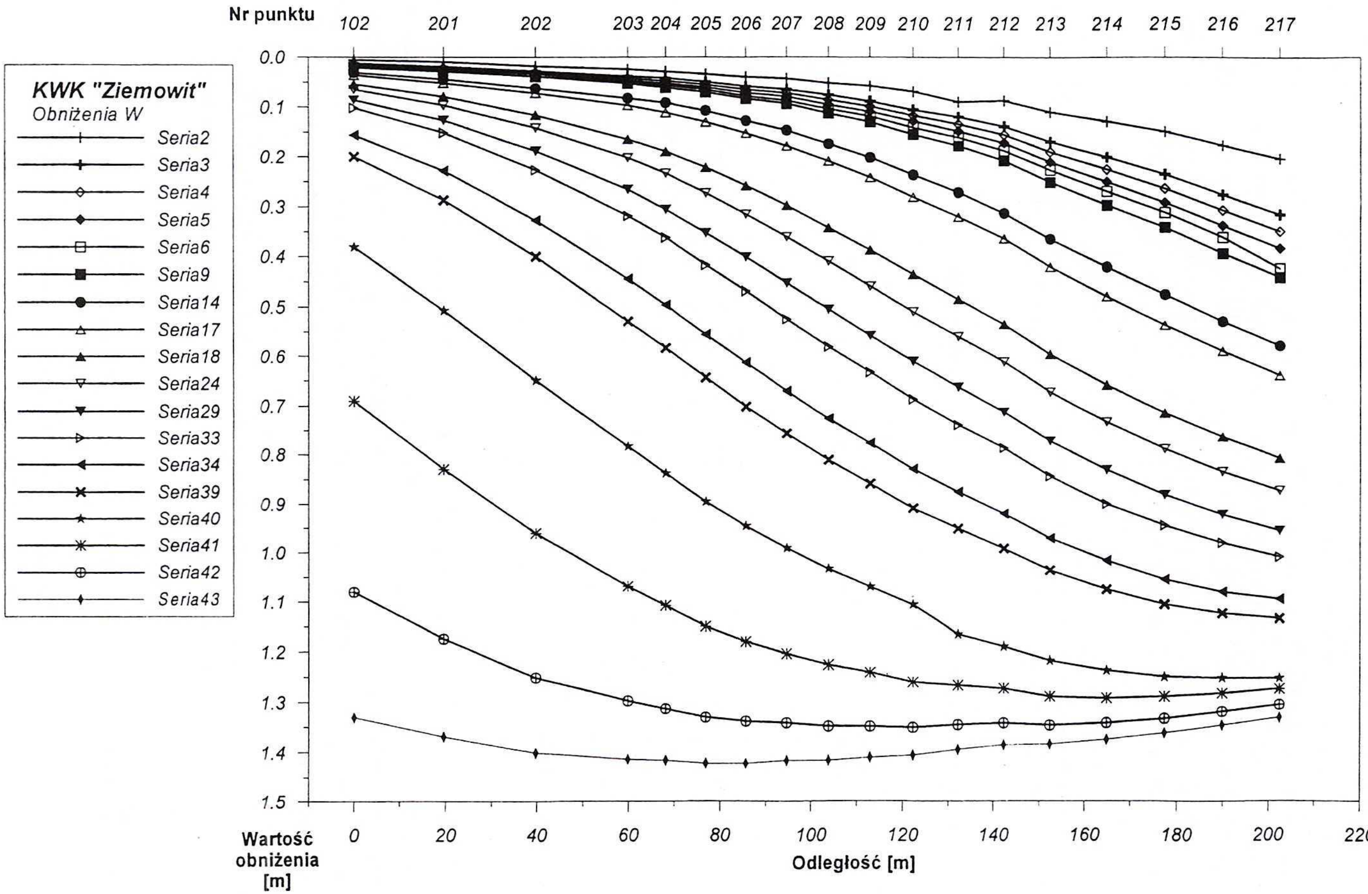

Fig. 12. The course of the dynamic subsidence trough alongside observation line Z1, hard coal mine "Ziemowit"

Rys. 12. Rozwój dynamicznej niecki obniżeniowej wzdłuż linii obserwacyjnej Z1, KWK „Ziemowit" effect is provided by small growths of subsidence during the breakdown when the advance of the front was diminished, till its stopping. After stopping the front of wall 719, the increase of the subsidence of the points per day diminished from the value of above 35 mm/24 hrs even to the value of 5–7 mm/24 hrs after the days of the break. This phenomenon was observed during all four registered exploitation breaks and during the breakdown. In table 4 maximal values of daily increases of subsidence "dw_{max}" on all the points of line Z1 are presented. The biggest daily subsidence growth, 40.4 mm/24 hrs, was registered in point no. 217.

TABLE 4

Maximal daily increases of the subsidence of the observation points on line Z1

TABLICA 4

Maksymalne dobowe przyrosty obniżeń punktów linii obserwacyjnej Z1

Number point	dw_{max} [mm/m/d]	Number point	dw_{max} [mm/m/d]	Number point	dw_{max} [mm/m/d]
102	13.0	206	27.0	212	33.7
201	18.7	207	27.6	213	34.3
202	21.8	208	26.4	214	36.1
203	26.5	209	26.9	215	38.8
204	27.0	210	25.8	216	38.2
205	28.4	211	29.0	217	40.4

The observed influence of breaks in exploitation front on the course of the subsidence of observation points on line Z1 qualitatively complies with the results obtained in region I (mine "Wesoła"). Based on the results obtained in region II, it can be stated that the results fully comply (in qualitative terms) with the ones obtained in region I. Bigger subsidence values can indicate less stiff and less compact rock mass compared to the rock mass of region I. The results of the last, 43rd measurement series show the formation of a flat bottom of a subsidence trough in its longitudinal section. This is also confirmed by a small scatter of maximal values of the subsidence of observation points of line Z1 around their mean value.

