Archives of Mining Sciences **48**, 2 (2003) 197–218

JERZY GUSTKIEWICZ*, ADAM KANCIRUK*, LESZEK STANISŁAWSKI*

THE INFLUENCE OF PAUSES IN LONGWALL WORKING ON SURFACE STRAINS AS MEASURED BY SOIL-STRAIN MEASUREMENT DEVICES

WPŁYW PRZERW W EKSPLOATACJI PODZIEMNEJ NA ODKSZTAŁCENIA POWIERZCHNI W ŚWIETLE POMIARÓW TENSOMETRAMI GRUNTOWYMI

Observations have been conducted of horizontal soil strains resulting from longwall working as monitored by lines of strain transducers. The observation lines were installed in the area where the underground extraction took place parallel to their laid direction. Measurements were taken every three hours. In one case the observation period exceeded one year; in the other took place over a period of over 8 months. With a face advance of about 8 m per working day, an evident influence of weekend breaks in working on regular accelerations and retardations of strains in time could be observed. However, the phenomenon was not observed when the face advance was only 4 m per day. Hence, there must be a critical face advance rate above which the influence of rhythmic stoppages in working is manifested on the surface.

Key words: influence of mining , longwall face advance, pauses in working, surface strain

Obserwacje ruchów powierzchni terenu wywołanych podziemną eksploatacją górniczą o szybkościach przekraczających pewne, dawniej niespotykane wartości wykazały pojawienie się zjawisk wcześniej niezauważalnych. Należy do nich wpływ przerw w eksploatacji na zachowanie powierzchni. Wpływ ten jest słabo udokumentowany, a o jego skutkach trwają dyskusje. Dotychczasowe doświadczenia sugerują, że wpływ zatrzymań frontu eksploatacji na powierzchni pojawia się już po upływie czasu rzędu dni.

Projektowanie obserwacji takiego wpływu skłania do zastosowania metod pomiarowych ruchów gruntu na powierzchni pozwalających na dowolnie częste odczyty w czasie. Podjęto obserwacje rozwoju odkształceń i ich zmian w czasie pod wpływem eksploatacji i jej rytmicznych sobotnio-niedzielnych zatrzymań i uruchomień. Do pomiaru poziomych odkształceń gruntu zastosowano gruntowe przetworniki odkształcenia i temperatury typu TTCS-4000.3 (rys. 1) wraz z odpowiednią aparaturą rejestracyjną typu KA-8D (rys. 2). Aparatura pomiarowa jest w stanie dokonywać rejestracji odczytów z dowolną częstotliwością.

Idea obserwacji polegała na instalacji w gruncie, wzdłuż jednej linii biegnącej nad środkiem pasa obszaru eksploatowanego systemem ścianowym, ciągu przetworników (rys. 4) i pomiarze za ich

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

pomocą odkształceń podczas zbliżania się frontu eksploatacji do początku linii obserwacyjnej, podczas przesuwania się pod nią i po oddaleniu się frontu od końca linii (rys. 3, 5).

Przetworniki były zainstalowane w wykopach na głębokości 1,5 m pod powierzchnią, a więc poniżej zasięgu przemarzania gruntu i wahań dobowych temperatury. Wpływ zmian temperatury T podlegającej rocznym wahaniom na wskazania odkształceń ε na tensometrach korygowany był na podstawie odczytów początkowych i bieżących według cytowanych w artykule wzorów. Przetworniki miały długość 4 m. Odczyty odkształceń dokonywane były automatycznie co 3 godziny i zapisywane w pamięci urządzenia rejestrującego.

Tensometryczne linie obserwacyjne zainstalowane były na terenie dwóch kopalń węgla kamiennego Górnego Śląska: „Wesoła" i „Ziemowit".

W kopalni „Wesoła" eksploatowany był pokład 308, zaś w kopalni „Ziemowit" pokład 207 systemem ścianowym. W obu przypadkach długość ściany wynosiła 200 m. Postęp ściany w kopalni „Ziemowit" wynosił około 4 m/dobę, a w kopalni „Wesoła" około 8 m/dobę.

Rozwój odkształceń w czasie dla kopalni „Wesoła" przedstawiają rysunki 6, 7, 8, a dla kopalni „Ziemowit" 9, 10, 11. Ponadto rysunki 7, 8 i 10,11 zawierają dobowe przyrosty odkształceń dla wybranych tensometrów.

Rysunki 12, 13, 14 i 15 przedstawiają przykładowo rozwój odkształceń zmierzonych pewnymi tensometrami i postęp frontu eksploatacji w obu przypadkach kopalń, z widocznymi datami jego sobotnio-niedzielnych zatrzymań. Widać, że w przypadku kopalni „Wesoła" istnieją wyraźne związki między zatrzymaniami frontu a zmianami odkształceń. W przypadku kopalni „Ziemowit" taki związek nie jest widoczny.

Należy zaznaczyć, że w kopalni „Wesoła" szybkość przesuwu frontu wynosiła około 8 m/dobę natomiast w kopalni „Ziemowit" była około dwa razy mniejsza.

Można zatem wysnuć wniosek, że istnieje pewna graniczna szybkość przesuwu frontu eksploatacji, powyżej której zatrzymania frontu przejawiają się wyraźnie na powierzchni. Wyniki sugerują, że te przejawy w postaci przyspieszeń i spowolnień odkształceń dokonują się równocześnie, niezależnie od miejsca pomiaru odkształceń w stosunku do pozycji frontu eksploatacji w większym obszarze.

Słowa kluczowe: wpływy eksploatacji, prędkość eksploatacji, przestoje frontów

1. Introduction

Over the past few years in the underground mining the advance of the working face has been continually increased. Nowadays it may reach values higher by one order of magnitude than those obtained in the past. The influence of the face advance on surface movements was a subject of discussion even in the middle of the last century (e.g. Knothe 1951). The observations of soil surface movements caused by greater face advance revealed the appearance of some phenomena that had not previously been noticed. They include a perceptible noticeable influence of pauses in mining on the soil surface reaction. That influence on the strata and, consequently on the mining damages is not well supported by documentary evidence.

One of the important questions refers to the time elapse after which the effects of stopping and restarting the working face manifest themselves on the surface. There is a difference in opinions about that. For instance, Kowalski (1993, 1995) estimates that a period in the order of weeks is necessary, whilst Sroka (1999) reduces the time-span to mere days. The effective time-span seems generally to depend on several factors: the face advance, the depth at which extraction is taking place, the mechanical properties of the overall rock massif and its component parts.

It should be observed that every subsequent restarting of extraction contributes to the intensification of rock movements and every period of standing face to their retardation. Since the strata up to the surface can be described as a deformable medium, every abandon and restarting of the face resulting in either acceleration or retardation of its mass movement will cause corresponding changes of strains in time.

The purpose of this work has been to observe strains resulting from mining and their changes due to recurrent abandon and restarting the working face. Measurements were taken with the use of strain transducers specially constructed for operation in the soil. The read-outs were automatically recorded.

2. General remarks about the method of taking soil-strain measurements. Description of the apparatus

The choice of an appropriate method of measurement and suitable measuring instruments has a decisive influence on ability to obtain reliable results. It depends on the nature and properties of the medium under observation, the kind and course of the phenomenon being measured and, lastly, on the conditions to which the medium is subjected.

Measurement of surface strains is difficult. Soil is a set of detrital minerals differing in distribution and grain-size as well as in their cohesion, which is usually low. The layers of the earth crust close to the surface are subject to atmospheric conditions, which are very changeable and can adversely influence the results obtained. They can cause disturbances merely in the indications of the measuring instruments or produce additional soil strains. Lastly, the strains themselves which result from mining excavation appear over very long periods of time, which can take months or years and their changes in time are usually very slow. It would seem, however, that in the case of the strain measurements described here the changes are much faster than those usually observed. Those quick changes are the main subject of the research

It seems advisable, since soil is the medium in which readings are to be taken, that measuring instruments specifically designed for the purpose be employed.

The transducer of a measuring apparatus must remain in the soil in unfavourable atmospheric conditions for a very long period; possibly for years or even decades. Therefore it must be simple and light in structure, durable and moisture-resistant. It should be reliable during a long-term operation and guarantee an optimal sensitivity and accuracy. It should also remain as unaffected by fluctuations of the environmental temperature as possible.

