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DEFORMATION CHARACTERISTICS OF A TECHNOLOGICAL PILLAR IN THE CHAMBER-PILLAR MINING SYSTEM

CHARAKTERYSTYKA DEFORMACYJNA FILARA TECHNOLOGICZNEGO W KOMOROWO-FILAROWYM SYSTEMIE EKSPLOATACJI

The article presents the suitability of the new measurement techniques for monitoring deformations of the technological pillars and fragments of the face in underground mining. The conducted observations concerned the mined pillar located in the lead of mining field G-3/4 of Rudna mine (mine belongs to KGHM Polska Miedź S.A.) in a situation of constant progress of mining works in its direction.

The observations conducted underground provided results demonstrating the suitability of the applied observation techniques in this area. The obtained measurement data directly describe the volumetric changes which form the basis for assessing the stress of the rock formation. This issue is well recognised based on the tests on rock samples. Further studies should concern the transfer of these experiences to the results of in situ observations.

Keywords: chamber-pillar mining system, pillars' deformation, volumetric deformations, pressure probe, inclinometric measurements

W komorowo-filarowych systemach eksploatacji jednym z podstawowych zagadnień do rozpoznania jest właściwy dobór wymiarów filarów technologicznych i ich kształt. W danych warunkach geologiczno-górniczych filary te powinny zapewniać oczekiwaną efektywność procesu eksploatacyjnego przy zachowaniu maksimum bezpieczeństwa tego procesu i pracujących załóg górniczych.

Wynikająca z wymiarów filarów i parametrów wytrzymałościowych ośrodka skalnego ich sztywność w istotny sposób wpływa na stan zagrożenia tąpaniami i zawałami. Do ograniczenia tego zagrożenia dąży się między innymi poprzez zachowanie wymaganej podporności filarów przy doprowadzaniu ich do stanu wytrzymałości pozniszczeniowej (resztkowej).

Podstawą doboru wymiarów filarów technologicznych są głównie wyniki badań laboratoryjnych na próbkach skalnych (Lis & Kijewski, 1987, 2007; Lis et al., 1997; Kijewski et al., 2007) oraz rezultaty modelowania numerycznego (Pytel, 2002; Flisiak et al., 2003). W praktyce, w dużej mierze, na podstawie dołowych obserwacji procesu deformacji filarów dokonuje się korekty ich wymiarów. Różnice pomiędzy wynikami badań na próbkach skalnych a rzeczywistym przebiegiem deformacji filarów wynikają z ograni-

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czonych warunków eksperymentu laboratoryjnego oraz tzw. efektu skali. Z tego też względu bardzo cenne są wszelkiego rodzaju próby określenia procesu deformacji filarów technologicznych w warunkach in situ.

W artykule przedstawiono wyniki badań dotyczących rozpoznania reakcji filara technologicznego podanego wpływom ciśnienia eksploatacyjnego. Do wyznaczenia charakterystyki deformacyjnej filara wykorzystano dwie nowe metody pomiarowe zapewniające dużą czułość i dokładność pomiaru oraz quasi ciągły charakter rejestracji. Pierwsza z technik polega na pomiarze zmian ciśnienia oleju w specjalnych sondach pomiarowych umieszczonych w poziomych otworach wiertniczych wykonanych w części dolomitowej i piaskowcowej filara. Druga metoda pomiarowa realizowała pomiar zmian nachylenia specjalnego repera zastabilizowanego w filarze (Rys. 3). Obserwacjom podlegał filar usytuowany na wyprzedzeniu frontu eksploatacyjnego w sytuacji ciągłego postępu robót wybierkowych w jego kierunku. W takiej lokalizacji filara, postępujący wzrost obciążenia na filar znajdował swoje odzwierciedlenie w mierzonych zmianach ciśnienia oleju w sondzie i zmianach nachylenia wspomnianego repera.

Obserwację filara technologicznego rozpoczęto w drugiej połowie listopada 2011 r., w sytuacji kiedy front robót wybierkowych był oddalony od niego o ok. 250 m, natomiast linia likwidacji – o ok. 390 m (Rys. 1). Na koniec okresu sprawozdawczego, odległości te wynosiły odpowiednio: dla frontu – 60 m, dla likwidacji – 265 m.

Przeprowadzony eksperyment pozwolił wydzielić w zachodzących zmianach ciśnienia oleju poszczególne fazy jego wzrostu i spadku, które bardzo dobrze mogą być objaśnione przez zmiany objętościowe ośrodka skalnego, obserwowane w badaniach na próbkach skalnych. Występujący, gwałtowny spadek ciśnienia oleju, który wystąpił z chwilą zbliżenia się frontu eksploatacyjnego na odległość 65 m od stanowiska pomiarowego, można uznać za przejście filara w stan pozniszczeniowy (Rys. 10). Stwierdzono także, iż zachodzące zmiany ciśnienia oleju są dobrze skorelowane z rejestrowanym przebiegiem zmian nachylenia, które świadczy o wyciskaniu filara od spągu w kierunku wyrobiska (Rys. 5).