5.2.2. Horizontal deformations and their course in time

The graphs of the course of horizontal deformations were presented in Fig. 13. The graphs confirm (like in region I) the already known character of the process: growing stretching deformations with the approaching exploitation front to the me-

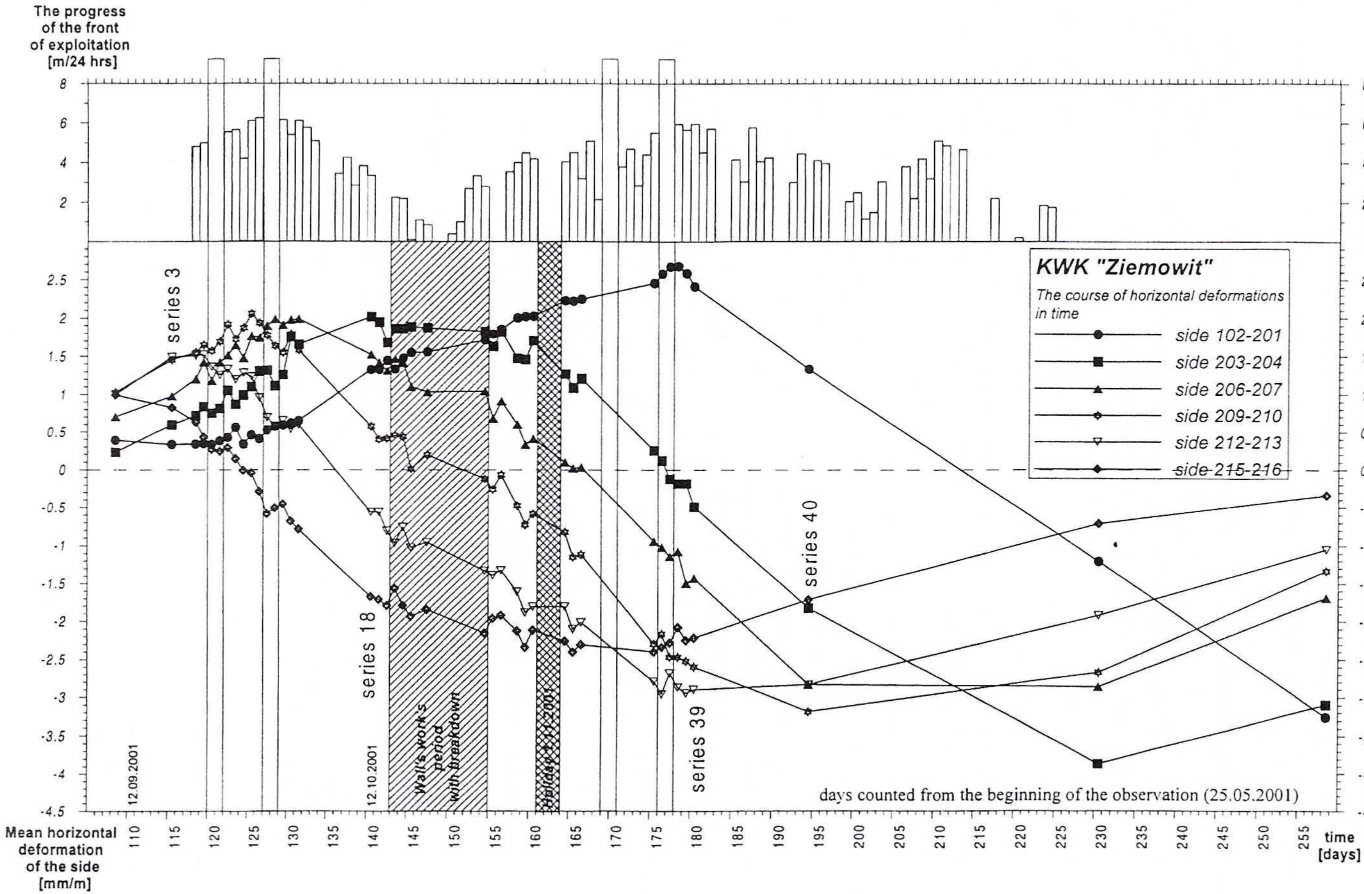

Fig. 13. The course of horizontal deformations in time on the sides of observation line Z1, hard coal mine "Ziemowit"

Rys. 13. Przebieg odkształceń poziomych w czasie na bokach linii obserwacyjnej Z1, KWK „Ziemowit" asurement base, presence of compressing deformations after the front passes under a given base and close to zero final values of horizontal deformations. Because of the situation of Z1 in the bottom part of the trough, final values horizontal deformations do not reach zero, which is the result of the occurrence of so-called post-exploitation inventories.

Temporary, extreme stretching deformations reached the value $\varepsilon_{extr}(+) = +2.68$ mm/m (in section 102–201), and compressing deformations $\varepsilon_{extr\ śr}(-) = -4.09$ mm/m (in section 207–208). Mean value from the extreme values of stretching deformations was $\varepsilon_{extr\ śr}(+) = +1.82$ mm/m (scatter $\sigma_{\varepsilon+} = 0.51$ mm/m), while in similar compressing deformations $\varepsilon_{extr\ śr}(-) = -3.03$ mm/m (scatter $\sigma_{\varepsilon-} = 0.53$ mm/m).

The influence of five breaks in exploitation on the course of the process of horizontal deformations was registered by the measurements in the period from 20th September 2001 until 21st November 2001. From the graphs in Fig. 13 it can be concluded that after stopping and restarting the exploitation front the fluctuations of this deformation index occur. The graphs of the growth of deformations per day "$d\varepsilon$" (e.g. side 212–213 Fig.14) show the fluctuations of these increases in short time intervals. In tables 5 and 6 maximal value of the deformation increases per day on line Z1 were presented.

The greatest increase of stretching deformations per day was $d\varepsilon_{max}(+) =$ $= +0.55$ mm/m/24 hrs (in section 207–208). The mean value of maximal growths of stretching deformations per day was: $d\varepsilon_{śr\ max}(+) = +\ 0.30$ mm/m/24 hrs. The greatest growth of compressing deformations per day was also $d\varepsilon_{max}(-) = -0.55$ mm/m/24 hrs (in section 8–9). Mean value of maximal compression increase per day was $d\varepsilon_{śr\ max}(-) =$ $= -0.35$ mm/m/24 hrs.

