Archives of Mining Sciences **48**, 1 (2003) 65–80

TADEUSZ MAJCHERCZYK*, MIECZYSŁAW LUBRYKA**

THE INFLUENCE OF THE DEPTH OF AN EXPLOITED SEAM ON STRESSES AROUND THE SHAFT

WPŁYW GŁĘBOKOŚCI WYBIERANEGO POKŁADU NA NAPRĘŻENIA W OTOCZENIU SZYBU

The paper deals with the influence of mining exploitation, carried out in the area of the shaft pillar, on the stress around the shaft. The paper also presents the results of measurements of vertical and horizontal dislocations in three shafts in the vicinity of which mining had taken place for some time. Numerical calculations of the state of stress around the shaft were carried out using Cosmos/M software. The problem was treated as a 3D task. The model of rock mass contained one heading and a shaft. The qualities of rock mass were changed from 5 GPa to 20 GPa using a variable module for the coefficient of linear elasticity and changing the exploitation depth from 400 m to 800 m. An analysis of results was made for cross sections at distances between 50 m and 500 m from the shaft axis to the face of the longwall face. Changes of the coefficient of vertical stress concentration on the shaft section for a given distance between the shaft and the face are analysed in the paper. The coefficient decreases in a hyperbolic manner as the distance between the face and the shaft increases. As the depth of exploitation increases, its serious influences on the shaft are discernible at greater distances from the shaft. For a coefficient of linear elasticity of the rock mass E = 20 GPa, the distance at which the influences cease to be significant is as follows: depth = 400 m, distance = 270 m; depth = 600 m, distance = 320 m; depth = 800 m, distance = 360 m. The change of depth only slightly influences the value of the coefficient of vertical stress concentration. However, its value increases in proportion to the increase of rock mass rigidity. As the result of maximum vertical stresses occurring at levels of 50 to 150 m above the exploited seam, damage may appear in the shaft in this zone. The bigger the value of Young's module, the longer the distance from the shaft to the α =1.05 iso-line of vertical stress coefficient. In view of these findings, workings at great depths allow the dimensions of the shaft pillars to be reduced significantly.

Key words: shaft, shaft pillar, subsidence, depth of exploitation

Artykuł dotyczy wpływu eksploatacji górniczej prowadzonej w rejonie filara szybowego na naprężenia w otoczeniu szybu. Praca zawiera wyniki pomiarów przemieszczeń pionowych i pozio-

---

* KATEDRA GEOMECHANIKI, BUDOWNICTWA I GEOTECHNIKI, AKADEMIA GÓRNICZO-HUTNICZA, AL. MICKIEWICZA 30, 30-059 KRAKÓW, POLAND

** JSW S.A. KWK Jas-Mos, UL. GÓRNICZA 1, 44-330 JASTRZĘBIE ZDRÓJ, POLAND

mych, jakie uzyskano w trzech szybach w długim czasie eksploatacji okołofilarowej. Wykonana ocena stateczności górotworu w rejonach na zewnątrz kilku filarów szybowych pozwala na stwierdzenie, że wartość osiadań maleje wraz z głębokością. Tezę tę potwierdzają wyniki pomiarów geodezyjnych uzyskane na poszczególnych poziomach szybu Jas-III (rys. 1). Sumaryczne przemieszczenia pionowe odnotowane w ciągu 43 lat prowadzonych pomiarów do głębokości 176 m (poziom +70 m) wynoszą 147 mm, natomiast na głębokości 486 m (poziom –240 m) wynoszą 7 mm. Zatem na tej głębokości nie ma praktycznie osiadań powodowanych prowadzeniem działalności górniczej. Podobne wyniki otrzymano z pomiarów wykonanych w Szybach 1 i 2 w KWK „Morcinek" (rys. 2 i 3). W szybie 2 deformacja rury szybowej obudowy szybu spowodowana została przez przemieszczenia poziome (rys. 4). Obliczenia numeryczne stanu naprężenia w otoczeniu rury szybowej wykonano przy wykorzystaniu programu Cosmos/M, traktując zagadnienie jako zadanie przestrzenne. Model górotworu zawierał wyrobisko ścianowe oraz szyb (rys. 5). Własności ośrodka skalnego zmieniano poprzez zróżnicowanie modułu sprężystości liniowej od 5 do 20 GPa oraz zmianę głębokości eksploatacji od 400 do 800 m. Wyniki obliczeń rozpatrywano w przekrojach przyjmowanych w odległości od 50 do 500 m od osi szybu do czoła eksploatowanej ściany. W pracy przeanalizowano zmiany współczynnika koncentracji naprężeń pionowych na konturze szybu dla zadanej odległości pomiędzy szybem a frontem ściany. Współczynnik ten zmniejsza się w sposób hiperboliczny wraz ze zwiększaniem się odległości frontu ściany od szybu (rys. 6 i 7). Ze wzrostem głębokości eksploatacji rośnie odległość, przy której zanikają istotne wpływy wybierania pokładu na szyb. Dla modułu sprężystości liniowej ośrodka skalnego E_3 = 20 GPa odległość, gdzie wpływy są już niewielkie wynoszą odpowiednio: dla głębokości 400 m — 270 m, dla głębokości 600 m — 320 m, a dla głębokości 800 m — 360 m. Współczynnik koncentracji naprężeń rośnie wraz ze zwiększaniem się sztywności górotworu, natomiast zmiana głębokości eksploatacji praktycznie nie wpływa na zmianę jego wartości (rys. 8 i 9). Maksymalna wartość współczynnika α w odległości 200 m od szybu dla górotworu o module E_1 wynosi 1,023, a dla górotworu o module E_3 — 1,096. Zmiany współczynnika koncentracji naprężeń wraz ze zwiększaniem się głębokości eksploatacji dla bliskich odległości od konturu szybu, tj. w zakresie 0–200 m (rys. 10), wskazują, że na konturze wyrobiska szybowego następuje spadek naprężeń pionowych do około 0,4 p_z. Z analizy wyników obliczeń numerycznych i obserwacji w naturze wynika, że deformacje rury szybowej czy obudowy mogą wystąpić głównie wskutek występowania nadmiernych pionowych naprężeń ściskających, poziomych naprężeń rozciągających bądź naprężeń ścinających w szybie w odległości od 50 do 150 m nad eksploatowanym pokładem, przy bliskiej odległości frontu eksploatacyjnego od szybu. W miarę wzrostu modułu Younga rośnie odległość od szybu izolinii współczynnika koncentracji naprężeń pionowych o wartości α = 1,05 (rys. 11). W przypadku największego przyjętego modułu sprężystości liniowej E_3 = 20 GPa izolinie te mieszczą się w granicach wyznaczonego filara do głębokości około 580 m. Sugeruje to możliwość zmniejszenia filarów ochronnych szybów dla głębokości eksploatacji ponad 600 m.