Przeprowadzone w warunkach dołowych obserwacje dostarczyły wyniki świadczące o przydatności zastosowanych technik pomiarowych do śledzenia przebiegu deformacji filarów technologicznych. Uzyskane dane pomiarowe wprost opisują zmiany objętościowe, które są podstawą oceny wytężenia ośrodka skalnego. Zagadnienie to jest dobrze rozpoznane z badań na próbkach skalnych i kwestią dalszych badań jest przeniesienie tych doświadczeń na wyniki obserwacji obiektowych. Z oczywistych względów zapoczątkowane badania wymagają dalszego rozwinięcia poprzez poszerzenie zakresu prowadzonych obserwacji. Powyższe odnosi się do pojedynczego filara jak i danego rejonu obejmującego kilka wybranych filarów czy fragmentów calizny. Uzyskane wyniki dowodzą, że dalsze rozwinięcie i doskonalenie przedmiotowych badań może stanowić właściwą drogę do opracowania metody oceny wytężenia ośrodka skalnego (filarów, fragmentów calizny) w warunkach kopalnianych.

Słowa kluczowe: komorowo-filarowy system eksploatacji, deformacja filarów, odkształcenia objętościowe, sonda ciśnieniowa, pomiary inklinometryczne

1. Introduction

The appropriate determination of dimensions of technological pillars and their shape is one of the basic issues that need to be identified in chamber-pillar mining systems. Under the given geological-mining conditions these pillars should ensure the expected effectiveness of the mining process with parallel assurance of maximum safety of this process and the mining crews operating.

The rigidity of the pillars resulting from the dimensions of the pillars and resistance parameters of that rock formation has a material impact on the threat of bounces and breakdowns. This threat is mitigated by efforts to maintain the required support parameters of the pillars in the course of reaching their post-demolition (residual) strength status.

The dimensions of technological pillars are selected based mainly on the results of laboratory tests of rock samples (Lis & Kijewski, 1987, 2007; Lis et al., 1997; Kijewski et al., 2007) and the results of numerical modelling (Pytel, 2002; Flisiak et al., 2003). In practice the dimensions of the pillars are adjusted to a high degree based on the underground observations of the pillar deformation process. The differences between the results of the tests of the rock samples and the actual course of the pillar deformation result from the limited conditions of the laboratory experiment and the scale effect. For this reason any attempts at determining in situ the process of deformation of technological process are very valuable.

Determining the actual process of deformation of technological pillars is a very difficult task because of the dimensional and technical reasons. The authors applied two new measuring techniques to determine the method of deformation of technological pillars, which are used under a thermodynamic and inclinometric method (Grzebyk & Stolecki, 2012). The pressure probe consisting of a flexible tank of 70 cm diameter and 360 mm length is a basic element of the measurement system under the thermodynamic method. The probe is inserted into the borehole to a determined depth and subsequently filled with oil under pressure, which seals the borehole above the probe. The measurements that are taken include the changes in pressure of the gas agent in the sealed part of the borehole and the oil pressure in the probe. The inclinometric method uses instruments consisting of the inclination sensor (RNS) and communication terminal, which ensures wireless communication with the sensor. The sensor in the form of a flat plastic box with dimensions 94×94×57 millimetres is mounted to a stabilised bench-mark and measures the changes in the angle in two axes perpendicular to each other. Measurements are taken under both methods according to the set frequency and the recorded data is stored in static memory.

2. Testing field

The conducted observations concerned the mined pillar located in the lead of mining field G-3/4 of Rudna mine in a situation of constant progress of mining works in its direction.

Field G-3/4 is a closing field, whose right wing adjourns the Rudna Główna fault zone. The deposit is mined across its entire width and is conducted under the chamber-pillar system with hydraulic filling in cases of variable stability of the ceiling occurring. The deposit is developed in full profile (white sandstones of the Rotliegend, Lower Zechstein copper bearing shales and the dolomites) and its thickness varies, ranging from 6-9 m in the right part of the field to 8-13 m in the left part. The carbonate complex is deposited in the roof of the workings with a thickness of 65 to 90 metres. Generally the deposit in this area is poorly involved tectonically.

The studied pillar was located in the lead of the right part of the mining field and was one of several pillars separated during the stage of cutting the deposit in the 1980s (drawing 1). The pillar was approximately the shape of a triangle with approx. 28, 30 and 34 metre sides and a height of approx. 4.0 m. The uncovered part of the deposit in the area of the pillar is made from quartzite sandstone (approx. 2 m), dolomite shale (approx. 0.t2 m), striped dolomite (approx. 0.4 m) and dolomite limestone (approx. 1.4 m). The geomechanical properties of the rock in this area are presented in drawing 2. The determined profiles of compression strength R_c, strain energy storage index W_{et} and volumetric density ρ_c clearly show a separate lower, approx. 2.5 m thick zone of dolomites representing higher values.