TABLE 5

Maximal daily increases of horizontal stretching deformations on the sides of observation line Z1

TABLICA 5

Maksymalne dobowe przyrosty odkształceń poziomych rozciągających na bokach linii obserwacyjnej Z1

Side	$d\varepsilon(+)_{max}$ [mm/m/d]	Side	$d\varepsilon(+)_{max}$ [mm/m/d]	Side	$d\varepsilon(+)_{max}$ [mm/m/d]
102–201	+0.14	206–207	+0.29	212–213	+0.28
201–202	+0.23	207–208	+0.55	213–214	+0.26
202–203	+0.29	208–209	+0.38	214–215	+0.32
203–204	+0.50	209–210	+0.24	215–216	+0.22
204–205	+0.40	210–211	+0.26	216–217	+0.17
205–206	+0.36	211–212	+0.19		

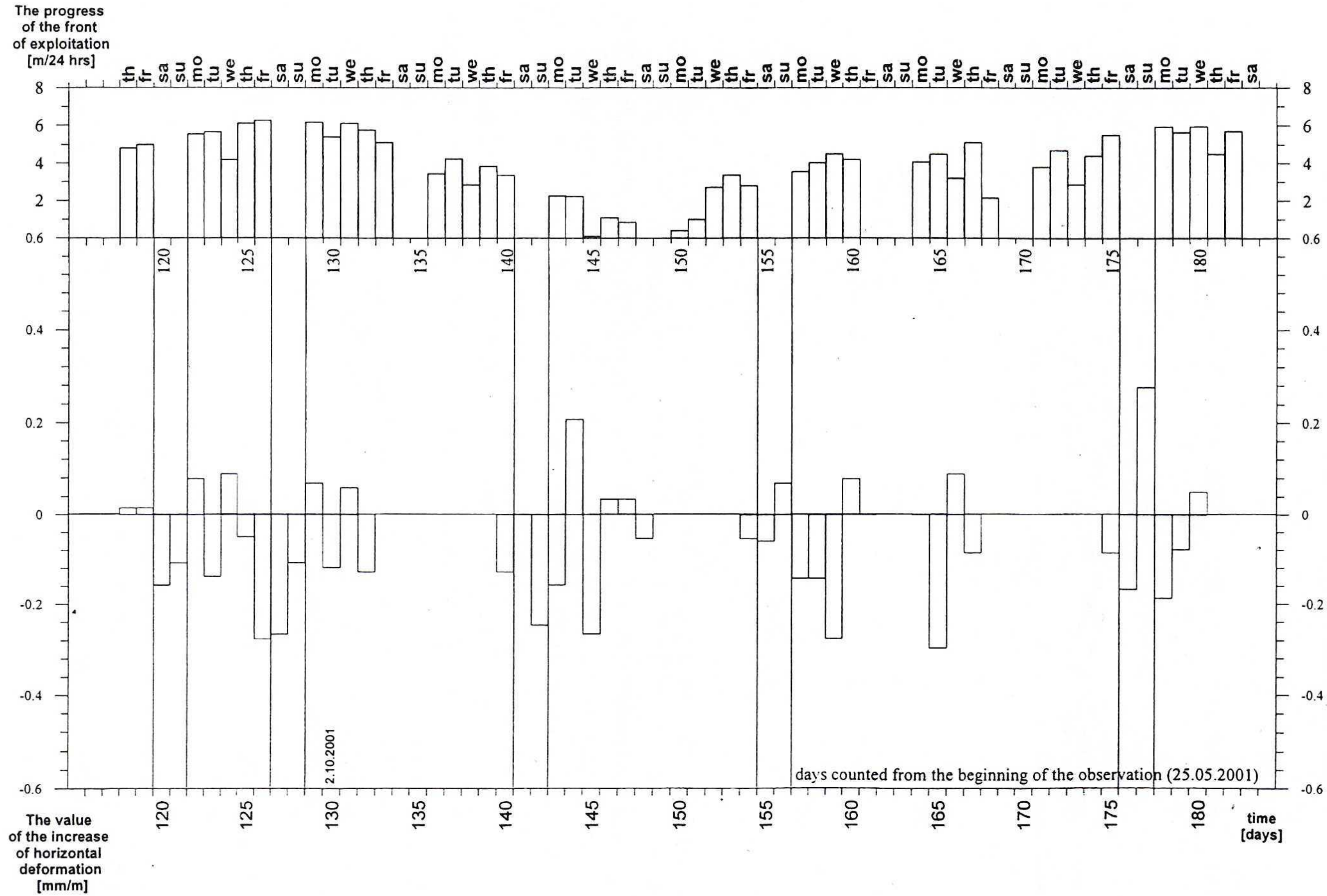

Fig. 14. The increase of horizontal deformations on side 212–213 in time (observation line Z1), hard coal mine "Ziemowit"

Rys. 14. Przyrost odkształceń poziomych na boku 212–213 w czasie (linia obserwacyjna Z1), KWK „Ziemowit"

TABLE 6

Maximal daily increases of horizontal compressing deformations on the sides of the observation line Z1

TABLICA 6

Maksymalne dobowe przyrosty odkształceń poziomych ściskających na bokach linii obserwacyjnej Z1

Side	$d\varepsilon(-)_{max}$ [mm/m/d]	Side	$d\varepsilon(-)_{max}$ [mm/m/d]	Side	$d\varepsilon(-)_{max}$ [mm/m/d]
102–201	–0.22	206–207	–0.42	212–213	–0.30
201–202	–0.18	207–208	–0.48	213–214	–0.37
202–203	–0.17	208–209	–0.55	214–215	–0.41
203–204	–0.31	209–210	–0.42	215–216	–0.30
204–205	–0.36	210–211	–0.38	216–217	–0.26
205–206	–0.44	211–212	–0.41		

The phenomenon of the delay in the manifestation of the results of breaks in exploitation on the course of horizontal deformations was presented in graphs of the changes of horizontal deformations in the function of the distance of exploitation front from a given measurement section (e.g. for side 212–213 Fig.15). The graphs show that the change of stretching into compressions occurred in the moment when the exploitation front moved away from the given measurement base on the distance of 50 m to above 100 m (on average 75 m, like in case of inclinations). This means that, at the moment, when the front of exploitation moved under the section was still subdued to stretching deformations.

The fluctuations of the increases of horizontal deformations caused by exploitation breaks, registered in region II (mine "Ziemowit"), qualitatively confirm the results obtained in region I (mine "Wesoła").

5.3. The qualitative comparison of the results of observations in both regions

The main purpose of doing research in two regions was not only examining the consequences of breaks in exploitation during intensive mining exploitation, but also showing the repeatability of the course of this process in similar geological and mining conditions.