Słowa kluczowe: szyb, filary ochronne szybu, eksploatacja, osiadanie

1. Introduction

The need to maintain workings in a stable condition whilst exploitation takes place is of paramount importance. This requirement applies equally to galleries from which materials are extracted, access roadways, mineshafts and shaft extensions.

Protection of the stability of shafts against the influences of exploitation is provided by safety pillars whose size is laid down in the appropriate rules (In Poland: Instrukcja 1961; Jędrzejec et al. 1996; Zasady 1986).

The technological demands of these legal regulations restrict mining operations to specific areas of the safety pillar. Therefore, the coal mines limit their operations to single areas of exploitation or give up the plans for further exploitation (Majcherczyk et al. 2002).

Observations in situ show that exploitation in the vicinity of the pillar for a long period of time affects its overall stability (Lubryka 2002). Thus it would appear to be an important topic for academic study — particularly to ascertain the effects of the proximity of mining operations, the depth at which the exploitation takes place and the qualities of the rock-mass on the forces set up in the pillar and their influence on the mineshaft itself. In order to carry out such an analysis, research on models and observations in situ are indispensable, with special attention being paid to strains at the ground surface and in the walls of the shaft.

The primary objective of this paper is to examine the influence of the forces set up by the extraction of a coal seam on the distribution of stresses around the shaft. It is achieved by means of an analysis of the coefficient of vertical stress concentration in different situations.

2. The stability of the shaft during exploitation around the pillar

The mine-shafts constitute an essential component of an operational the coal mine and are therefore continuously monitored for geodesic changes. This enables physical movements in response to shaft strains and dislocations to be monitored.

To date, observations indicate that strains on the shaft are mostly caused by intensive exploitation in the vicinity of the shaft pillar, especially if extraction involves several seams simultaneously in the same exploitation area. The increase of loading on the shaft lining is the most intense under such conditions, i.e. simultaneous compression and tension of the lining material causing shaft-pipe bending (Richardson, Jahn 1988). The compressive stresses may cause fractures, shear and spalling (stresses within the shaft liner create internal splitting and scales of material break off) of the shaft walling, which in turn may cause serious displacement of buntons and shaft guides (Ćwiertnia, Szczepaniak 1998). In the case of shaft walling, the compressive stresses may cause the falling of big pieces of walling down the shaft, which are liable to damage reinforcements and the equipment in the shaft. The tensile stresses may create gaps and multidirectional fractures in the shaft walling, and they can also result in the detachment of loose fragments from the walling (Zych 1996).

It is assumed that the amount of potential and actual damage to the shaft during exploitation is determined by vertical dislocations and strains. However, observations in-situ suggest that the extent of damage in shafts is also seriously influenced by horizontal dislocations.

The estimation of rock mass stability in the zones surrounding several shaft pillars prompts the assumption that the amount of subsidence decreases as the depth increases (Lubryka 2000). This hypothesis is supported by geodesic measurements taken at various levels of the Jas-III shaft (Fig. 1). It is evident from the charts that down to a depth of 176 m below the surface (level +70), the influence of exploitation on the shaft stability is still considerable, but at 246 m (level 0 m) the subsidence has diminished to only 18% of the value at +70 m. 120 m lower down (level –120) subsidence has decreased to 50% of the value at the 0 level, this figure being a mere 10% of the subsidence magnitude at level +70. Total vertical dislocations recorded at 486 m (level –240) over a period of 43 years of monitoring is 7 mm. Thus, at this depth there is virtually zero subsidence caused by mining exploitation.

It may be assumed from the measurements that the shaft-pipe of the Jas-III shaft is stable. However at the 452 section there is a lateral eastward shaft-pipe dislocation of 0.48 m. However, the shaft proper has not undergone any serious deformations. Similar observations resulted from measurements carried out in Shafts 1 and 2 in the "Morcinek" coal mine.