Observation of the technological pillar started in second half of November 2011, when the front of the excavation works was located a distance of approx. 250 m from the pillar and the post-excavation liquidation line was a distance of approx. 390 m (drawing 1). These distances at the end of the reporting period were 60 m for the front and 265 m for the liquidation line, respectively.

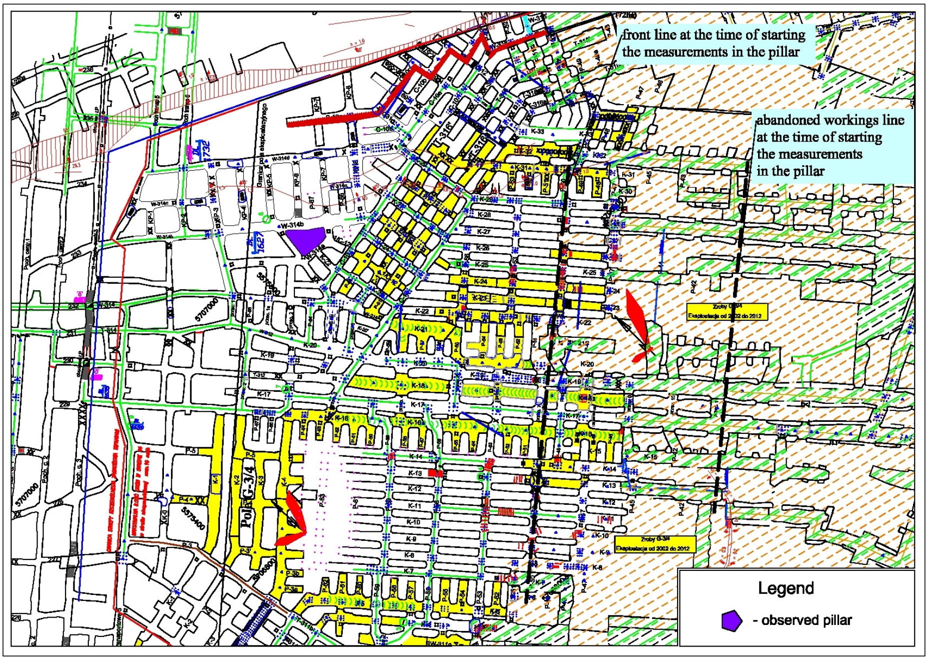

Fig. 1. Mining situation of field G-3/4

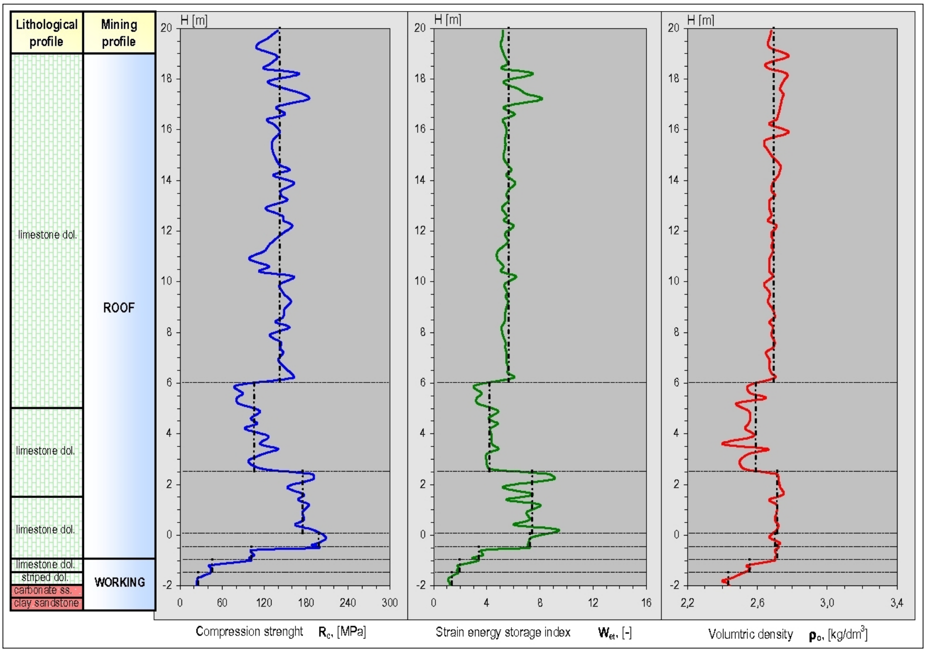

Fig. 2. Geomechanical profile of the properties of the rocks comprising the pillar

3. Measurement station

The configured measurement system included the observations taken with the use of the pressure probe in two horizontal boreholes made in the pillar, with one borehole in the sandstone part and dolomite part of the pillar and under the inclinometric method just in the sandstone part of the pillar.