Basic differences in both regions first of all referred to the speed of the advance of exploitation fronts. The geological structures of the regions was also different. These discrepancies, with the application of the same measurement methods had the influence

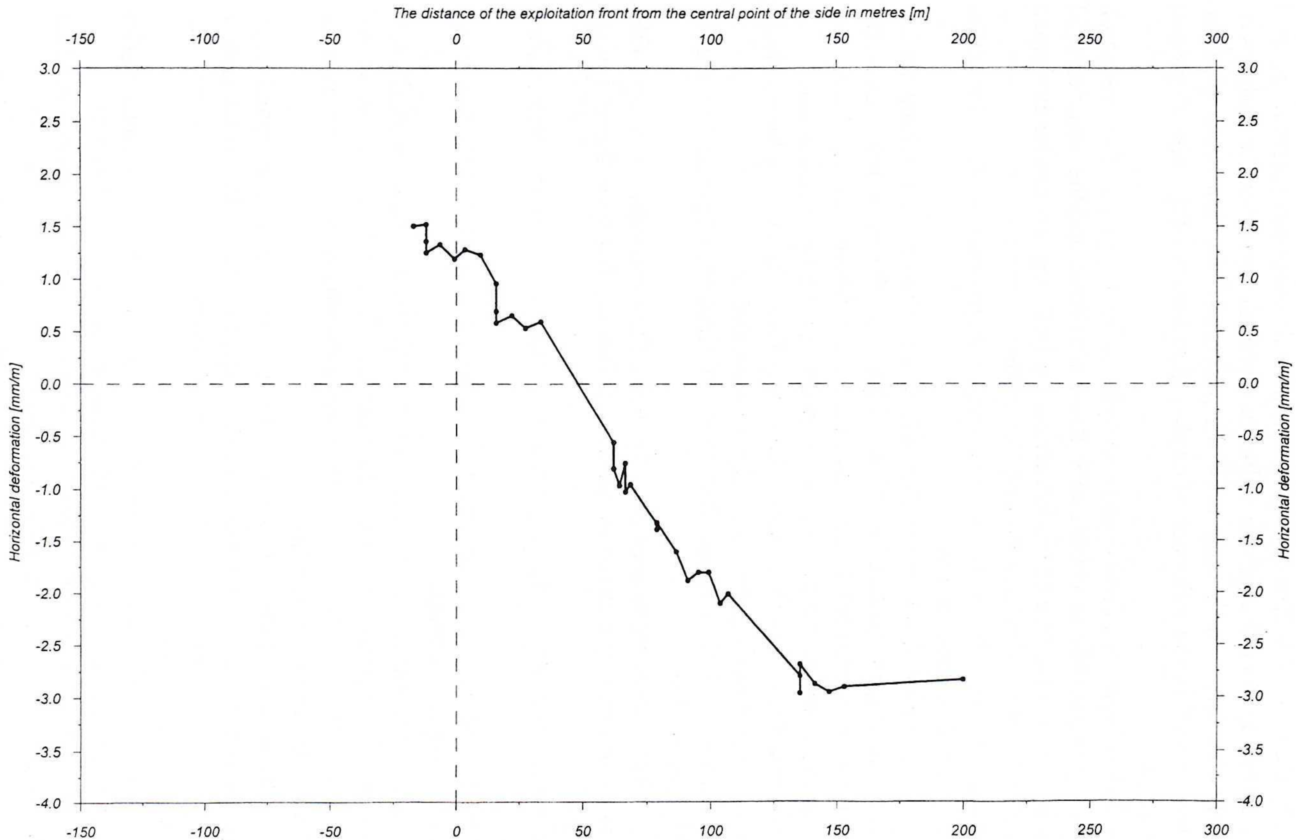

Fig. 15. The graph of the changes in horizontal deformations of side 212–213 in time, as the function of the distance between the exploitation front and the central point of the side. Observation line Z1 — hard coal mine "Ziemowit"

Rys. 15. Wykres zmian odkształceń poziomych boku 212–213 w czasie w funkcji odległości frontu eksploatacji od punktu środka boku. Linia obserwacyjna Z1 — KWK „Ziemowit" basically only on the quantitative differences of the measurement results. Smaller values of deformation indexes obtained in region I (greater exploitation speed than in region II) can be explained by the view of S. Knothe saying that after transgressing certain speed of the exploitation front the decrease of the value of dynamic deformation indexes is observed. In qualitative terms in the course of the process of the deformation of the surface of the area, as well as the influence of exploitation breaks of the disturbance of this process are similar.

Comparing the development of subsidence troughs in both regions of the research one can see that it is going on like in a classical S. Knothe's theory and the occurrence of different time delays in manifesting of the influence, for both regions can be explained by the difference in the geological and mining conditions.

The obtained results of the observations show a three-stage process of the formation of the formation of a subsidence trough:

- Stage I — exploitation front approaches the observation line, reaching its beginning and causing the deflection of the layers of the rock mass over the workings (positive curvature). During that time the following takes place:
  - a slow increase of the subsidence of the points of the observation line,
  - a slow increase of the inclinations of the sides of the observation line with the decrease towards the approaching edge of exploitation,
  - a slow increase of the horizontal stretching deformations of particular sides of the observation line.
- Stage II — exploitation front goes directly under the observation line up to the distance not exceeding the range of influence. During that time the following takes place:
  - an intensive increase of the subsidence of the points of the observation line,
  - an intensive increase of the inclinations of the sides of the line, they reach maximal temporary values,
  - at the beginning an intensive increase of horizontal stretching deformations, to their maximal temporary values, then slow transition into compression and intensive increase of horizontal compressing deformations until the moment their maximal values are reached.
- Stage III — exploitation front goes away from the end of the observation line on a significant distance beyond the range of the influence, then slow formation of the flat bottom of the trough over the area of workings takes place. During that time the following occurs:
  - slowing down the increases of the subsidence of the points of the observation line until their total disappearing and reaching maximal final values,
  - gradual decrease of the inclinations of the sides of the observation line until the final value is reached, in the bottom of the trough it is close to zero,
  - gradual decrease of horizontal compressing deformations on individual sections of the measurement line until the final value is reached, in the bottom of the trough it is often close to zero.

Comparing, in both studied regions, the influence of exploitation breaks on the disturbance of the progressing process of the deformation of the surface of the area, a full compliance of the results in qualitative terms. This is indicated by the results of the observation of the subsidence of points and horizontal deformations of the sides of the observation lines W1 and Z1. The analyses of the courses of the subsidence of the points of the line in time confirm the disturbances of the process of growing these translocations, namely a significant diminishing of their increases during the time of stopping the fronts. The analyses of horizontal deformations, which as a result of exploitation breaks show the increases towards stretching deformations draw to similar conclusions.