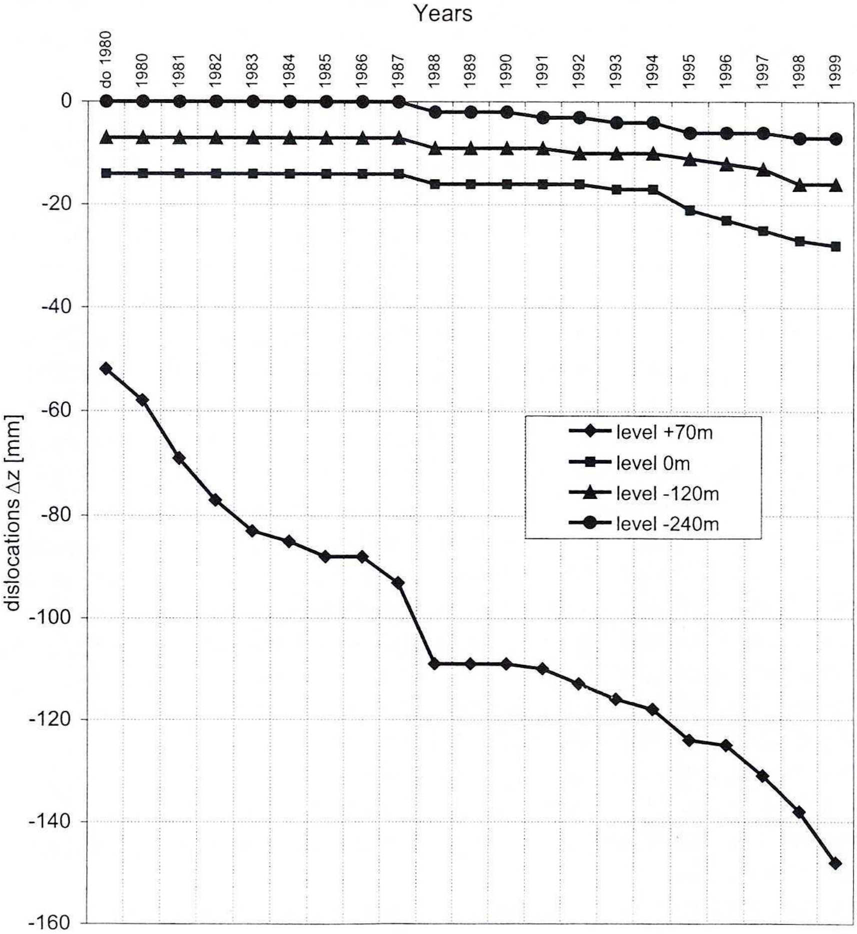

Fig. 1. Subsidence of datum points installed in the shaft Jas-III — lower section

Rys. 1. Osiadania reperów zainstalowanych w szybie Jas-III — odcinek dolny

In Shaft 1 the subsidence has exceeded 0.14 m since 1991 (Fig. 2). In 1997, prior to commencing operations to close the shaft, vertical dislocations at Bunton No 1 level (3 m) and Bunton No 12 (50 m) were almost 0.40 m.The degree of subsidence falls steadily in inverse proportion to the depth, but even at the lowest monitored level of Shaft 1, i.e. at 781 m, it was 0.12 m.

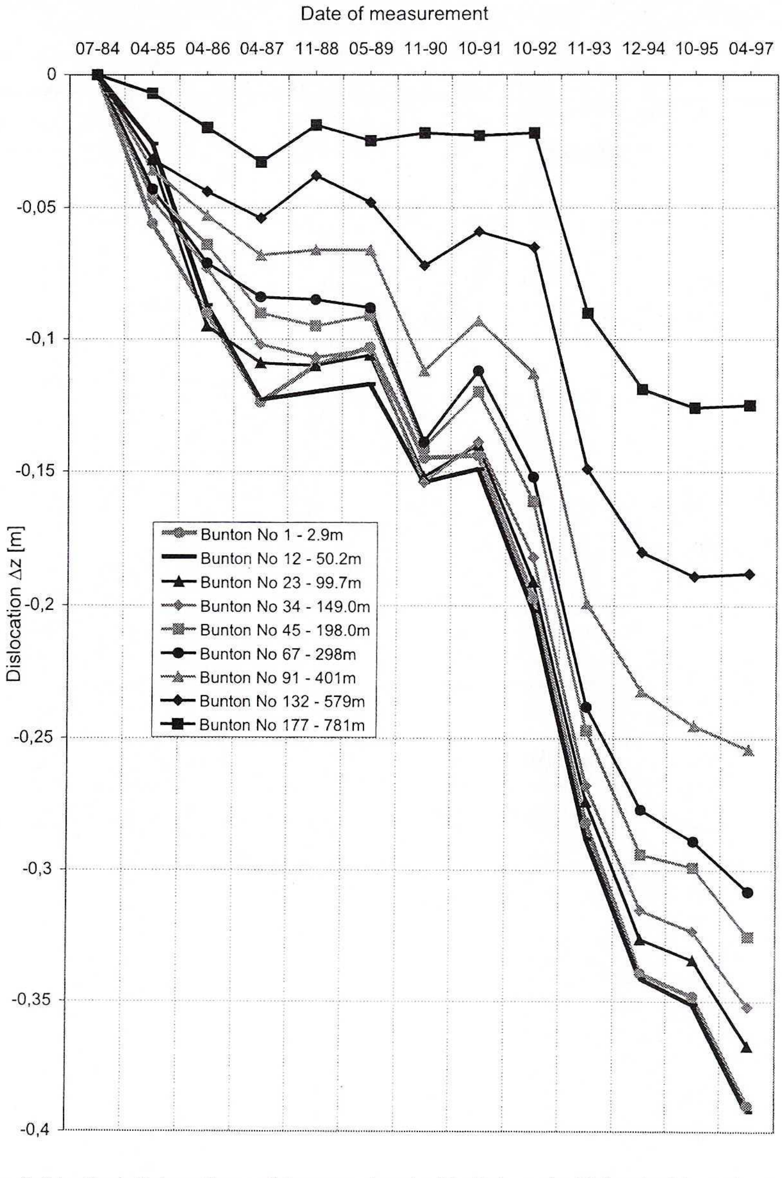

Fig. 2. Vertical dislocations of datum points in Shaft 1 — the "Morcinek" coal mine

Rys. 2. Przemieszczenia pionowe reperów w Szybie 1 — KWK „Morcinek"

On the basis of the analysis of the results of vertical dislocations obtained from the observation of subsidence at monitoring points in Shaft 2 of the "Morcinek" coal mine, it may be assumed that in the analysed period the results had an overall tendency to increase (Fig. 3). Only in 1991 did the vertical dislocations decrease their value at all levels by approximately 0.03–0.04 m. In general, the amount of subsidence decreased at greater depths and at the lowest monitored level of Shaft 2, i.e. at 960 m, subsidence was