The test boreholes were made in the pillar from the side of heading W-314b along the extension of chamber KP-6. Both boreholes had a length of approx. 11 m; however, the borehole in the sandstone was located approx. 0.8 m below the shale layer, while in the dolomite it was located approx. 0.6 m above this layer. The planned 7 m depth of inserting the probe into the borehole was obtained only for the probe in the sandstone; in the case of the probe in the dolomite it was blocked at the length of 4 m from the pillar side wall. The end sections of the boreholes were protected by cementing in them 3 m long sections of steel pipe protruding approx. 0.5 m beyond the borehole. At a later stage, i.e. at the beginning of March 2012, the RNS inclination sensor was installed to the pipe flange located in the sandstone, which allows measuring the changes in the inclination in two perpendicular axes, i.e. X and Y. The sensor was oriented so that the positive direction of axis X was directed perpendicular to the outside in relation to the pillar's edge, while the direction of axis Y was located parallel, with its positive direction towards the right edge of the mining field. The layout of the measurement system for observation of the deformations of the pillar is presented in drawing 3.

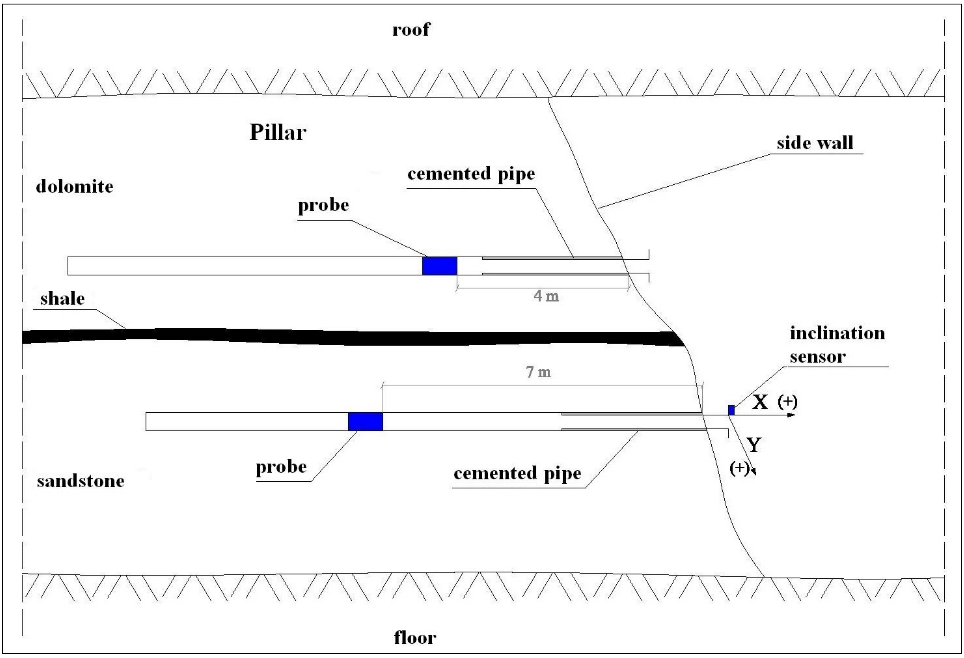

Fig. 3. Layout of the measurement system for observation of pillar's deformation

4. Results of measurements

a) Results of observations with the use of a pressure probe

The changes of air pressure in the sealed part of the borehole and of the oil entered into the probe, whose initial pressure was approx. 4400 hPa, were measured at the same time in both test boreholes. Upon preliminary deformation of flexible tanks of the measurement probes and stabilisation of the measurement conditions, the oil pressure in the sandstone was between 11th and 20th day of December 2011 approx. 240 hPa higher compared to the dolomite. From that time the oil pressure level in both rock formations was slowly decreasing. In mid-February 2012 both these pressures reached the lowest values, which for the sandstone was approx. 3170 hPa and for the dolomite approx. 3060 hPa. As of that time the oil pressure in the sandstone was increasing relatively quickly, while the pressure increase in the dolomite was slight and slated just to the beginning of July 2012. The oil pressure in the dolomite from July to early October 2012 stayed at a similar level and subsequently decreased. At the same time, from approx. mid November 2012, the oil pressure in the sandstone substantially decreased (approx. 2500 hPa) combined with very high periodical changes in its amplitude. The occurrence of pulse changes and rapid pressure impulses of relatively high value is characteristic for the oil pressure in this rock formation. A similar pattern of pressure changes was also observed in the dolomite, however at a clearly lower level. The changes in air pressure for some time matched very closely the changes in the atmospheric pressure in the working, which indicates a contact between the working and the sealed parts of the boreholes in both rock formations. A radical change was observed from 7 August 2012, when the air pressure in the sandstone decreased significantly, ranging around approx. 1100 hPa. The measured changes in pressure in the observed pillar are presented in drawing 4 in the form of appropriate graphs.