For the past few decades the Laboratory of Rock Deformation of the Strata Mechanics Research Institute of the Polish Academy of Sciences has been developing methods of measuring soil deformations caused by mining exploitation, landslides, etc.

At present, the laboratory is equipped with a measuring apparatus that can be used for measuring strains in a process lasting for as long as decades. For instance, in the vicinity of the Institute measurements supposed to serve as life-tests for the apparatus have been conducted for some 29 years. The results yielded prove that the apparatus functions correctly.

One of the devices used for taking measurements described here is a transducer of displacements and temperature of the soil TTCS-4000.3. Its precise in a study by Gustkiewicz et al. (1996). The transducer collaborates with an instrument which, according to the needs, can register that read-outs at an optional frequency and can be connected with transducers with the use a cable. Fig. 1 presents a transducer to record soil strains and soil temperature TTCS-4000.3.

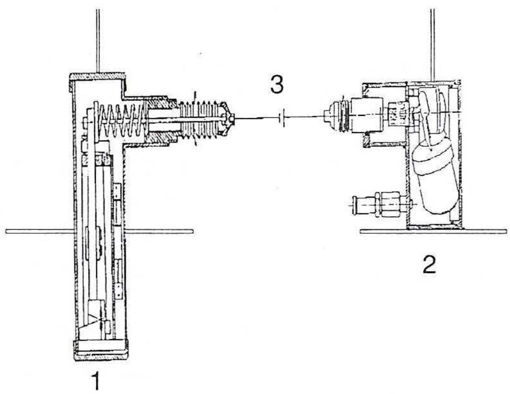

Fig. 1. Transducer to measure displacements and temperature; type TTCS-4000.3
1 — head, 2 — range adjuster, 3 — tensioned wire connecting the head with the adjuster

Rys. 1. Przetwornik przemieszczeń i temperatury TTCS-4000.3
1 — głowica, 2 — regulator zakresu, 3 — cięgno łączące pozycje 1 z pozycją 2

On starting to make measurements, the readouts of the gauge are set in the middle of of its measuring range. If the gauge arrives at the limit of its range in operation, the range may be altered by changing the length of the tensioned wire with the help of the range adjuster. This enlargement of the basic measuring range is achieved by means of a screw fixed in the adjuster. This operation may be conveniently performed manually or by remote control via an electric motor. The tensioned wire between the anchors is protected by rigid pipes composed of several sections. The pipes prevent the wire from direct contact with the soil and their sectional structure does not cause the stiffening of the transducer in the direction of strains being measured. The head 1 and the range adjuster 2 are fixed to anchors, which keep the transducer in positioned contact with the soil.

In order to measure the temperature of the medium surrounding the transducer (needed for the introduction of necessary corrections connected with thermal extension, a temperature-sensitive element was installed. It consisted of a brass bar with a vibrating-wire stretched over it, placed inside the transducer. Thermal changes in deformation of the bar alter the tension of the wire.

On the assumption that:

- T_0 is the temperature at the beginning of taking strain measurements,
- N_0 is a read-out of the measuring instrument corresponding to that temperature,
- M_0 is a read-out corresponding to the zero strain,
- N and M are current indications of the measuring instrument which result from the changes in temperature and strain,

the temperature is described by the formula:

$$T = T_0 + \kappa_t(N - N_0)\ [^\circ\mathrm{C}]$$

and the soil strain by the formula:

$$\varepsilon = \kappa_\varepsilon(M - M_0) + \alpha(N - N_0)\ [\mathrm{mm/m}]$$

Here, κ_t, κ_ε, $\alpha = 1.1 \cdot 10^{-2} \cdot \kappa_t$ are constant values of a strain transducer established during its calibration. For instance, the constants of the transducers installed in the mines "Wesoła" and "Ziemowit" were as follows:

$$\kappa_\varepsilon = 3.94 \cdot 10^{-3}\,, \qquad \alpha = 0.231 \cdot 10^{-3}\,, \qquad \kappa_t = 21.06 \cdot 10^{-3}$$

The technological and metrological data of transducer type TTCS-4000.3

• measurement base of the strain transducer	2–4 m
• basic measuring range	30 mm
• extended measuring base	150 mm
• measurement accuracy	±0.03 mm
• measurement resolution	5 μm
• size of anchors	300 × 300 mm
• maximal and minimal stretch of the tensioned wire	50–70 N
• pressure of anchors on the soil	<1 kPa
• temperatore measurement range	–10 – +30°C
• temperature measurement accuracy	±0.03°C
• frequency range of measuring wires	672–821 Hz

Vibrating-wire transducers are not independent measuring instruments. In order to conduct measurements it is necessary to connect them to electronic devices such as, for example, a 15-input measurement-recording instrument KA-8D, which can be seen in Fig. 2. The measuring instrument is supposed to should be installed in the vicinity of a set of transducers.

It can operate in one of four modes:

- manual simplified (only a visual read-out of the results),
- manual with the possibility of recording measurement results,
- automatic,
- remotely controlled by a program installed on a personal computer.

Each mode is pre-programmed. The method of recording the data makes it possible to identify them with many transducers used simultaneously. The recorded data can be send to the computer for further processing. The instrument is equipped with a 15-channel input multiplexer, which at a given moment adjoins a transducer to the

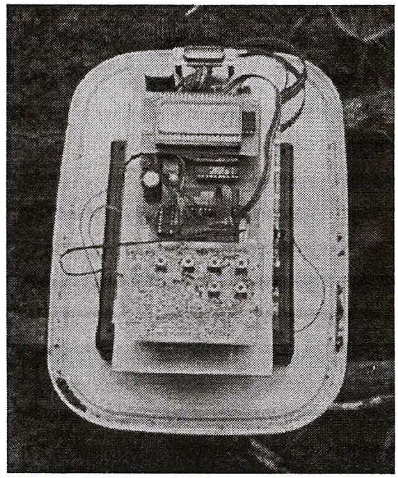

Fig. 2. The measurement-recording instrument KA-8D

Rys. 2. Miernik-rejestrator KA-8D

input of its electronic systems. Their switching is bipolar; the particular transducers are not galvanically connected with one another.

The technological and metrological data of measuring instrument type KA-8D:

- vibrating frequency range of the transducer wire 611–1220 Hz,
- input sensitivity 1 mV,
- accuracy of measuring the period of wire vibrations 40 ns,
- capacity of inner memory of measuring data up to 4000 results in the automatic mode,
- minimum period of time for repetition of measurem ents in the automatic mode 60 s,
- maximum period of time for repetition of measurements in the automatic mode 12 h,
- maximum number of adjoined transducers 15
- power supply a set of 6 batteries R20

Considerable disturbances in the indications of transducers can result from temperature fluctuations on the surface. The amplitude of temperature fluctuations decreases in geometric progression with the depth. In our climate daily temperature fluctuations practically disappear at a depth of 0.8–1.0 m whereas the amplitude of yearly fluctuations disappears at a depth 19 times as great, i.e. 15–20 meters. There is a considerable decrease of amplitude with a decrease of the content of water in the soil, which is connected with the large thermal capacity of water. The longer the duration of periods of high or low air temperature, the deeper the influence of temperature has an effect (Prikłoński 1958; Bac 1952).

Changes in temperature, which are the cause of freezing and thawing of the soil, produce a vertical state of strain in it. Therefore rigid bodies placed in the freezing zone are subject to vertical upward displacement (Bac 1952). The depth of the freezing level depends on many factors, such as the kind of soil, the degree of saturation, the duration and thickness of a snow cover as well as the duration of frosts. The value of that depth is estimated at 0.8 m in western Poland, at 1 m for the central part and at 1.2 m for the parts of the country situated 500 m above sea level. On average, frost penetration in Poland is around 1 m and during severe winters may be twice this value (Huckel 1958).

Certain kinds of soil show some tendencies to changes in volume resulting from their water content. The water-content is subject to similar fluctuations as the temperature; deeper layers exhibit lower variations of moisture than those close to the surface.

This suggests that the optimum depth of placing the transducers is below the freezing zone: this also excludes effects of daily temperature fluctuations, avoids the displacement of anchorages during frosts, avoids large temperature fluctuations in the transducer surrounding and implies lower variations of moisture and hence, possible changes in the soil-mass volume. Lastly, placing transducers at such depth ensures their natural protection against the interference of other undesirable factors.