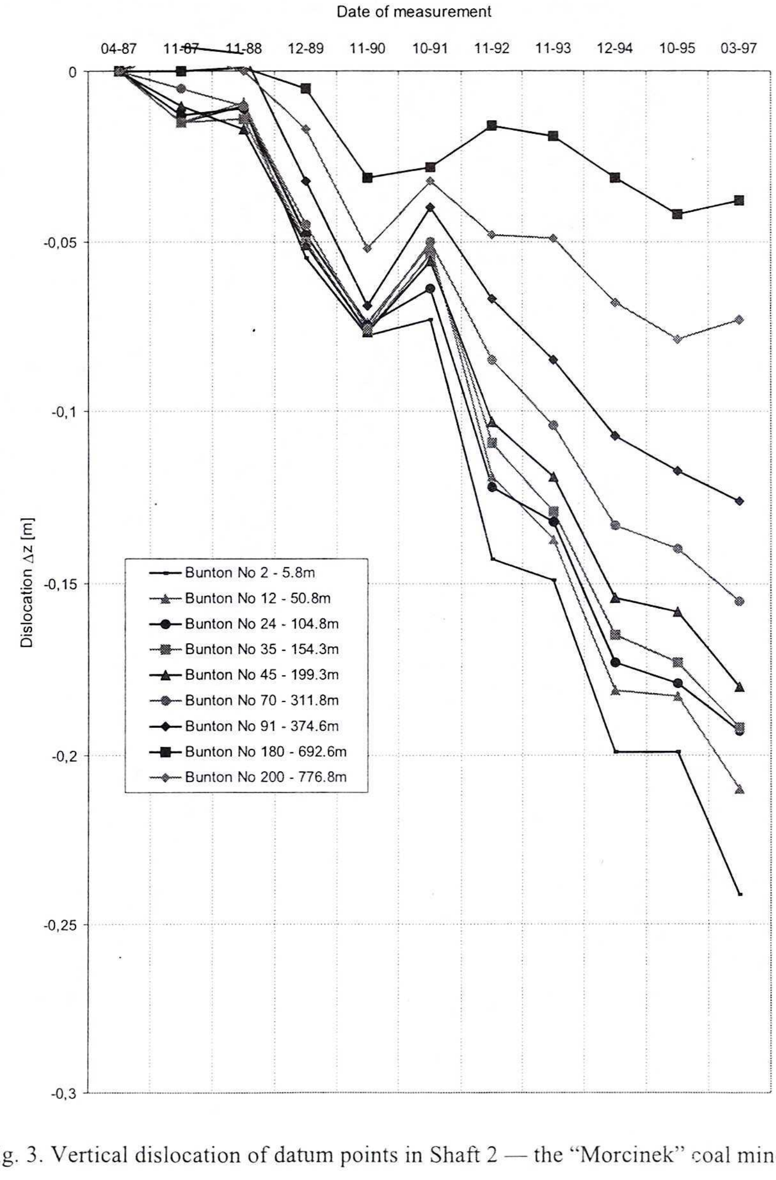

Fig. 3. Vertical dislocation of datum points in Shaft 2 — the "Morcinek" coal mine

Rys. 3. Przemieszczenia pionowe reperów w Szybie 2 — KWK „Morcinek"

0 mm. The increase of vertical dislocations in the shaft below the depth of 374 m is minute and during the ten-year measurement period was 0.07 m at 518 m (Bunton No 132), and at 692 m (Bunton No 180) — 0.04 m, with values of 0.13 m and 0.16 m recorded at shaft depths 374 m and 311 m respectively. Thus, in this instance, more than doubling the depth from 154 m to 311 m yielded a decrease of vertical dislocations of only 25%.

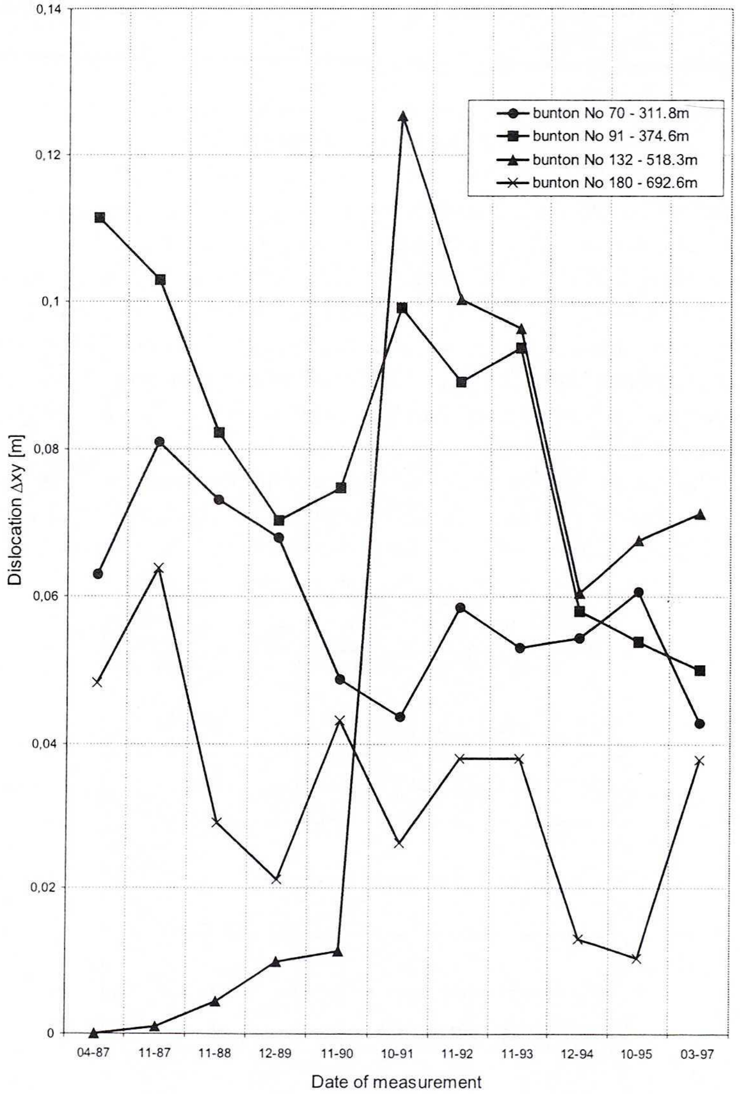

Fig. 4. Vertical dislocations of datum points in the Shaft 2 — lower sector — the "Morcinek" coal mine

Rys. 4. Przemieszczenia poziome reperów w Szybie 2 — odcinek dolny — KWK „Morcinek"

It may be assumed on the basis of the geodesic measurements that the shaft-pipe of Shaft 2 has not undergone significant vertical strain-movements. The deformation of the shaft-pipe and the shaft lining must therefore be caused by the horizontal dislocation (Fig. 4). Their resultant value exceeds the value of vertical dislocations recorded in Shaft 2 by 30% ($\Delta_{xy\mathrm{max}} = 0.32$ m, $\Delta_{z\mathrm{max}} = 0.24$ m). The influences of the exploitation around the pillar additionally caused the shaft to twist. The macroscopic observations, as well as the measurements of reinforcement and lining verticality indicated, however, that the lining still preserved and retained the stability of the rock mass in the immediate neighbourhood of the shaft.