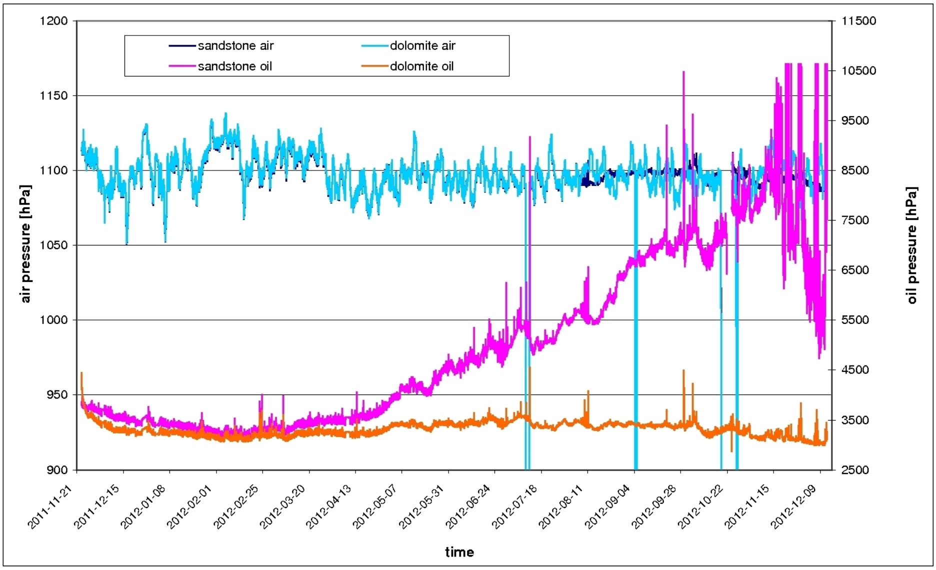

Fig. 4. Graphs of changes in oil and air pressure measured in the pillar

b) Results of observations under the inclinometric method

The observations of deformations on technological pillar under inclinometric method concern the measurement of the changes of inclination of an appropriately stabilised bench-mark, which in this case concerned a steel pipe cemented in the pillar.

The obtained results of the changes in the inclination angle for individual components are presented in drawing 5. The presented graphs indicate that the changes in the inclination angle occur mainly for component X and occur uniformly in relation to numerous rapid movements of approx. 0.01 degree. The change in the angle for this component observed over approx. a 10 month period was from –3.486 to –5.214 degrees. In real terms it means the deflection of positive axis X by 1.728 degrees upwards, which is equal to displacement of the edge of the pillar from the side of working W-314b by this value.

The changes in the angle of component Y seem irrelevant compared to the changes in the angle of component X and throughout the observation period changed by 0.271 degree. The obtained result of the changes in the angle of this component is not a straight line, but shows some oscillations. Generally the direction of the changes of component Y demonstrates a slight displacement of the pillar's edge towards the right side of the mining field.

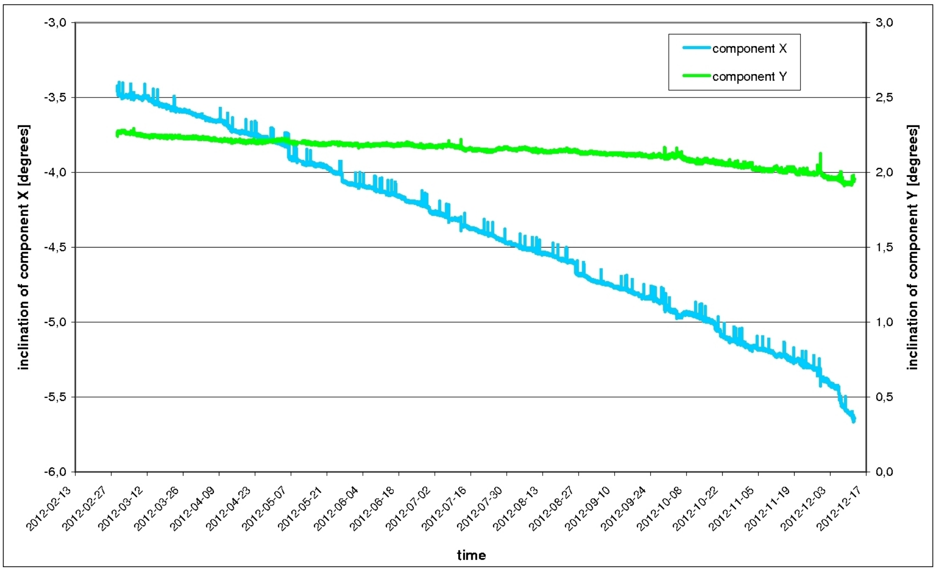

Fig. 5 Graph of changes of inclination for individual components

c) Correlation of the observed changes in the pressure and inclination angle

Drawings 6 and 7 summarise the changes in the oil pressure measured in the pillar including the individual components of the changes of the inclination angle. Despite the very small range of the changes in the inclination angle of component Y, it is this component that shows the