Placing a transducer at a depth of 1.5 m seems to be satisfactory for measuring soil strains. Deeper burial to avoid temperature fluctuations does not seem expedient as the cost of labour for placing transducers at greater depths is not justified by reduction in annual temperature fluctuations. The problem of determining the surface strains is another reason for placing transducers as close to the surface as possible although at such a deep location of the cause of the strain i.e. underground mining, the vertical gradient of horizontal strains in the close-to-surface layers of the earth crust should be negligible.

In order to place the transducers at the predetermined depth, longitudinal trenches should be dug alongside a future measurement line. Because of the disturbance of the original soil structure caused by excavating trenches their width and length should be as small as possible so as to disturb the environment minimally. In practice, a trench width of about 0.5–0.6 m and a length exceeding the transducer base by 0.3–0.4 m are quite sufficient for secure placement of a transducer. After setting the transducer in the soil, the initial length of the measuring base is determined with the use of a measuring device. While the signals from the transducer are continually checked, the tensioned wire connecting its extremal parts is covered with a special shield which prevents it from direct contact with the soil mass. The shield is made of rigid material but due to its sectional structure it is vulnerable to soil deformations. The trench is infilled and the loose soil in it is carefully compacted only after the back-filling has been completed.

The read-outs taken directly after the installation of transducers in the soil are used for initial calibration purposes. The real start-readings are taken after a few months, when the transducers have become bedded into the soil. This also gives time for soil temperature stabilization.

3. The transducer network in the "Wesoła" and "Ziemowit" hard coal mines

The measuring line in the "Wesoła" coal mine above longwall no. 104 in bed 308 is presented in Fig. 3.

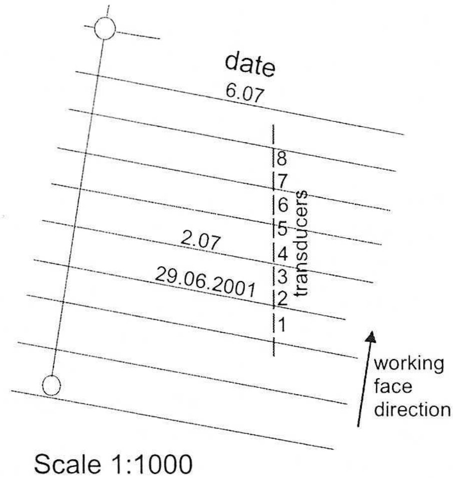

Fig. 3. The layout of strain transducers ("Wesoła" coal mine)

Rys. 3. Schemat rozmieszczenia tensometrów (KWK „Wesoła")

That line was determined by the geodesic staff of the mine approximately perpendicularly to the working face line. Some of the positions of the front have been marked in the form of parallel lines in Fig. 3 and 5. On Oct. 10th, 2000, ten strain transducers were installed at one-metre spaces with a measuring base equal to 4 m. The measuring line was 50 m long. Because of the scarcity of transducers available the line was not supplemented with rosettes, consisting of 3–4 transducers. Such rosettes could provide some additional local information about the strain tensor. The line was shifted about 30 m from the axis of symmetry of the wall because of the soil conditions. The length of the wall was about 200 m. The transducers were placed in the bottom of a trench 50 m long. The two photographs of the trench in the "Wesoła" mine, presented in Fig. 4, can serve as an example. The first of them (A) shows a trench prepared for the installation of transducers; in photograph B transducers on the trench bottom can be seen before they have been covered with soil. The trench was about 1.5 m deep and about 0.6 m wide.

A measurement line was installed in the area of the "Ziemowit" coal mine above longwall no. 719 in bed 207 (Fig. 5). That line, similarly to the "Wesoła" mine, had been determined by the measuring services in the direction perpendicular to the working face line. On October 5th, 2000, ten transducers were installed along a 100-metre-long line at equal intervals of 5 metres, with a 4-metre-long measuring base. The length of the observation line and its localization had been determined by the size of the area in a forest region as well as by the number of transducers available. Here, as in the "Wesoła" mine the line was not supplemented with rosettes. In the "Ziemowit" coal mine the observation line was placed almost on the axis of symmetry of the longwall. The length of the wall was about 200 m. The transducers were placed in a series of 5-metre-long trenches, the distance between neighbouring trenches also being 5 m. The trenches were dug along the same axis.

Fig. 4A. Trench for installing transducers

Rys. 4A. Wykop dla instalacji tensometrów

Fig. 4B. Transducers placed in the trench bottom

Rys. 4B. Tensometry ułożone na dnie wykopu

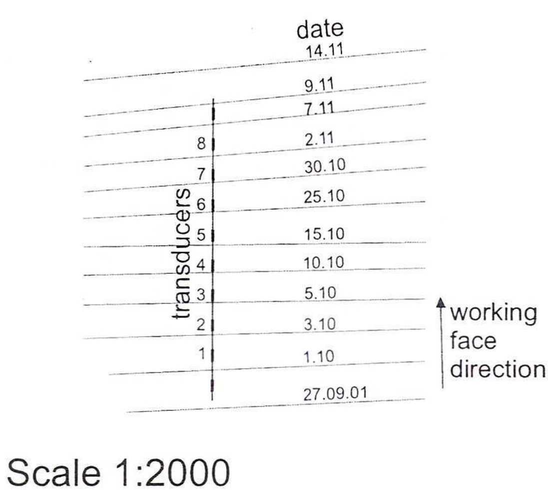

Fig. 5. The layout of transducers ("Ziemowit" coal mine)

Rys. 5. Schemat rozmieszczenia tensometrów (KWK „Ziemowit")

3.1. Strain-measurement tests with the use of strain transducers

The observations of horizontal strains in the mining area were conducted, as mentioned before, above longwall no. 719 in the "Ziemowit" coal mine as well as above wall no. 104 in the "Wesola" mine. The excavation in the mine "Ziemowit" started at the end of 2000, with an expected working face advance of up to 5 m per day. On the other hand, in the "Wesoła" mine the excavation was begun in April 2001, with wall advance of up to 10 m per day. The dates of installation of the measurement apparatus, the initial read-outs as well as the completion of observations in each mine are as follows:

	Coal mine "Ziemowit"	Coal mine "Wesoła"
Date of installation	5.10. 2000	10.10.2000
Date of initial reading	14.03.2001	10.05.2001
Date of completing observations	26.03.2002	23.01.2002

After the installation, measurements were taken by observers in order to watch the process of the transducers becoming adapted to the soil. Those observations lasted a few months and took place at a time when the influence of excavation had not yet been observed. During those observations the instruments were recalibrated because the subsidence of the disturbed surface subjected the transducers to considerable deformations. Approximately one measurement per month was made. After the stabilization of the transducers in the soil, an automatic recording of strains began.

An appropriate apparatus, presented above, registered strains 8 times per day at equal time intervals, that is, every three hours. This frequency of measurement seemed to be well justified as, according to contemporary knowledge about the surface reaction to swift extraction and especially to stoppages at the working face, it was expected that changes in strains resulting from such stoppages would appear from day to day. The automatic recording in the "Ziemowit" coal mine was begun on March 14th, 2001, when the observation line was at the distance of about 400 m from the face. By comparison, in the "Wesoła" coal mine automatic recording at the same frequency started on May 10th, 2001, when the face was about 250 m away from the observation line starting point. The mining process of wall no. 719 in the "Ziemowit" mine started at the end of 2000, with a planned face-advance of 5 metres per day. In the "Wesoła" mine longwall no. 104 was started in April, 2001, with an advance of 10 metres per day. As mentioned above, the initial measurements were taken manually until the soil stabilized, which took a few months.

4. The results

The developments of horizontal strains in time are presented in Fig. 6, 7, and 8 for the "Wesoła" coal mine; for the "Ziemowit" mine they can be seen in Fig. 9, 10 and 11. In both cases the axis of the abcissae (the X-axis) is an axis of time, where consecutive days, counted from January 1st, 2001, have been marked. The axis of ordinates (Y-axis, with one 1‰ (per mille) as a basic unit.