3. Research method

The numerical model of the rock mass (Lubryka 2000), applied in the analysis, constitutes a $3D$ copy of a rock mass section with dimensions 800 × 800 × 1,000 m, containing a longwall and a shaft (Fig. 5). The existence of Tertiary and Quaternary layers, roof and floor layers, a coal seam and abandoned working were taken under consideration in the calculation model. In order to make the calculations simpler it was assumed that particular layers were isotropic, homogeneous and elastic.

It was assumed that the longwall had the length of 200 m; it was being cut in a seam with a thickness of 5 m; caving was used, and the longwall was approaching the hypothetical shaft such that its mid point moved directly towards the axis of the shaft. In Fig. 5 the vertical lines represent the situations, in which the shaft is at respective distances of: 100, 200, 300, 400 and 500 m from the wall being extracted.

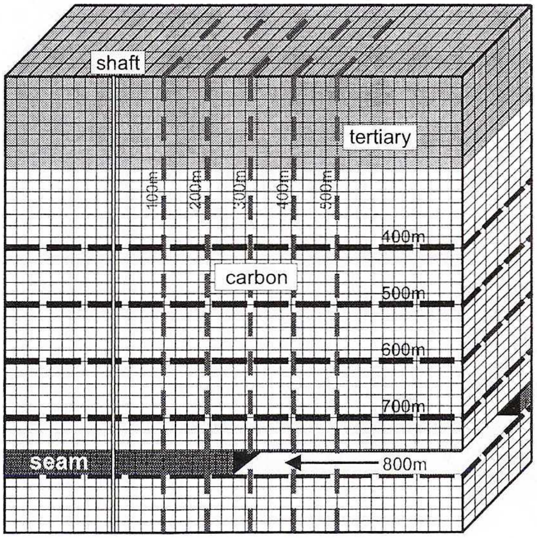

Fig. 5. The scheme of numerical model

Rys. 5. Schemat modelu numerycznego

The exploitation process was modelled for five depth — from 400 to 800 m — and for three values of Young's modulus for the rock mass surrounding the seam — $E_1 = 5$ GPa, $E_2 = 10$ GPa and $E_3 = 20$ GPa, with a constant Poisson's ratio $\nu = 0.25$.

The applied Cosmos/M calculation software made it possible to determine the value of the stress tensor components at all junction points of a rectangular prism cut out from the rock mass. The computational results were analysed for cross sections assumed to be 50 ⇒ 500 m from the shaft axis to the face of the longwall.

The adopted assumptions made it possible to analyse selected components of the state of stress in the section of the rock mass being analysed.

3.1. An analysis of the results of calculations

The results obtained are presented in the form of diagram on the basis of the so-called *coefficient of vertical stress concentration* — α. The coefficient is defined as the quotient of vertical stresses σ_z and primary vertical stresses p_z. The parameter, defined in this way, makes it possible to avoid comparing absolute values of stresses that change continuously as the depth alters. Furthermore, the parameter shows a surplus percentage of the stress appearing due to the mining exploitation in relation to the primary stress in a very convenient way. As research in situ indicates, those vertical horizontal stresses have the greatest impact on the behaviour of the shaft.

For instance, Fig. 6 and 7 present the change of the coefficient of vertical stress concentration in relation to the change of value of the Young's modulus for various distances between the longwall exploitation and the shaft at assumed depths of $H_1 = 400$ m (Fig. 6) and $H_2 = 800$ m (Fig. 7). The value of the coefficient of stress concentration decreases hyperbolically as the distance between the face and the shaft increases. If the depth increases, the value of coefficient a decreases slightly (by approximately 0.5–2% on average for each 100 m of depth) in relation to the type of rock mass (the higher the value of Young's modulus E, the bigger the decrease of the coefficient of stress concentration α). The maximum stress, determined at particular depths slows its rate of decrease between 170 and 159% of the value of primary stresses in the case of module E_3, from 147 to 141% of the value of primary stresses in the case of module E_2, and from 131 to 128% of the value of primary stresses in the case of module E_1. The most rapid decreases of stress concentration were recorded between 50 and 100 m — approximately 25%, and between 100 and 200 m — approximately 9%.

Taking the distance between the exploitation face and the shaft into consideration, it should be mentioned that the effects of extraction are discernible at progressively greater distances from the shaft as the depth of mining increases. For the coefficient of linear elasticity E_3 at exploitation depth $H_1 = 400$ m, the distance of influence is approximately 270 m; and at depth $H_2 = 800$ m it increases to approximately 360 m. For the coefficient of linear elasticity E_1, the distances are respectively approximately 140 m and approximately 130 m. Thus, it may be assumed that the most pronounced changes of the coefficient of stress concentration in relation to the distance from the exploited