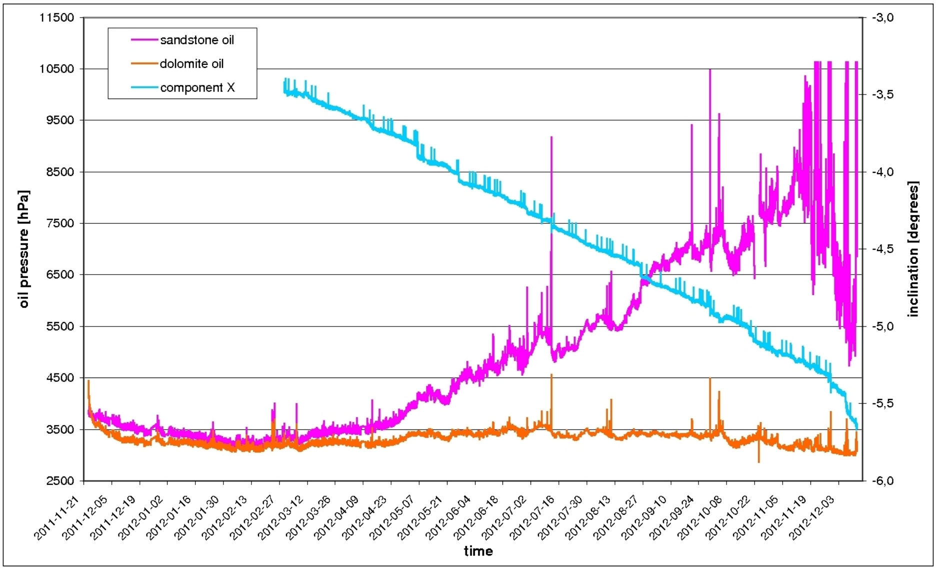

Fig. 6. Graphs of changes in oil pressure and component X measured in the pillar

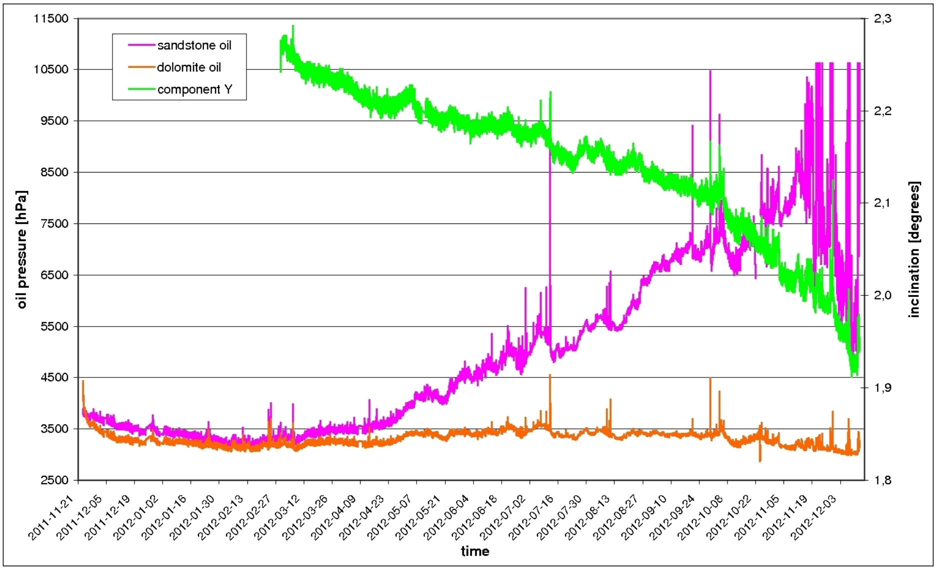

Fig. 7. Graphs of changes in oil pressure and component Y measured in the pillar

highest correlation of the nature of the changes with the measured changes of oil pressure. The comparison of individual sections of the history of measured data allows demonstrating some correlation between some trends in respect both to the changes of the oil pressure and component Y of the inclination angle. These are probably important time intervals, during which the pillar was a subject of determined phases of the deformation process. It should be stressed that in a few cases referring to the impulse changes in oil pressure, similar changes in the value of component Y of the angle were observed as well. In respect to the changes to component X of the angle, it shows a uniform pattern throughout the observation period conforming to the general trend of the oil pressure changes.

5. Dependence of the changes in the observed parameters on the progress of mining works

The impact of the mining works in field G-3/4 on the observed changes in the parameters is presented on drawing 8. The appropriate graphs of the oil pressure changes and inclination angle changes referred to the progress of the mining works in the right part of the mining field in relation to the measurement station (*fp*), the distance of the breakdown line (*zp*) and the difference between the front line and the breakdown line (*dp*) in this part of the mining field. With a fairly stabilised process of mining the deposit and thus successive approaching of the front to the observed pillar, a general increase in oil pressure was observed in mid-February 2012, when *fp* = 192 m, *zp* = 372 m and *dp* = 180 m. Another situation worth noting concerned the beginning of August 2012, when the borehole was sealed in its sandstone part. This took place under following operating parameters: *fp* = 100 m, *zp* = 300 m and *dp* = 200 m. Another situation which should be mentioned concerns the time of significant change in the inclination angle of component Y at the beginning of October 2012 and the rapid decrease of oil pressure combined