6. The characteristic of the influence of the exploitation breaks on the course of subsidence and deformation of the area surface based on the carried out studies

The influence of exploitation breaks on the course of deformation process was analysed based on the observed subsidence and horizontal deformations. The results of each stopping of the exploitation front in study regions I and II, are, in qualitative terms similar, which indicates similar reaction of the rock mass on the disturbances in the continuity of the exploitation of the deposit. It should be stated that only breaks not shorter than 48 hours were investigated.

Looking at the courses of subsidence at individual points of the observation line W1 and Z1 (Fig. 4 and Fig. 11), characteristic "flatten" of graphs can be noticed at the moment of exploitation breaks in the periods of measurements in a 24 hours cycle. A characteristic effect is a differentiation of the increases of the subsidence points in 24 hours time intervals. To make a more detail analysis of this effect, the graphs of the increases of subsidence in time for 2 points of lines W1 and Z1 were drawn (Fig. 6, 7 and 16). On these graphs a similar effect of slowing down the process of the growing of subsidence within 24 hours from stopping the exploitation front and its speeding up after 24 from restarting the exploitation is seen. Thus it is justified to state that the time of the delaying the reaction of the rock mass and surface of the area on stopping and restarting the front is about 24 hours. A significant importance for the carried out analyses had a three days test break in exploitation organised owing to the Board of the mine "Wesoła". The results of the observations made during that time showed undoubtedly that the rock mass reacts very quickly on all the disturbances in the continuity of exploitation, and overthrew earlier views that such a reaction can occur only after a week or even a longer time. During the test break a 24 hours interval of the delay and acceleration of the process of growing subsidence was undoubtedly found in every point of the observation lineW1.

Exactly the same effect was observed in case of all the examined exploitation breaks on line Z1 in study region II (mine "Ziemowit). More differentiated lengths of breaks, occurring there less regularly, confirm the remarks made above and allow accepting

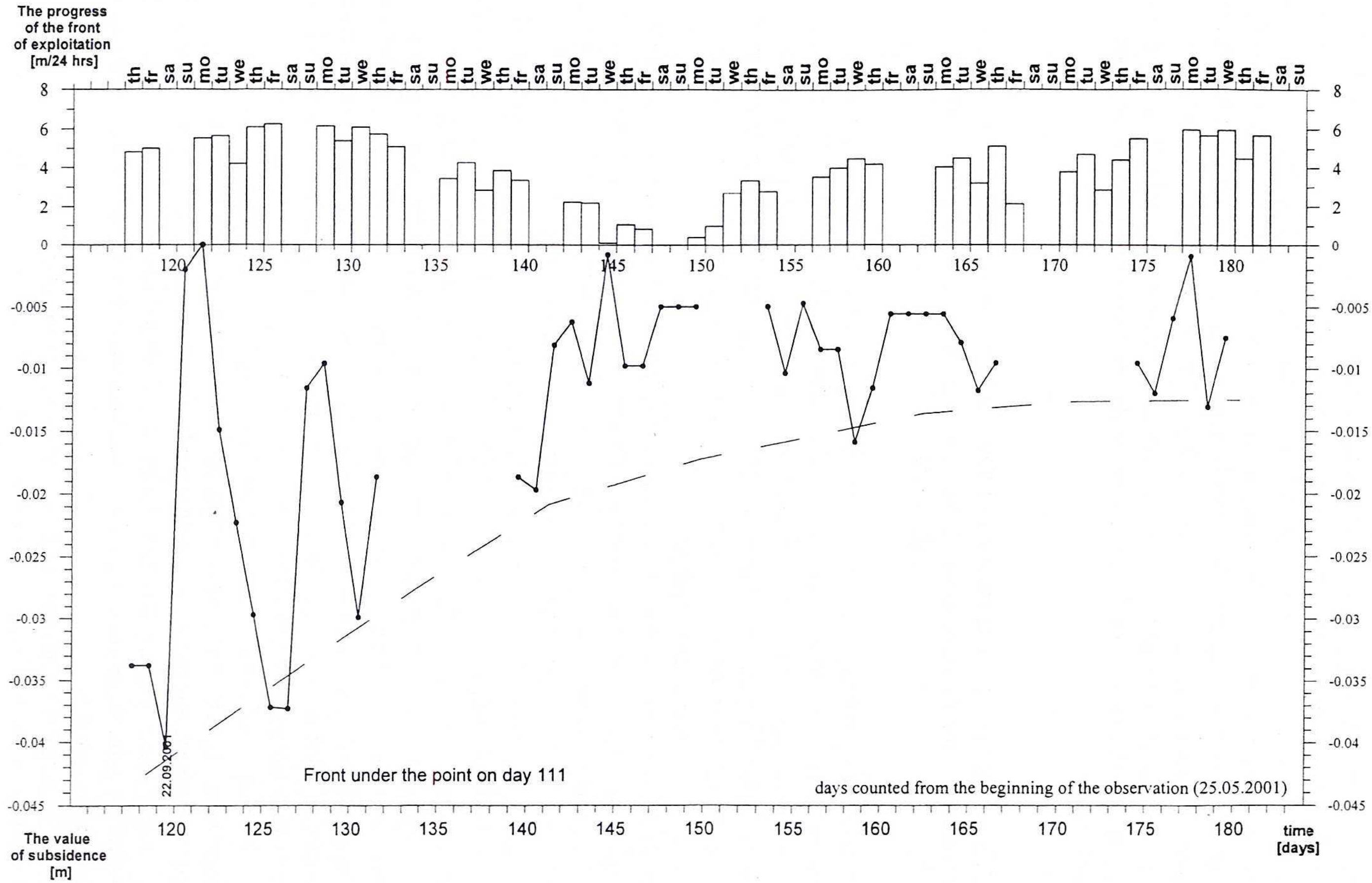

Fig. 16. The course of the increases of subsidence of point 217 in time (observation line Z1), hard coal mine "Ziemowit"