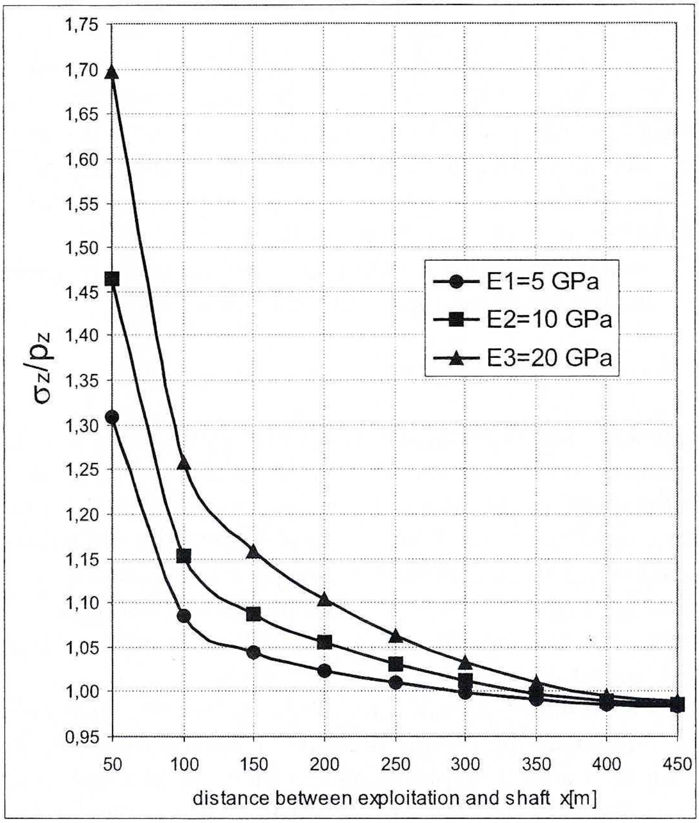

Fig. 6. The change of coefficient of vertical stress concentration $\alpha = \sigma_z/p_z$ for particular Young's modules at the depth of $H_1 = 400$ m

Rys. 6. Zmiana współczynnika koncentracji naprężeń pionowych $\alpha = \sigma_z/p_z$ dla poszczególnych modułów Younga dla głębokości $H_1 = 400$ m

face take place when the rock mass is more rigid. The pattern of changes in the state of stress is very similar for each type of rock mass at all depths analysed.

The following figures present the change of the coefficient of vertical stress concentration in relation to the change of the depth at which the extracted strata lie, for various distances between the longwall exploitation and the shaft, with assumed strain qualities for the rock mass; $E_1 = 5$ GPa (Fig. 8) and $E_3 = 20$ GPa (Fig. 9).

The coefficient of stress concentration increases proportionally to the increase of the rock mass rigidity, but the change of exploitation depth hardly alters the value of the coefficient at all. The maximum value of the coefficient a at a distance of 200 m from the shaft for a rock mass with modulus E_1 is 1,023, and for the rock mass with the modulus E_3 is 1,096. The distance from the shaft at which the primary stresses are not exceeded increases as the value of the elasticity coefficient rises. It also depends on

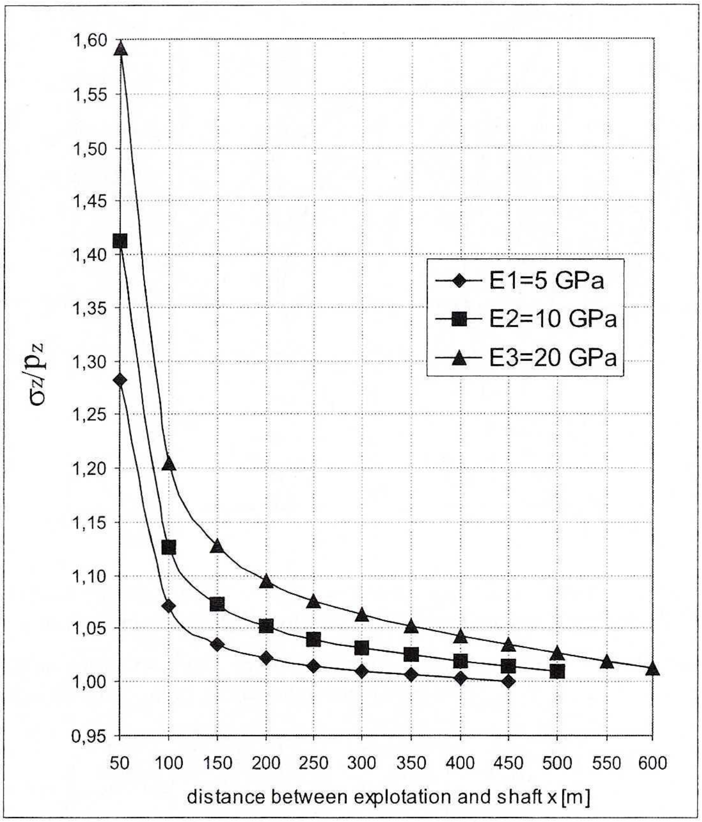

Fig. 7. The change of coefficient of vertical stress concentration $\alpha = \sigma_z/p_z$ for particular Young's modules for the depth H_2 = 800 m

Rys. 7. Zmiana współczynnika koncentracji naprężeń pionowych $\alpha = \sigma_z/p_z$ dla poszczególnych modułów Younga dla głębokości H_2 = 800 m

the depth, and for particular models it may be assumed that it is as follows: for H_1 = 400 m — approximately 300 ⇒ 400 m, and for H_2 = 800 m — approximately 450 ⇒ 650 m.

The changes of the coefficient of stress concentration alongside the increase of extraction depth, for close distances from the shaft contour, i.e. in the range 0 ⇒ 200 m (Fig. 10), indicate that on the shaft contour there is a decrease of vertical stresses by approximately 0.4 p_z. The maximum increase of the coefficient of vertical stress-concentration occurs at a distance of 50 m from the shaft, reaching 1.5 p_z. At a distance of 200 m between the heading and the shaft the influence of exploitation is practically imperceptible — the plot of change-rates is almost linear.

The maximum values of the coefficient of vertical stress concentration change fairly steadily over the range of depths analysed with the assumed values of Young's modulus.

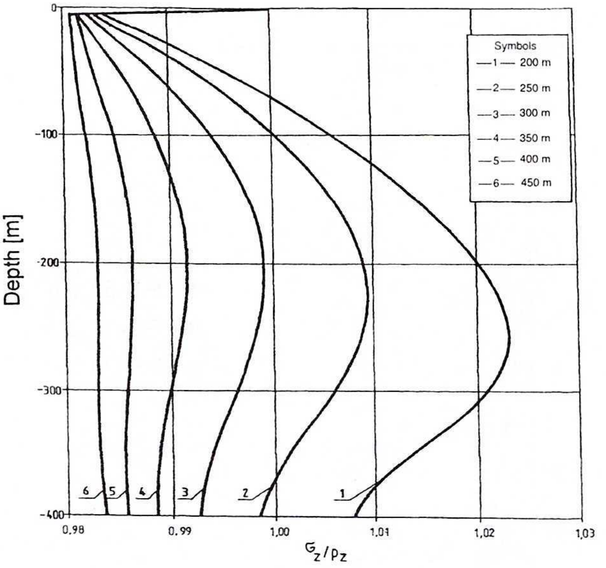

Fig. 8. The change of coefficient of vertical stress concentration for the exploitation at the depth of 400 m and the Young's module E_1 = 5 GPa at various distance from the face to the shaft