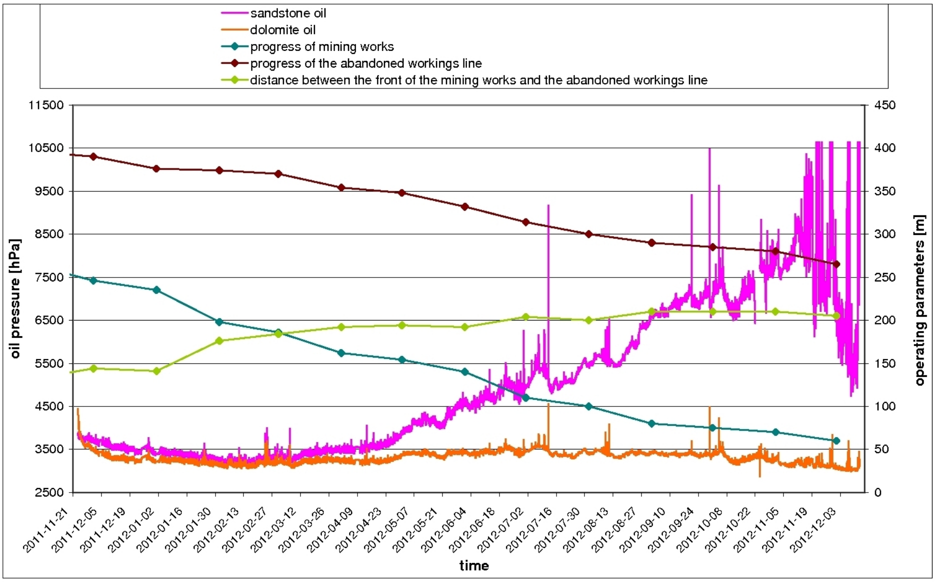

Fig. 8. Graphs of the oil pressure changes in the pillar in relation to the progress of the mining works in field G-3/4

with high fluctuations of its value in the sandstone in mid-November 2012. The last observations concern a situation when the mining front was in direct vicinity to the measurement station (approx. 50-70 m). At present it is difficult to give a clear answer whether the characteristic changes of measured parameters are mainly the result of the determined progress of the mining works in field G-3/4. Clearly, the obtained results will form a basis for further studies in this area.

6. Preliminary assessmet of the process of deformation of the observed pillar

The best equivalent of the observed process of deformation of the technological pillar concern the results of the process of brittle deformation and destruction performed on the rock samples under single- and tri-axial compression. These tests demonstrated that a few characteristic sections representing the individual stages of rock deformation and destruction can be identified in respect to characteristics of deformation/stress – longitudinal, cross and volumetric (drawing 9)

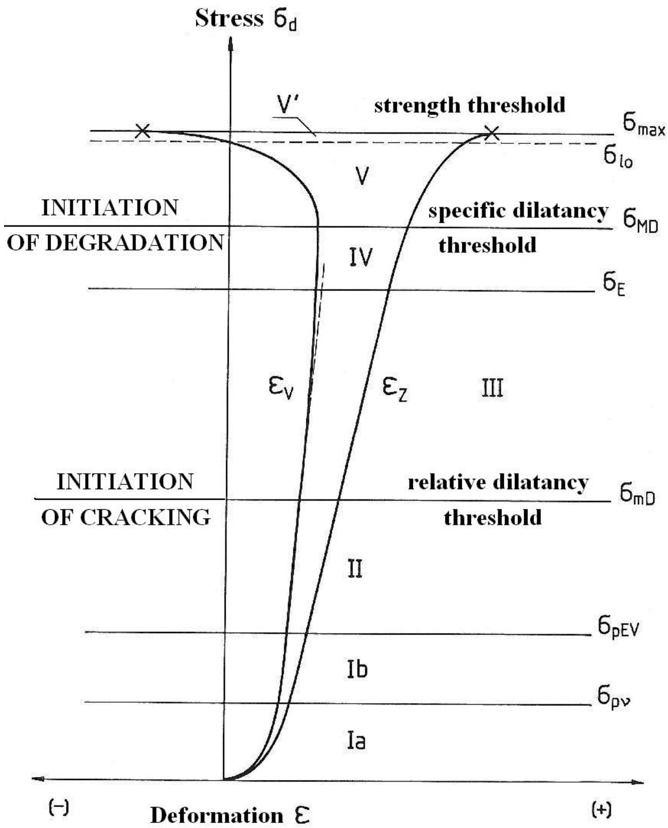

Fig. 9. Typical characteristics of stress-deformation (longitudinal ε_z and volumetric ε_v) for brittle rock under compression conditions (see Kwaśniewski, 2007)

(Kwaśniewski, 1986, 1992, 2007; Takahashi, 1984). A special role in this process is played by dilatancy, i.e. the phenomenon of non-elastic increase of the volume under the conditions of compression load (Brace et al., 1966).