The respective curves refer to the values measured by the transducers, the numbers of which have been marked on the diagrams. In the observation line the transducers were numbered from 1 to 8, starting from the side where the working face was approaching. Fig. 6 and 9 present the full courses of horizontal strain development in time and comprise cover the whole period of measurement. Fig.7 and 8 as well as Fig. 10 and 11 present the developments of horizontal strains together with their daily increases for some transducers chosen at random (no. 7 in the "Wesoła" mine and no. 6 in the "Ziemowit" mine) in periods when the influence of pauses in the working face was most evident.

4.1. "Wesoła" hard coal mine

Fig. 6 presents the results of daily measurements taken at hours intervals in the coal mine "Wesoła" in the observation period from May 10^{th}, 2001, to January 23^{rd},2002.

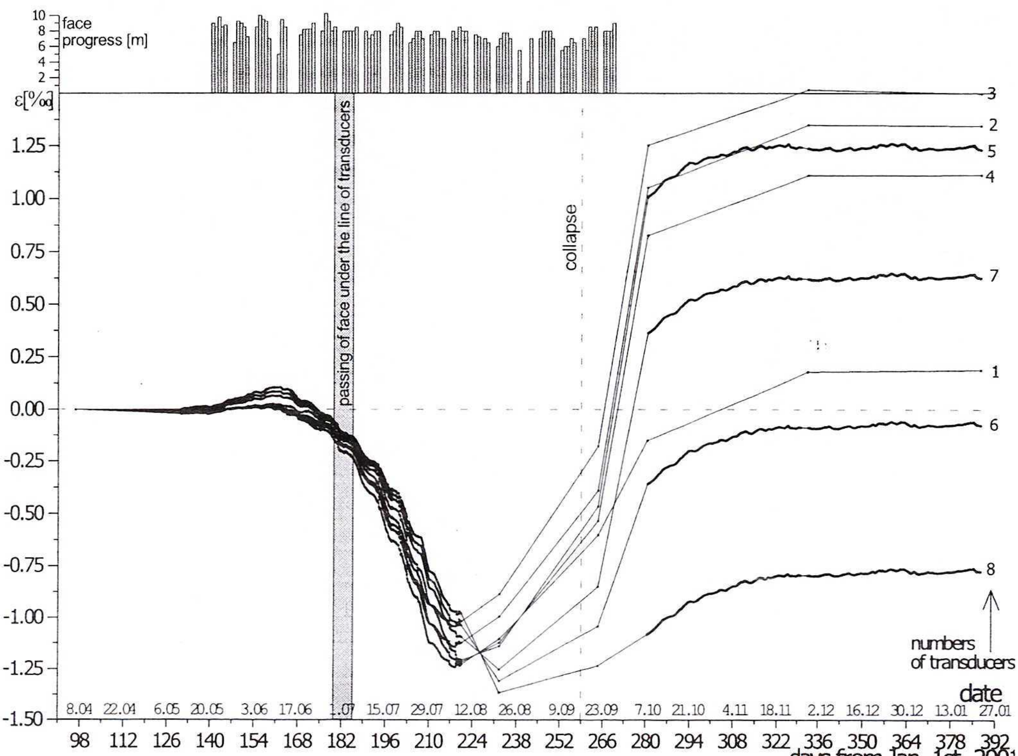

Fig. 6. The "Wesoła" coal mine. Soil strains as a function of time

Rys. 6. KWK „Wesoła". Odkształcenia gruntu jako funkcja czasu

The curves presented in the figure differ in thickness. The curve sections drawn with thick lines were obtained as a result of automatic recording of strains taken 8 times per day at intervals of 3 hours. The curve sections marked with thin lines were obtained on the basis of manual measurements. The measurements were taken manually because of flooding of the measuring apparatus. The flooding took place in August (as can be seen in the figure).

The starting point of observation in the coal mine "Wesoła" was on May 10th 2001 when the face was at the distance of about 250 m from the beginning of the observation line. The noticeable initial slight tensile strains reached a value of 0.1‰. With the approach of the face the tensile values were gradually transformed into a compressive value, i.e. 1.4‰ was obtained on the 223rd day of the observation. The horizontal strains recorded at all the transducers ran to a similar pattern. After the face passed beneath the observation line and after the strains reached a minimum (i.e. compressive) values, the strain values increased. The last reliable measurement was taken on August 20th 2001,

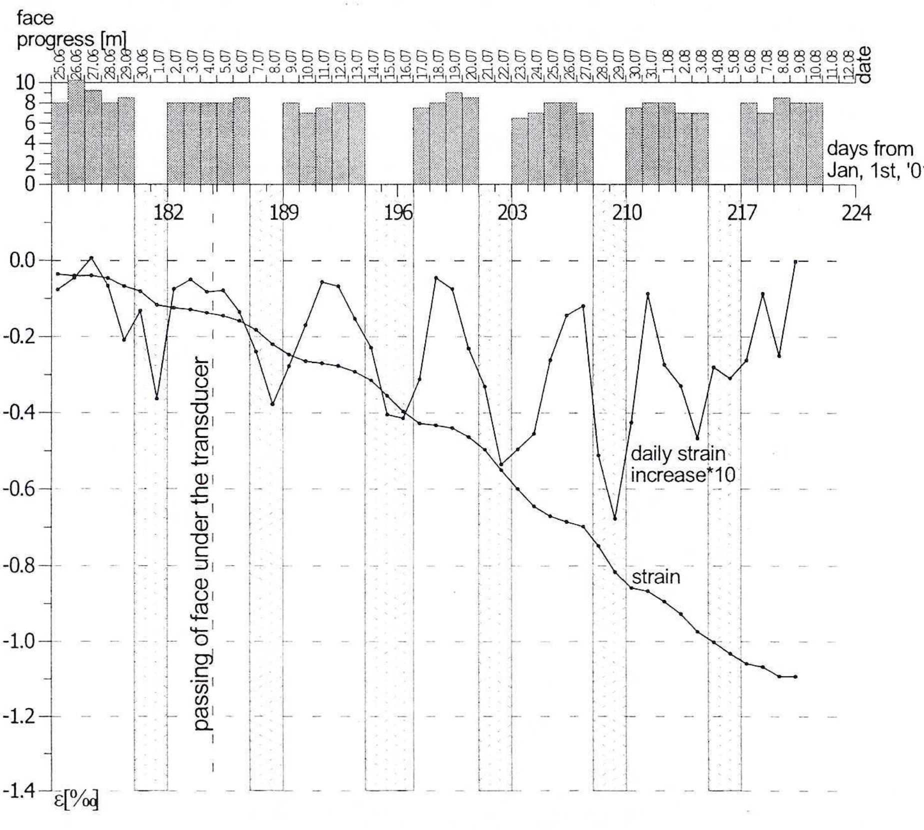

Fig. 7. The "Wesoła" coal mine, transducer no. 7. The strain and its daily increase with measurements taken every 24 hours

Rys. 7. KWK „Wesoła", tensometr nr 7. Odkształcenie i jego dobowy przyrost przy pomiarach prowadzonych co 24 godziny before the collapse that took place on September 16th 2001. The measurements after that date are unrepresentative.

Fig. 7 presents, by way of example, the measuring results for one of the transducers (no. 7) of horizontal strains and their daily increase on the basis of measurements taken at 12 a.m. every day. By comparison, in Fig. 8 the measuring results of horizontal strains are drawn on the basis of all 3-hourly measurements.