Rys. 8. Zmiana współczynnika koncentracji naprężeń pionowych dla eksploatacji na głębokości 400 m i modułu Younga E_1 = 5 GPa przy różnej odległości frontu ściany od szybu

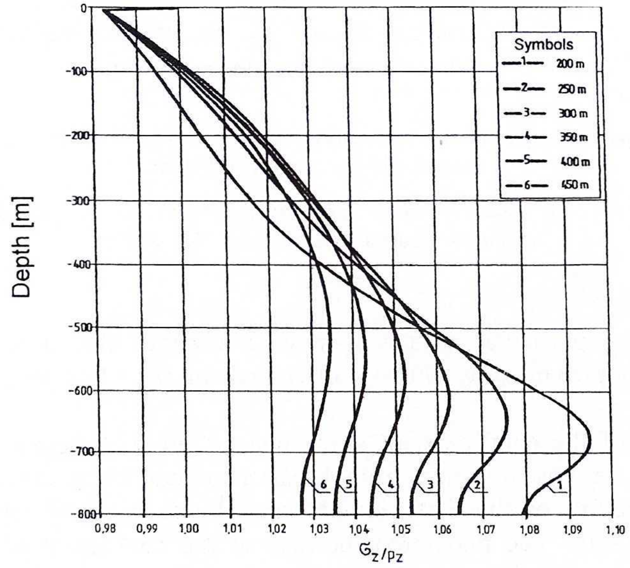

Fig. 9. The change of coefficient of vertical stress concentration for the exploitation at the depth of 800 m and the Young's module E_3 = 20 GPa at various distance from the face to the shaft

Rys. 9. Zmiana współczynnika koncentracji naprężeń pionowych dla eksploatacji na głębokości 800 m i modułu Younga E_3 = 20 GPa przy różnej odległości frontu ściany od szybu

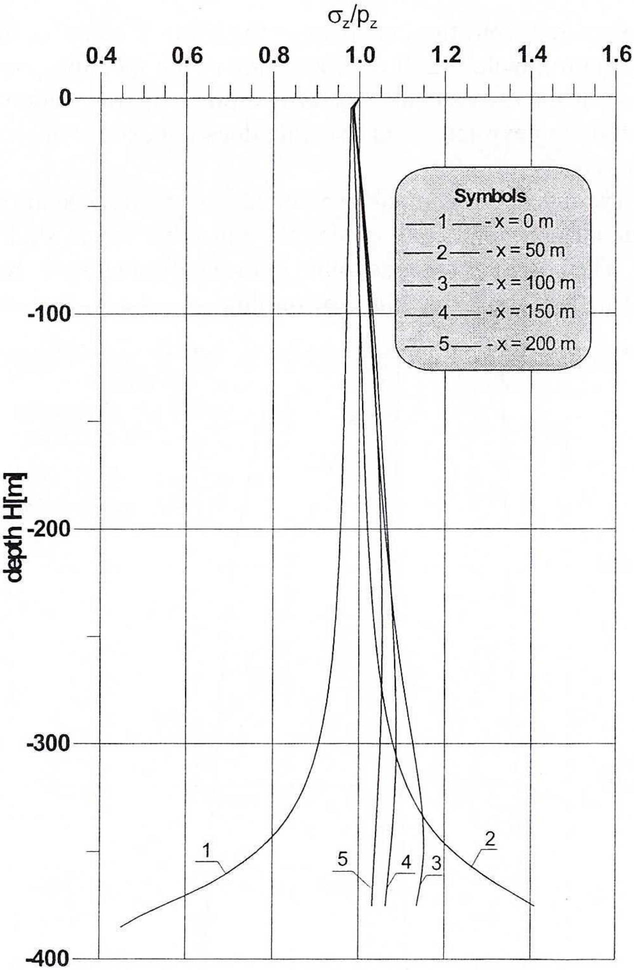

Fig. 10. The change of coefficient of vertical stress concentration for the close distances from the shaft's contour for the depth H_1 = 400 m for the rock mass with the coefficient of elasticity E_2 = 10 GPa

Rys. 10. Zmiany współczynnika koncentracji naprężeń dla bliskich odległości od konturu szybu dla głębokości H_1 = 400 m dla górotworu o module sprężystości E_2 = 10 GPa

3.2. Computed results and in-situ observation

It may be assumed on the basis of the analysis of numerical calculations and on the basis of observations in-situ that the deformations of the shaft pipe and the lining may mainly be attributed to the occurrence of excessive vertical compressive stresses, horizontal tensile stresses, or shear stresses in the shaft at a height of 50 to 150 m above the strata being extracted from the face near to the shaft. Increasing the face-distance from the shaft to approximately 200 ⇒ 300 m alters the location-point of maximum stress and strain — it moves vertically towards a plane approximately 300 ⇒ 350 m above the longwall being extracted and its value does not exceed approximately 120% of the primary stress.

The theoretical results are confirmed by practical observations in the mine, indicating that in spite of the current practice of exploitation at great depth, shaft linings are not exposed to strain. The horizon of strains found in the shafts analysed always lies at least several dozens of metres above the plane of mining.