Rys. 16. Przebieg przyrostów obniżeń punktu nr 217 w czasie (linia obserwacyjna Z1), KWK „Ziemowit" them as fully justified. Interesting information was provided during the time of the problems in the mine "Ziemowit", where the front was drawn with a great irregularity and on one day was even stopped due to the breakdown. In a qualitative aspect it can be seen that the changes of the increases of the subsidence points depend both on the length of the exploitation break (during a longer break there is a greater limitation in the growth of subsidence than during a shorter break), as well as on the distance of the edge of exploitation from the point during the break. This is caused by greater values of the increase of subsidence for the points located closer to the exploitation edge. This effect is also visible for a single point, where in subsequent measurement days the moving front causes the change in the increase of subsidence per day, showing a general trend of the increase or decrease of the speed of the subsidence of the point. This trend on graphs (Fig. 16 and 6, 7) was shown by the discontinuous line, which should be treated as a hypothetical picture of the changes in the speed of subsidence point, assuming a continuous and uniformly progressing mining exploitation. The increase of the subsidence per day in region I diminished maximally from the value of about 20 mm/24 hrs with a progressing front to 3–5 mm/24 hrs after its stopping. Bigger differences were observed in region II, where the increase of the subsidence after stopping the exploitation front, maximally diminished from the value of about 35 mm/24 hrs to 5–7 mm/24 hrs.

The preliminary analysis of the course of horizontal deformations in time (Fig. 8 and 3) in both study regions drew into a remark that as the effect of stopping and restarting the exploitation front, the disturbances of these courses i.e. daily changes of the increases of deformations occur. To make a more accurate analysis of this effect, for all the sections of the measurement lines W1 and Z1 the graphs of the increases of horizontal deformations in time (e.g. for side 1–2 Fig. 9 and side 212–213 Fig. 14) were made. In the graphs the effect of fluctuations in the increases of horizontal deformations in short time intervals not exceeding 2–3 days (sometimes even 24 hours) are presented. The changes show that every measurement base during the period of the exploitation break and restarting the exploitation front is subdued to small compression or stretching, regardless whether in these periods the base is in the phase of stretching or compressing. This can cause an unfavourable for different surface objects effect of alternately occurring compression and stretching of the building foundations.

To define the cause of the mentioned above effect more accurately, the attempt to analyse statistically the results of the measurements in terms of the increases of horizontal deformations, occurring after the period of 24 and 48 hours after stopping the exploitation front and 24 hours after its renewal were made. This task was fulfilled regarding altogether 20 sides of observation line W1 and 17 sides of the observation line Z1 and 10 investigated exploitation breaks. The results of the analysis, where the zone of compression and the zone of stretching were treated separately, were presented in tables 7 and 8, where the percentage of the number of sections of the measurement lines on which the increase of compressions or stretching occurring after stopping the exploitation fronts and directly after restarting them was given.

TABLE 7

Statistic analysis of the measurements of the increases of horizontal deformations on the sides of observation lineW1 after stopping and restarting exploitation mine "Wesoła" (region I)

TABLICA 7

Statystyczne opracowanie wyników pomiarów przyrostów odkształceń poziomych na bokach linii obserwacyjnej W1 po zatrzymaniu i wznowieniu eksploatacji, KWK „Wesoła" (rejon I)

Symbol	Zone of stretching				Zone of compression			
	24 hrs after stopping the exploitation	48 hrs after stopping the exploitation	24 hrs after restarting the exploitation	48 hrs after restarting the exploitation	24 hrs after stopping the exploitation	48 hrs after stopping the exploitation	24 hrs after restarting the exploitation	48 hrs after restarting the exploitation
↓	47%	37%	41%	48%	91%	60%	52%	79%
↑	40%	53%	51%	43%	0%	31%	42%	18%
—	13%	10%	8%	9%	9%	9%	6%	3%

TABLE 8

Statistic analysis of the measurements of the increases of horizontal deformations on the sides of observation line Z1 after stopping and restarting exploitation mine "Ziemowit" (region II)

TABLICA 8

Statystyczne opracowanie wyników pomiarów przyrostów odkształceń poziomych na bokach linii obserwacyjnej Z1 po zatrzymaniu i wznowieniu eksploatacji, KWK „Ziemowit" (rejon II)

Symbol	Zone of stretching deformations				Zone of compression			
	24 hrs after stopping the exploitation	48 hrs after stopping the exploitation	24 hrs after restarting the exploitation	48 hrs after restarting the exploitation	24 hrs after stopping the exploitation	48 hrs after stopping the exploitation	24 hrs after restarting the exploitation	48 hrs after restarting the exploitation
↓	48%	44%	44%	56%	70%	64%	58%	67%
↑	48%	52%	46%	38%	21%	33%	33%	30%
—	4%	4%	10%	6%	9%	3%	9%	3%

↓ — increase of horizontal deformations on the side of the line in the direction of compression;
↑ — increase of horizontal deformations on the side of the line in the direction of stretching;
— — no increase of horizontal deformations on the side of the line.

TABLE 9

The list values of the increases of horizontal deformations on the sides of the observation lineW1 after stopping the and restarting exploitation, exceeding the value of mean measurement error $m_\varepsilon = \pm 0.18$ mm/m/24 hrs, mine "Wesoła" (region I)

TABLICA 9

Wyszczególnienie wartości przyrostów odkształceń poziomych na bokach linii obserwacyjnej W1 po zatrzymaniu i wznowieniu eksploatacji, wykraczających poza wartość średniego błędu pomiarowego $m_\varepsilon = \pm 0{,}18$ mm/m/dobę, KWK „Wesoła" (rejon I)