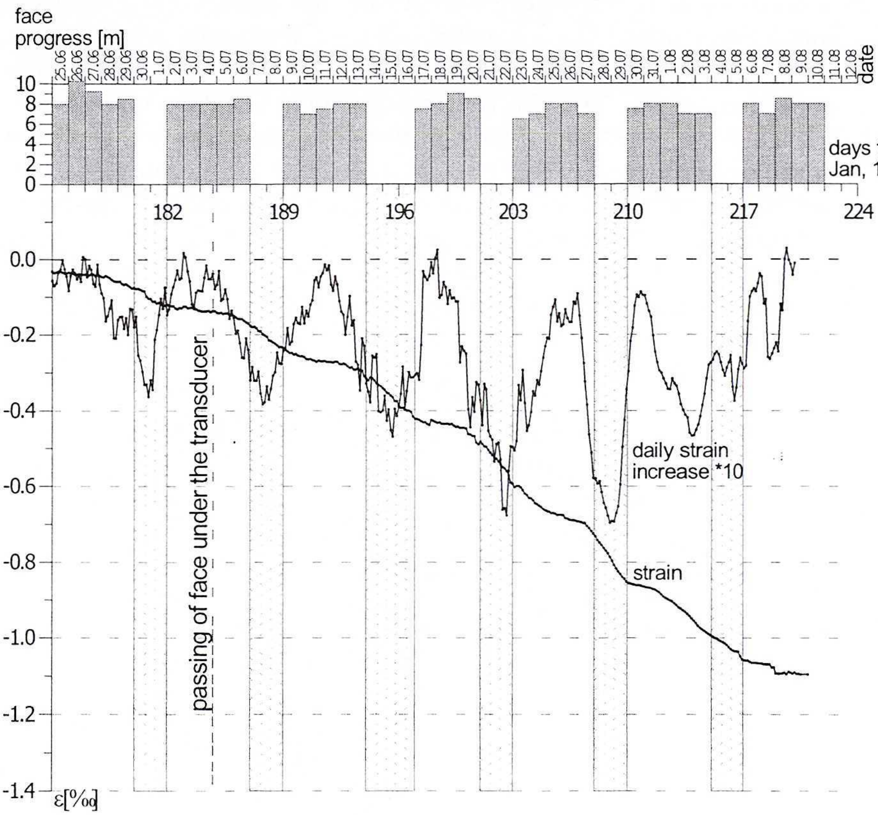

Fig. 8. "Wesoła" coal mine, transducer no. 7. The strain and its daily increase with measurements taken every 3 hours

Rys. 8. KWK „Wesoła", tensometr nr 7. Odkształcenie i jego dobowy przyrost przy pomiarach prowadzonych co 3 godziny

4.2. "Ziemowit" hard coal mine

The measurements covering the period of observation from March 14th 2001 to March 26th 2002, concerning the "Ziemowit" coal mine are presented in Fig. 10 and Fig. 11. The method of numbering particular transducers is identical with the one applied in the "Wesoła" mine. Fig. 9 presents a diagram of soil strain development over time. Fig. 10 presents a diagram of strain and its daily increases for a selected transducer (no. 6) with the measurements taken every 24 hours. On the other hand, Fig. 11 presents a similar diagram but for measurements taken every 3 hours. In the "Ziemowit" coal mine the starting point of the graph (Fig. 9) is the day when the face was at the distance of about 400 m from the beginning of the observation line. As the face approaches, an increase in horizontal tensile strains can be observed at all transducers except two, numbered 1 and 2, which show minimal compressive strains. The maximum value of horizontal tensile strains is about 2‰. The working face reached the beginning of the observation line on October 1st 2001, that is on the 274th day of the observation. The diagram shows that at transducers placed at the beginning of the observation line(no. 1 and 2) compressive strains of low values appear, which are still imperceptible at the transducers at the end of the line. As the front was passing beneath the observation line and moving away from it all the transducers displayed evident compression till the 370th day, when the compressive strain reached its highest value, i.e. 4.5‰ (transducer 2). In the subsequent months a decrease in strain was observed. Complete stabilization was

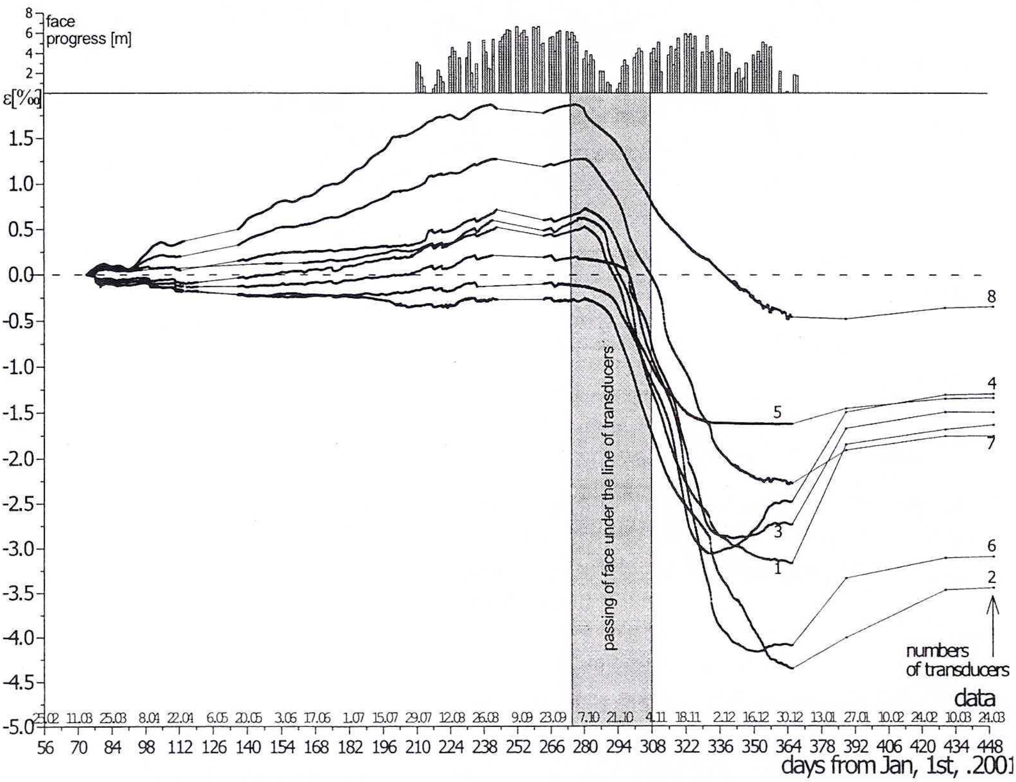

Fig. 9. The "Ziemowit" coal mine. Soil strain as a function of time

Rys. 9. KWK „Ziemowit". Odkształcenia gruntu jako funkcja czasu

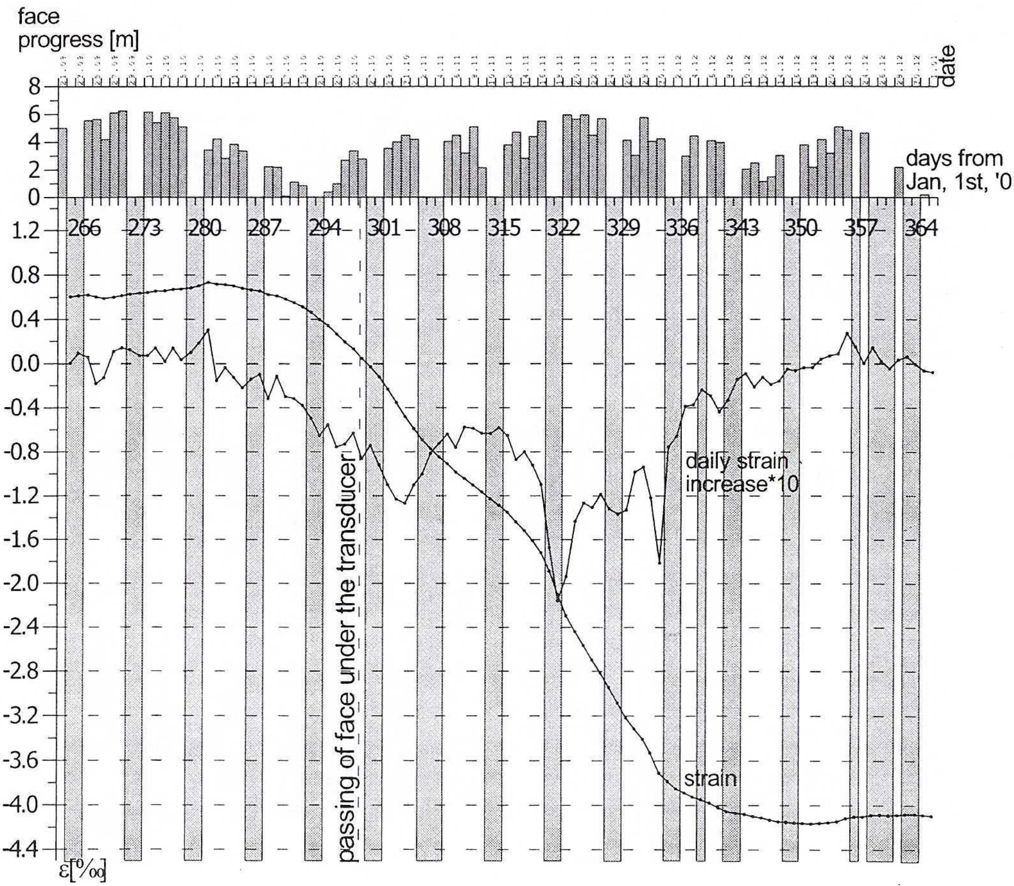

Fig. 10. The "Ziemowit" coal mine, transducer no. 6. The strain and its daily increase with measurements taken every 24 hours

Rys. 10. KWK „Ziemowit", tensometr nr 6. Odkształcenie i jego dobowy przyrost przy pomiarach prowadzonych co 24 godziny

achieved on the 450th day of observation, that is on March 26th 2002; that date was accepted as the end of the observation periode. The passage of the working face under the observation line took 40 days.