At present a direct transfer of the experiences from the tests performed on rock samples to the results obtained from the observations seems unjustified. This conclusion results from the different conditions of the test performed under the laboratory tests and in situ studies. The essential differences concern:

- meth external load to a rock sample and the pillar; in the strength testing instrument the rock sample is mounted between two very rigid plates compared to the burden and the roof performing a similar function in actual conditions (in situ),
- the uniformity of the tested model; the rock sample is made from the same rock material, while the pillars are built from various rocks, i.e. dolomite, shale and sandstone,
- effect of scale; incomparable dimensions of the samples and actual pillars,
- impact of time on physiochemical parameters of the rocks under actual conditions resulting from climate conditions: the change of these parameters e.g. under the influence of humidity.

Despite these limitations an attempt was made to compare the results of the measurements considering the characteristic changes in the process of measured pressure in relation to the mining situation in field G-3/4. The analysis was conducted only for the changes in pressure in the sandstone. The results of the observations to date suggest that the deformation of the dolomite part of the pillar is closer to the reaction of the overlaying roof rocks (Grzebyk & Stolecki, 2012). The individual stages of the deformation of the sandstone part of the pillar are marked in black by numbered sections of the straight line in drawing 10.

Stage I of deformation covers the section of pressure decrease from the beginning of observation to approx. mid-February 2012. It appears that contrary to the tests on the samples (stage Ia and Ib) it is not the outcome of the decreasing volume of the pillar, but rather a result of the decreasing load by the roof rocks.

Stage II of deformation covers the period from mid-February to mid-November 2012 corresponding generally to the process of initial dilatancy and specific dilatancy. During that stage disturbances in the changes in the air pressure in the sandstone were observed (as of 7 August) in relation to the air pressure in the workings, which might indicate the increased plasticity of its structure (dotted line).

Stage III covers the period from mid-November 2012 and is characterised by high decreases in pressure, which might indicate that the pillar moved to a post-critical state. Therefore, the critical load of the sandstone part of the pillar would occur when the front of the mining works is located a distance of approx. 65 m from the pillar.

Reviewing the development of the oil pressure changes in the sandstone in stage II, the occurrence of at least three sequences of its increase should be noted as well, followed by its relatively rapid decrease. This process is reflected by the increase, stabilisation and decrease of oil pressure in the dolomites, respectively.

The performed analysis allows one to conclude that under actual conditions in situ, certain stages of the deformation process of the rock formation overlap.

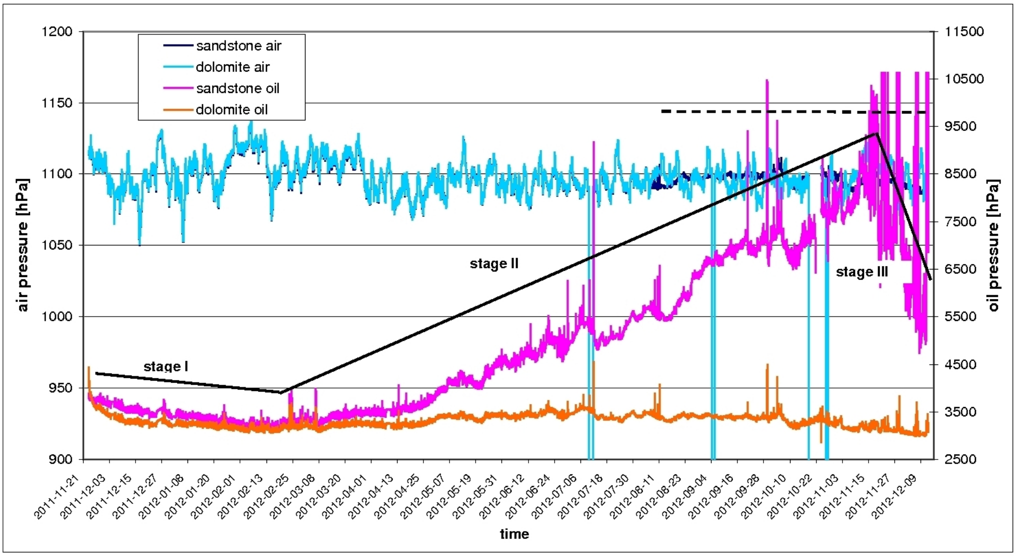

Fig. 10. Method of deformation of the sandstone part of the observed pillar

7. Summary – conclusions

The primary objective of the currently initiated studies was to demonstrate the suitability of the new measurement techniques for monitoring the deformations of the technological pillars and fragments of the face. The observations conducted underground provided results demonstrating the suitability of the applied observation techniques in this area. The obtained measurement data directly describes the volumetric changes which form the basis for assessing the stress of the rock formation. This issue is well recognised based on the tests on rock samples and further studies should concern the transfer of these experiences to the results of in situ observations.

For obvious reasons the initiated studies should be further developed by enhancing the scope of conducted observations. This refers both to a single pillar and a given region covering a few mined pillars or fragments of the face. However, already at the current stage of works it can be concluded that the proposed solution delivers promising results in the area of monitoring and assessing the method of deformation of a rock formation.

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