<table>
<tr><th colspan="8">Zone of stretching deformations</th><th colspan="8">Zone of compression</th></tr>
<tr><th colspan="2">24 hrs after stopping the exploitation</th><th colspan="2">48 hrs after stopping the exploitation</th><th colspan="2">24 hrs after restarting the exploitation</th><th colspan="2">48 hrs after restarting the exploitation</th><th colspan="2">24 hrs after stopping the exploitation</th><th colspan="2">48 hrs after stopping the exploitation</th><th colspan="2">24 hrs after restarting the exploitation</th><th colspan="2">48 hrs after restarting the exploitation</th></tr>
<tr><th>Δε</th><th>%</th><th>Δε</th><th>%</th><th>Δε</th><th>%</th><th>Δε</th><th>%</th><th>Δε</th><th>%</th><th>Δε</th><th>%</th><th>Δε</th><th>%</th><th>Δε</th><th>%</th></tr>
<tr><td>−0,20</td><td>50</td><td>−0,22</td><td rowspan="3">60</td><td>−0.38</td><td rowspan="6">25</td><td>−0.26</td><td rowspan="6">75</td><td>−0.28</td><td>100</td><td>−0.22</td><td rowspan="2">50</td><td>−0.19</td><td>100</td><td>−0.52</td><td rowspan="5">83</td></tr>
<tr><td>+0.20</td><td>50</td><td>−0.21</td><td>−0.33</td><td>−0.22</td><td></td><td></td><td>−0.21</td><td></td><td></td><td>−0.31</td></tr>
<tr><td></td><td></td><td>−0.19</td><td>−0.27</td><td>−0.22</td><td></td><td></td><td>+0.20</td><td rowspan="2">50</td><td></td><td></td><td>−0.29</td></tr>
<tr><td></td><td></td><td>+0.28</td><td rowspan="2">40</td><td>−0.25</td><td>−0.22</td><td></td><td></td><td>+0.20</td><td></td><td></td><td>−0.26</td></tr>
<tr><td></td><td></td><td>+0.21</td><td>−0.19</td><td>−0.22</td><td></td><td></td><td></td><td></td><td></td><td></td><td>−0.22</td></tr>
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<tr><td></td><td></td><td></td><td></td><td>+0.82</td><td rowspan="18">75</td><td>+0.26</td><td rowspan="2">25</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td>+0.65</td><td>+0.20</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
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<tr><td></td><td></td><td></td><td></td><td>+0.45</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
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<tr><td></td><td></td><td></td><td></td><td>+0.36</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
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<tr><td></td><td></td><td></td><td></td><td>+0.29</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td>+0.29</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
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<tr><td></td><td></td><td></td><td></td><td>+0.25</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td></td><td></td><td></td><td>+0.22</td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
</table>

Δε [mm/m/24 hrs] — value of the increase of a horizontal deformation;
(–) — increase of horizontal deformations on the side of the line in the direction of compression;
(+) — increase of horizontal deformations one the side of the line in the direction of stretching.

TABLE 10

The list values of the increases of horizontal deformations on the sides of the observation line Z1 after stopping and renewing the exploitation, exceeding the value of mean measurement error $m_\varepsilon = \pm 0.18$ mm/m/24 hrs, mine "Ziemowit" (region II)

TABLICA 10

Wyszczególnienie wartości przyrostów odkształceń poziomych na bokach linii obserwacyjnej Z1 po zatrzymaniu i wznowieniu eksploatacji, wykraczających poza wartość średniego błędu pomiarowego $m_\varepsilon = \pm 0{,}18$ mm/m/dobę, KWK „Ziemowit" (rejon II)

Zone of stretching deformations								Zone of compression							
24 hrs after stopping the exploitation		48 hrs after stopping the exploitation		24 hrs after restarting the exploitation		48 hrs after restarting the exploitation		24 hrs after stopping the exploitation		48 hrs after stopping the exploitation		24 hrs after restarting the exploitation		48 hrs after restarting the exploitation	
Δε	%	Δε	%	Δε	%	Δε	%	Δε	%	Δε	%	Δε	%	Δε	%
–0,36		–0.26		–0.26		–0.41		–0.48		–0.31		–0.35		–0.42	
–0.30		–0.22	38	–0.23	43	–0.34		–0.44		–0.27		–0.26	67	–0.35	
–0.26		–0.20		–0.22		–0.29	55	–0.41		–0.26		–0.20		–0.34	
–0.24	54	+0.30	62	+0.31		–0.25		–0.38		–0.25	75	–0.19		–0.34	
–0.22		+0.25		+0.24	57	–0.24		–0.38		–0.24		+0.22	33	–0.23	77
–0.22		+0.23		+0.23		–0.19		–0.33	85	–0.22		+0.20		–0.23	
–0.19		+0.19		+0.22		+0.50		–0.30		+0.28	25			–0.23	
+0.41		+0.19				+0.38		–0.27		+0.20				–0.20	
+0.24						+0.36	45	–0.27						–0.19	
+0.22	46					+0.24		–0.23						–0.19	
+0.21						+0.19		–0.20						+0.32	
+0.21								+0.26	15					+0.21	23
+0.20								+0.19						+0.20	

Δε [mm/m/24 hrs] — value of the increase of a horizontal deformation;
(–) — increase of horizontal deformations on the side of the line in the direction of compression;
(+) — increase of horizontal deformations one the side of the line in the direction of stretching.

From the data contained in tables 7 and 8 it can be concluded that in the zone of stretching the rock mass does not always react in the same way on stopping and restarting mining exploitation. Significant fluctuations appear: i.e. small compression or stretching of measurement sections, without differentiation of the numbers in both cases. In the zone of compressing deformations, however, small increases of compression are predominant both during the exploitation break and after restarting the front, particularly during the first 24 hours after stopping the exploitation front.

Based on the analysis of the values of the changes in horizontal deformations one can state that the fluctuations of this process, caused by the breaks in exploitation, basically do not disturb a general trend of the changes of this deformation index. For these changes are small and stay within the limits of tenth parts of mm/m. Particular analysis is even more difficult, because these changes are often within the limits of the error in the determination of the index, which is about $m_\varepsilon = 0.18$ mm/m. Analysing the data contained in Tables 9 and 10 it can be stated that in a relatively small number of cases the changes of the increases of horizontal deformations per day in the periods of breaks in exploitation exceed the value of the error in determining them. Maximal values of the increases of horizontal deformations per day in region I do not exceed $\Delta\varepsilon(\mathrm{I}) = 0.65$ mm/m/24 hrs, while in region II — $\Delta\varepsilon(\mathrm{II}) = 0.5$ mm/m/24 hrs. It can be stated that the values of the changes in the increases of horizontal deformations depend on the present distance of the exploitation front from a given side, which is connected with the dynamics of growth of the deformation index. The biggest changes are observed in the areas of the most intensive increases of horizontal deformations.

From the surveying measurements it can be stated that there is no (on the defined level of significance) correlation between the time of the exploitation break and the value of the changes in horizontal deformations. Neither it can be stated that the rock mass reacts on stopping and restarting the exploitation front only in a one way (e.g. through the increase of only compressing or only stretching deformations per day). After restarting the front after the break both daily growth of compression and stretching occurs, while after one, two, three days and sometimes later, much smaller increase of the deformation is usually observed.