One of the basic aims was to determine the effects of cessations in mining on the surface. In the "Wesoła" mine, apart from usual breaks on Saturdays and Sundays, an additional three-day pause occurred on July 14th, 15th, and 16th, 2001. Its effects were observed in strain measurement results. For instance, Fig. 12 and 13 present the development of horizontal strains in the "Wesoła" mine as measured by transducers 6 and 8 as well as the progress of the face. Those figures show explicitly that the effects of stopping and restarting the face manifest themselves on the surface with a day or 2 days' delay.

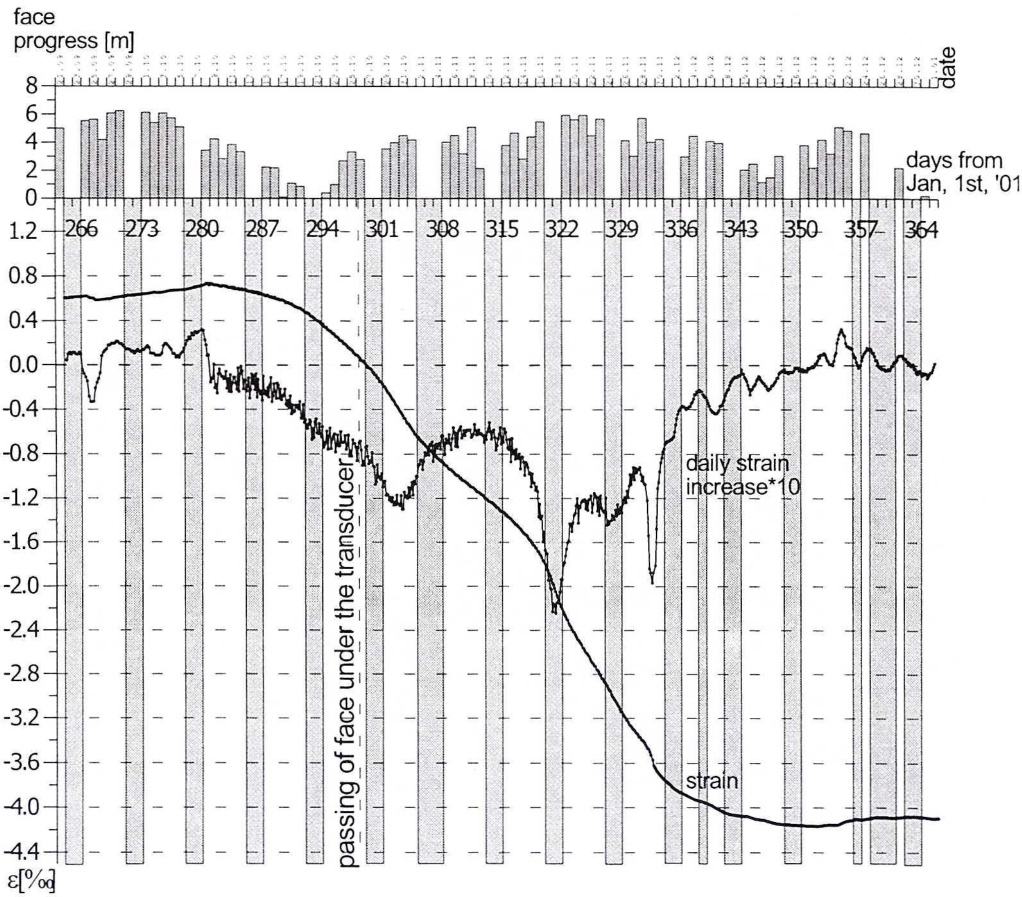

Fig. 11. The "Ziemowit" coal mine, transducer no. 6. The strain and its daily increase with measurements taken every 3 hours

Rys. 11. KWK „Ziemowit", tensometr nr 6. Odkształcenie i jego dobowy przyrost przy pomiarach prowadzonych co 3 godziny

On the other hand, Fig. 14 and 15 present a situation analogous to Fig. 12 and 13 but referring to the "Ziemowit" mine. In that case it is difficult to find changes in the rate of strains caused by interruptions in the progress of the face. It may be connected with the face advance rate, which in the "Ziemowit" mine was only half that in the "Wesoła" mine, as well as with geological conditions (Fig. 12).

5. The analysis of results

On the basis of the observations using soil-located transducers conducted in the "Wesoła" and "Ziemowit" coal mines it can be stated that.

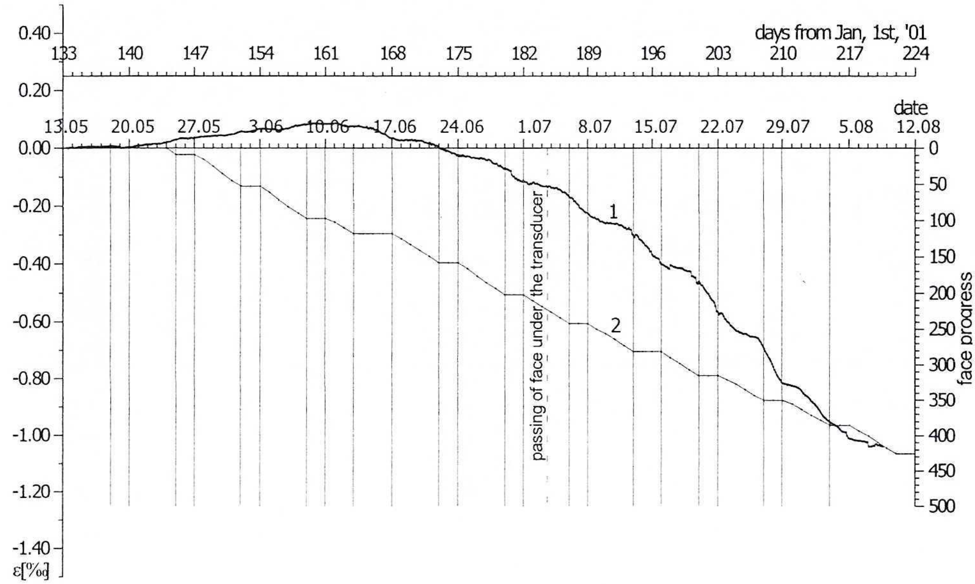

Fig. 12. The "Wesoła" coal mine. Horizontal strains measured by transducer 6(1) and face advance (2)

Rys. 12. KWK „Wesoła". Odkształcenia poziome zmierzone przez tensometr 6 (1) i postęp frontu eksploatacji (2)