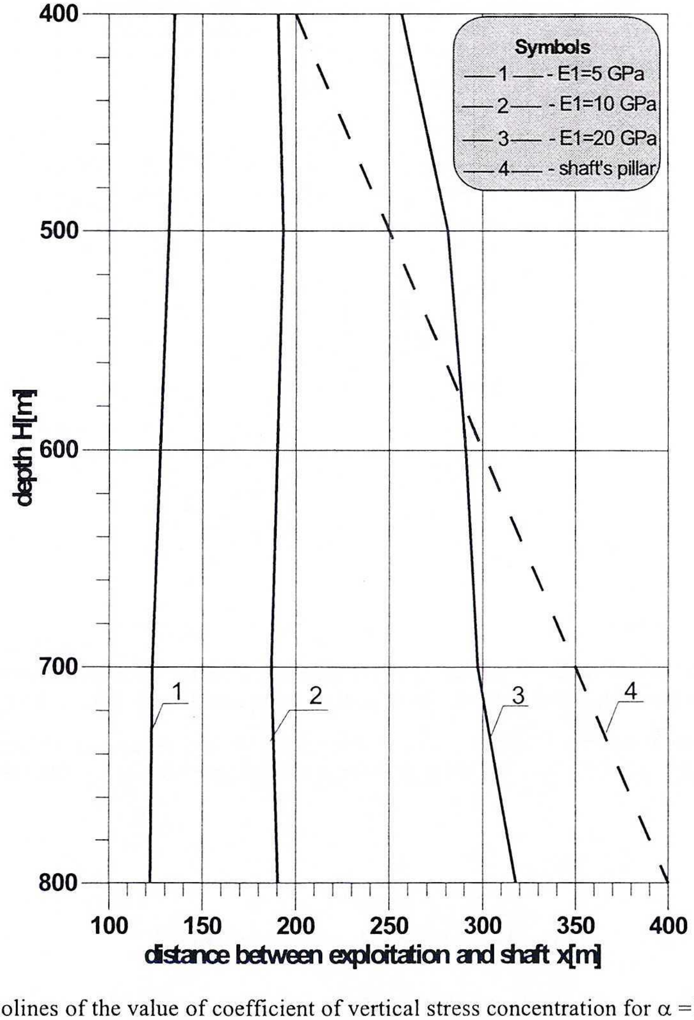

Fig. 11. The isolines of the value of coefficient of vertical stress concentration for $\alpha = 1.05$ in relation to the depth at various coefficients of rock mass elasticity

Rys. 11. Izolinie wartości współczynnika koncentracji naprężeń pionowych dla $\alpha = 1,05$ w zależności od głębokości przy różnych modułach sprężystości górotworu

Fig. 11 shows how the state of stress changes with depth at various distances between the longwall face and the shaft. The iso-lines of the coefficient of vertical stress concentration were selected as having a value of $\alpha = 1.05$, and it was assumed that they only changed slightly with the depth. However, their position largely depends on the elastic qualities of the rock mass. As Young's modulus increases, the distance between the shaft and the iso-line of the coefficient of vertical stress concentration with the value of $\alpha = 1.05$ also increases. In the case of the biggest assumed coefficient of linear elasticity $E_3 = 20$ GPa, the iso-lines are situated at the limit of the assumed pillar at a depth of approximately 580 m. The above suggests the possibility limiting the dimensions of safety pillars in shafts below extraction depths of 600 m.

4. Conclusions

1. The observations and measurements in situ indicate that exploitation carried out near pillars for a long period of time influences the behaviour of the shaft protected and contained by the pillar.
2. The analysis of the numerical calculations indicated that the closer the exploitation approaches the shaft, the higher the concentration of vertical stress around the shaft. The coefficient of stress concentration decreases in a hyperbolic manner as the distance between the face and the shaft changes. The most significant increase of stress concentration is visible between 50 ⇒ 100 m; approximately 25%.
3. Alongside with an increase of depth, for 400, 600 and 800 m respectively, the distance at which the influences of seam extraction continue to be felt increases,. For the linear elasticity coefficient $E_3 = 20$ GPa, the distances are 270, 320, 360 m. Change of depth has almost no influence on the value of the coefficient of vertical stress concentration. However, the value of the coefficient increases with an increase of the rigidity of the rock mass.
4. The damage to shafts caused by mining exploitation around the safety pillar may occur through the agency of excessive vertical compressive stresses and horizontal tensile stresses, or the occurrence of shear stresses in the shaft at a height of 50 ⇒ 150 m above the extracted seam, at a very close distance between the face and the shaft. The computed results are confirmed by practical observations.
5. In individual cases, depending on local geological and mining conditions, there is a possibility of changing the limits of the pillar, especially at considerable depths, providing that knowledge of the strain parameters of the rock mass in the vicinity of the pillar is adequate.

REFERENCES

Ćwiertnia K., Szczepaniak Z., 1998:. Wizualne określanie stateczności murowych obudów szybowych o kształcie kołowym. Materiały konferencyjne "Geomechanika '98", Ustroń-Gliwice.

Jędrzejec E., **Kowalski** A., **Kwiatek** J., 1996: Wyznaczanie filarów ochronnych dla obiektów na powierzchni szybów i szybików w granicach obszarów górniczych kopalń węgla kamiennego. Wyd. GIG seria Instrukcje nr 3, Katowice.

Lubryka M., 2000: Wpływ eksploatacji górniczej w rejonie filara ochronnego na deformacje powierzchni terenu i zachowanie się rury szybowej. Praca doktorska (niepubl.), AGH, Kraków.

Majcherczyk T., **Małkowski** P., **Majchrzak** J., 2002: Analiza wybranych skutków eksploatacji górniczej dokonanej w filarze ochronnym szybu Jas-5. Wydawnictwa Głównego Instytutu Górnictwa, Górnictwo, seria Konferencje nr 41, Katowice.

O wyznaczaniu filarów ochronnych dla obiektów, urządzeń i terenów w granicach obszarów górniczych kopalń węgla kamiennego Górnośląskiego Zagłębia Węglowego. Zarządzenie nr 19 MGiE z dnia 23.03.1961.

Richardson A.M., **John** C.M., 1988: A concrete shaft liner design methodology for nuclear waste repositories. Key Questions in Rock Mechanics, Cundall et al., Balkema Rotterdam.

Wyznaczanie filarów ochronnych dla obiektów powierzchniowych i podziemnych na obszarach górniczych kopalń węgla kamiennego. Zarządzenie nr 4 MGiE z dnia 1.02.1986.

Zych J., 1996: Czynniki wpływające na wielkość i rozkład deformacji w szybie. Materiały konferencyjne Szkoły Eksploatacji Podziemnej '96, Szczyrk.

REVIEW BY: PROF. DR HAB. INŻ. EDWARD POPIOŁEK, KRAKÓW

Received: 11 June 2002