To summarise the results of the analyses of the results of the breaks in exploitation on subsidence and horizontal deformations of the surface of the area it should be stated that also according to present views (Sroka 1999) that they can have unfavourable influence on the course of the deformation process, disturbing its regularity.

Conclusions

To summarise the studies carried out one should state that they, for the first time, allowed obtaining a clear picture of the influence of the breaks in the exploitation front on the course of the process of the deformation of the area surface. The results can be summarised in the following conclusions:

1. The accepted in the studies on the results of the breaks in exploitation methods of surveying measurements, implemented in the grid of permanently stabilised points, configured in the measurement observation lines enabled us to observe the values of translocations and deformations with a satisfying accuracy equalling: ±3.5 mm for subsidence points and ±0.18 mm/m for horizontal deformations.

2. Examining the results of the exploitation breaks by the methods of surveying was, for practical reasons, possible in a daily measurement cycle, the advantage of tensometric methods, providing 3-hours time interval is significant in this case.

3. After stopping the exploitation front, a significant decrease of daily increases of subsidence of the points of the observation line was observed (up to 80%). The effect of stopping the front was visible after 24 hours from the moment of halting the exploitation and lasted for about 48–72 hours.

4. After renewing the exploitation front, a significant increase of the subsidence of the points of the observation line was observed. It started in the time of 24 hours from the moment of restarting the exploitation and lasted for about 72 hours, reaching a maximal value respective to a continuous progress.

5. The course of horizontal deformations and their increases in time, defined with a great reliability in mine "Wesoła", during the intensive movements (after passing of the front under respective measurement bases) showed a great regularity of the changes of the daily increases of deformations. The regularity of these changes reflects the regularity of the changes in the increases of subsidence, while the time till the beginning of the reaction of the changes of horizontal deformations was slightly longer. The reaction on stopping the front in this case started on the second day after its stopping and lasted for about 3 days, while the reaction on renewing the front started on 2nd or even 3rd day after its restarting and lasted for about 4 days until maximal indexes for the front of the constant progress were reached.

6. Generally it has to be stated that irregular mining exploitation (unequal speed of the progressing exploitation front, and in particular the breaks) in much greater degree than expected, disturb the course of the deformation process of the rock mass and surface of the area, involving great changes in the increases of vertical translocations and horizontal deformations per day. The values of these changes are significantly greater than in the case of a quick, continuous progress of the front and occur for the time of several days after stopping and restarting the front.

7. The carried out studies of the influence of the exploitation breaks, clearly showed that the breaks in exploitation front disturb the process of the deformation of the rock mass, already after a short period not exceeding 24 hours. Further studies can more accurately define the time of when the results of the exploitation breaks on the surface of the area can be seen.

8. It is practically important

9. to define the degree of additional threat for the buildings, caused by the breaks in the exploitation fronts, connected with the time of their lasting.

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REFERENCES

Dokumentacja geologiczna Kopalni Węgla Kamiennego „Wesoła".

Dokumentacja geologiczna Kopalni Węgla Kamiennego „Ziemowit".

Drzęźla B., 1996: Wpływ prędkości wybierania (postojów ścian) w świetle przyjętych modeli teoretycznych. Materiały Szkoły Eksploatacji Podziemnej 1996, PAN–AGH, Kraków.

Dżegniuk B., Sroka A., 1978: Prędkość postępu frontu eksploatacji górniczej a proces deformacji górotworu na powierzchni. Materiały na Konferencję n.t. „Wpływ prędkości eksploatacji na ochronę obiektów i powierzchni". PAN, Katowice.

Hejmanowski R., 1997: Optymalizacja prędkości eksploatacji górniczej i przerw eksploatacyjnych — oprogramowanie komputerowe. Konf. Nauk.-Techn.: IV Dni miernictwa górniczego i ochrony terenów górniczych, Rytro.

Hoffmann H., 1950: Beitrag zur Analyse der Gebirgsbewegungen. Mitt. a.d. Markscheidewesen, 57, Jahresheft, s. 24–38.

Knothe S., 1975: Prędkość posuwu frontu eksploatacyjnego. Poradnik Górnika t. 2, Wyd. Śląsk, Katowice, s. 1554–1556.

Knothe S., 1984: Prognozowanie wpływów eksploatacji górniczej. Wyd. Śląsk, Katowice.

Kowalski A., 1993: Deformacje terenu powstałe w wyniku szybkiej eksploatacji górniczej. Nowe doświadczenia. Konf. Nauk.-Techn.: II Dni miernictwa górniczego i ochrony terenów górniczych, Ustroń–Jaszowiec.

Kowalski A., 1995:Deformation powierzchni nad szybko postępującym frontem eksploatacyjnym na podstawie badań na kopalni Staszic. Prace Naukowe GIG, seria Konferencje nr 3. Ochrona powierzchni i obiektów budowlanych przed szkodami górniczymi, Katowice.

Kratzsch H., 1994: Geringe Bergschaden durch langsamen Abbau? Das Markscheidewesen 101, Heft 1, 1994.

Lippmann W., 1974: Ausgewachlte Faelle aus der Bergschadenpraxis. Mitt. a. D. Markscheidewesen 81, Heft 1, s. 133–142.

Marbach G., 1939: Der Abbau unter dem Hydrievwerk Nordstern. Gelsenteirchen. Ekspertyza (niepubl.).

Nelson A., 1964: Ground movementsdue to mining. Canadian Mining Journal, s. 69–73.

Sroka A., 1993: Dynamika eksploatacji górniczej z punktu widzenia szkód górniczych. Konf, CPPGSME PAN, Szczyrk.

Sroka A., 1995: Przerwy w eksploatacji wyrobisk ścianowych — ich znaczenie z punktu widzenia szkód górniczych. Konf. nauk.-techn.: III Dni miernictwa górniczego i ochrony terenów górniczych, Ustroń–Zawodzie.

Sroka A., 1999: Dynamika eksploatacji górniczej z punktu widzenia szkód górniczych. Rozprawa habilitacyjna. Studia, Rozprawy, Monografie z. 58, IGSMiE PAN, Kraków.

Zych J., 2002: Wpływ dużego postępu frontu i przerw w eksploatacji na prędkość i przyspieszenie osiadania powierzchni terenu. XXV Zimowa Szkoła Mechaniki Górotworu, s. 789–802, Zakopane.

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