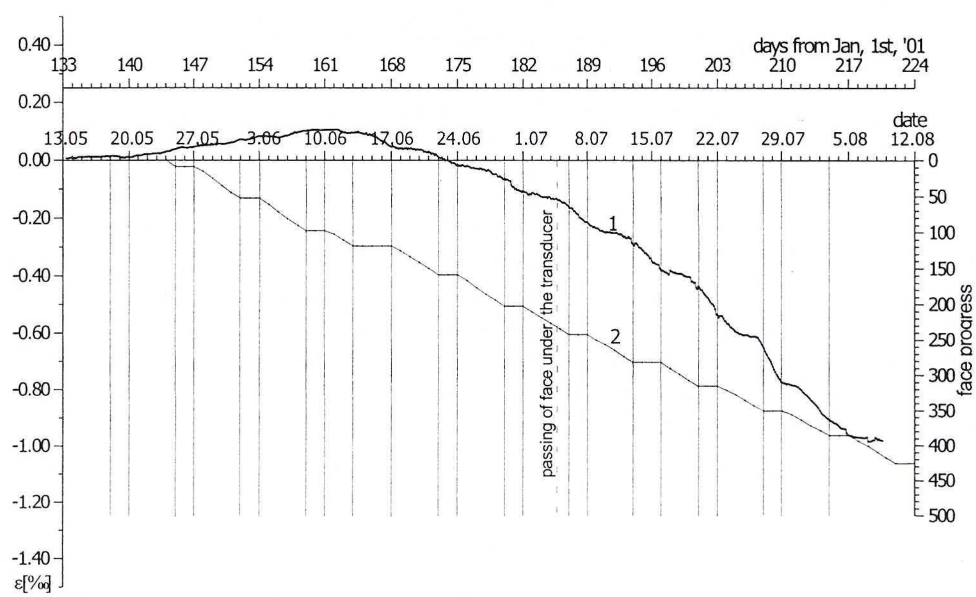

Fig. 13. The "Wesoła" coal mine. Horizontal strains measured by transducer 8(1) and face advance (2)

Rys. 13. KWK „Wesoła". Odkształcenia poziome zmierzone przez tensometr 8 (1) i postęp frontu (2)

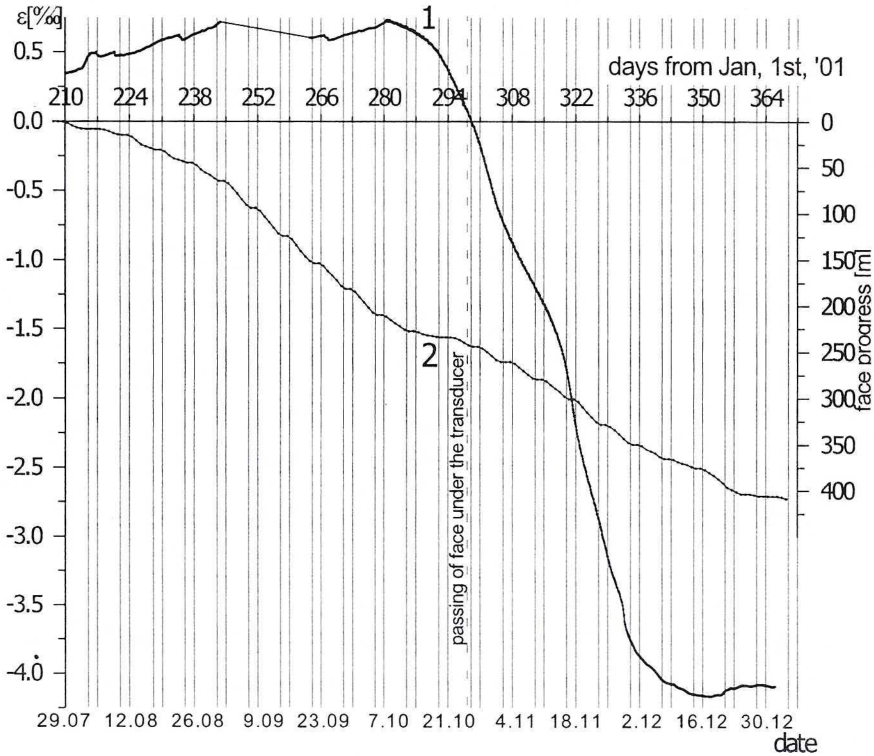

Fig. 14. The "Ziemowit" coal mine. Horizontal strains measured by transducer 6(1) and face progress (2)

Rys. 14. KWK „Ziemowit". Odkształcenia poziome zmierzone przez tensometr 6 (1) i postęp frontu (2)

1. The development of strains over time recorded on both measurement lines is characterized by fact that all changes in strain caused by the mining and its periodic pauses are closely analogous and independent of the positioning of transducers in relation to the face. The comparability of changes can be seen particularly clearly in Fig.16, which presents a fragment of the family of strain curves treated as a function of time in the "Wesoła" mine. The diagram has been scaled up in order to emphasize the simultaneity of respective strain changes in time.

The vertical strip indicates a time interval counted from the moment when the face advance line begins to pass under the first transducer on the line it has passed beneath the last one.

2. In both cases of excavation conducted in the "Wesoła" and "Ziemowit" coal mines the appearance of maximum tension is characterized by the fact that transducers of the lowest numbers, that is, the ones that were the first to be approached by the front, displayed the smallest strains. On the other hand, the transducers with the highest numbers, which were the last to be reached by the front, showed the greatest strains.

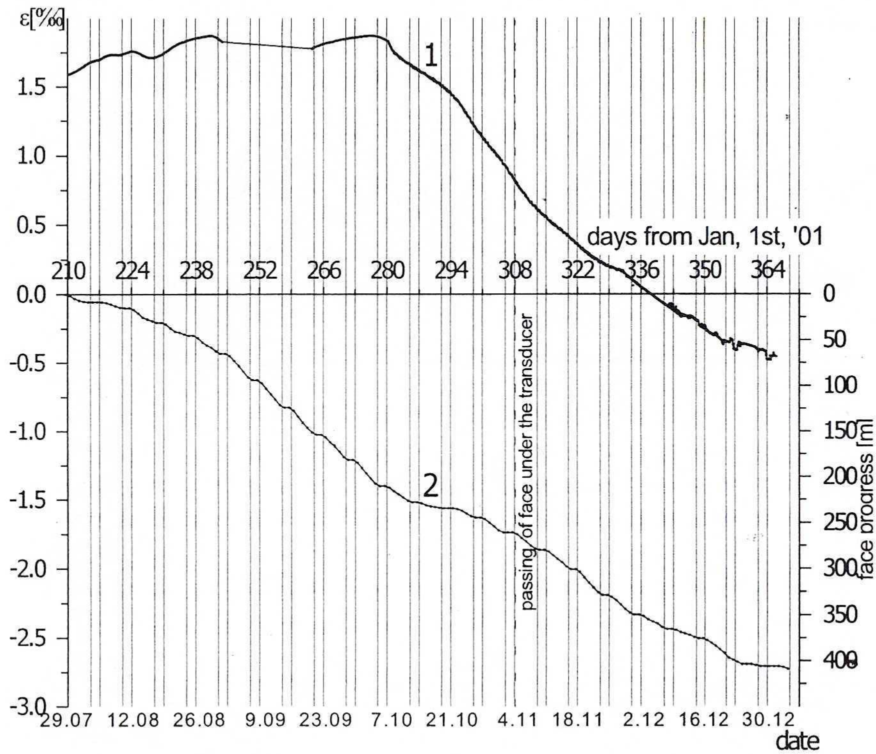

Fig. 15. The "Ziemowit" coal mine. Horizontal strains measured by transducer 8 (1) and face progress (2)

Rys. 15. KWK „Ziemowit". Odkształcenia poziome zmierzone przez tensometr 8 (1) i postęp frontu (2)

Generally, the strain values increase according to the numbering of transducers. Just as the soil deforming movements took place practically simultaneously, the above-mentioned maximum strain values appeared all simultaneously. The same can be said in reference to maximum compressive strains.

3. In the case of the "Wesoła" mine, at the initial sections of graphs (till the 224th day of measurements, Fig. 6), regular undulations can be seen on each curve, characterized by the alternations and retardations appearing within the same time-interval. In particular, the curves in Fig.12 and 13, obtained from selected transducers 6 and 8, reveal that there is a kind of shift of strain development in time in relation to the rhythm to the face advancement and stoppage. On the whole, the face stoppages are accompanied by more changes in strains than during continuous mining because of the retardation of the strata reaction to the cause of the movement. The accelerations in strain-changes begin after, approximately, the first three days after a pause in mining. However, during the pauses a gradual slowing down of the strain development begins. The above-mentioned rhythms of

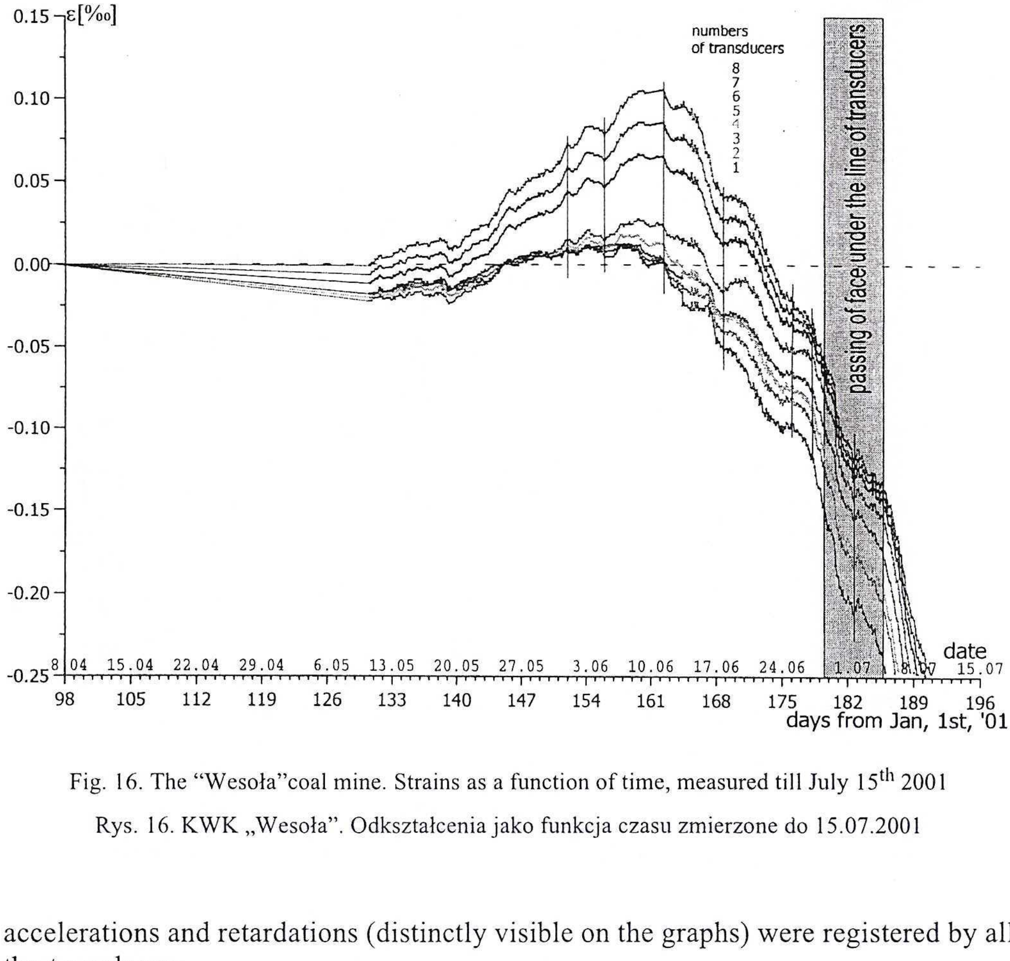

Fig. 16. The "Wesoła"coal mine. Strains as a function of time, measured till July 15th 2001

Rys. 16. KWK „Wesoła". Odkształcenia jako funkcja czasu zmierzone do 15.07.2001

accelerations and retardations (distinctly visible on the graphs) were registered by all the transducers.

4. The strains changes registered in the "Ziemowit" mine (Fig. 9) do not exhibit such regularity. They show that strains treated as functions of time do not indicate such characteristic undulations as it was in the case of the "Wesoła" mine. The daily increases in strains seem, at the first sight, to be accidental fluctuations.

5. Taking into account the fact that in both cases the depth of mining is practically the same, the appearance of regular undulations seems to be connected with the face advancement rate. In the case of the "Wesoła" mine, it was, on average, 8 metres per day, whereas in the mine "Ziemowit" only a half of that figure.

6. In Fig. 6 and 9 the days have been marked when the face was passing beneath the observation lines. In the case of the "Wesoła" mine the maximum tensile strains had appeared before the face started to pass under the line. On the other hand, in the "Ziemowit" mine the maximum horizontal strain appeared when the face reached the first transducer on the line, the strains fell down to the zero value and were transformed into compressive strains.

7. A brief glance at the development of strains in time in the "Wesoła" coal mine (Fig. 6) shows that for the face approaching the starting point of the observation line the tensile strains are very considerably lower, in respect to their absolute values, than the compressive ones.

After the face had moved away from the end of the line, some of the transducers displayed much higher tensile strains than those expected, which should have been next to zero. That deviation from the presumed values may have been connected with the previous collapse.

In the "Ziemowit" coal mine (Fig. 9) there were also certain transducers which neither showed the intuitively predicted tension nor did they return to the close-to-zero values after the face had moved away.

The anomalous indications of the transducers might have been explained by a faulty transducer contact with the soil had if not been for the fact that in some cases they showed either too high or too low strains in relation to the values theoretically postulated from our present knowledge about the effects of mining on surface strain. Due to the set-up of the strain transducers in the project, the force tensioning the steel wire tends to pull its ends together, which can result in excessive contraction strains. This force causes a maximal pressure of the anchors on the soil in the measurement direction that is equal to $7 \cdot 10^{-4}$ MPa. However, the overstretching cannot have resulted from failures in contact between the transducers and the soil, especially as it took about half a year from the installation to the first readings and because during installation, the soil mass was rammed down. On the other hand, little is known as yet about the strains of the strata, the cause for which appear and disappear periodically and which are sometimes accompanied by bounces. A study by Gibowicz et al. (1977) proves the possibility of influence by an underground tremor on the soil strain state, both before it and afterwards.

6. Conclusions

1. The comparison of the results of strain measurements taken in similar geological conditions in both mines suggests that there exists a certain front advance in the longwall mining below which the influence of pauses in excavations is not clearly manifested on the surface. In the two cases analyzed here the value of that advance is within 4–6 metres per day.

2. The effect of stopping and restarting the working face passing beneath the observation line on the appearing strains takes place simultaneously within a certain strata volume, in the area of the observation line.

3. The face stoppages correspond to maximal strain increases. The strain values begin to increase two to three days after the face being restarted.

4. Strain measurements taken every three hours, that is, 8 times per day, indicate random fluctuations without a definite tendency towards either a rise or fall in time from one measurement to another. It is connected with the inadequate resolution of the

apparatus in relation to the strain rate. Therefore long-lasting (i.e. taking at least several months) measurements of strains with the use of the apparatus, a frequency of measurements equal to one reading per day should be sufficient.

The work was executed within the research project 9T 12E 021 17, supported by the Committee of Scientific Research (KBN). The work presented here is a part of the subject generally formulated as "The Determination of Effects of Periodical Stoppages of Mining Faces on Displacements and Surface Soil Strains Based on Geodesic and Strain Measurements and Model Tests".

REFERENCES

Bac S., 1952: O ruchach gleby pod działaniem mrozu. Z badań czwartorzędu w Polsce, t. 2. Warszawa.

Gustkiewicz J., 1966: Rezonatorowy czujnik gruntowy. Prace Komisji Nauk Technicznych, Górnictwo 3.

Gibowicz S.J., Bober A., Cichowicz A., Droste Z., Dychowicz Z., Hordejuk J., Kazimierczyk M., Kijko A.,1979: Source Study of the Lubin Tremor of 24 March 1977. Acta Geophys. Pol. 27, 1, 3–38.

Gustkiewicz J., Kanciruk A., Stanisławski L., 1996. Aparatura do pomiaru odkształceń gruntu i jej zastosowanie. Materiały z konferencji naukowo-technicznej zorganizowanej w ramach obchodu Światowego Dnia Ochrony Środowiska, Krynica.

Hückel S., 1958: Zarys fundamentowania. Warszawa.

Knothe S., 1951: Zmniejszenie wpływów eksploatacji podziemnej na powierzchni terenu. Przegląd Górniczy t. 6, nr 10.

Kowalski A., 1993: Deformacje terenu powstałe w wyniku szybkiej eksploatacji górniczej. Nowe doświadczenia, II Dni Miernictwa Górniczego i Ochrony Terenów Górniczych, Ustroń–Jaszowiec.

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

Prikłoński W.A., 1958: Gruntoznawstwo. Warszawa.

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

REVIEW BY: PROF. DR HAB. INŻ. STANISŁAW KNOTHE, KRAKÓW

Received: 12 February 2003