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AN ANALYSIS ON THE EFFECT OF CROSSCUTS WITHIN SHAFT PROTECTIVE PILLARS ON DEFORMATIONS OF THE SURROUNDING ROCK MASS DEFORMATIONS

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Abstract: The development of crosscuts within mining shafts' protective pillars causes a change of state of stress in the surrounding rock mass. It also causes deformations of the rock mass and the surface. It is essential to conduct prediction analysis of the deformations and stresses in order to secure a proper functioning of a shaft located within the protective pillar. It is recommended that the analysis should be based on the integration of the finite element method (FEM) and geodetic monitoring results. FEM makes it possible to determine the rock mass stresses and displacements in the shaft protective pillars and in the surrounding rock mass. It makes is possible to determine the safety and proper functioning of the shaft. The results of the FEM analysis of the impact of crosscuts and mining activities on rock mass deformations inside and on the surface of the protective shaft pillar are presented. The influence of mining extractions was investigated. The mining panels were located around the safety pillar in three regions NW, SE and SW and the crosscut were located within the safety pillar. The presented methodology will allow for the determination of the deformations and strains in case of farther development of crosscuts within the protective shaft pilar and by planned mining activities around the pillar.

Keywords: *finite elements method, stress, protective pillar, deformation*

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1. INTRODUCTION

Mining shafts are located within sufficiently large protective pillars. They serve to provide: a) access for the transport of mined ore and mining service personnel, b) mining ventilation, and c) water drainage. The safety and proper operations of mining shafts are affected by mining activities around and within the safety pillars. In order to increase economy of under ground mining, there is often pressure to mine the deposit at a close proximity to the borders of the safety pillars or even within their borders. Additionally, various types of crosscuts are constructed within the boundaries of the shaft protective pillars. The shaft behaviour may be affected and the stability may be threatened by even a comparatively small amount of ore mined in its close vicinity (Pariseau et al. 1996). The Mining Department of Poland called for special attention to these type of situations. There was also an urgent need to analyze the impact of crosscuts on the deformation of the rock mass and its surface and the change of stress.

Until recently, nonparametric methods were used to predict surface deformations caused by underground mining. Nonparametric methods treat the deformable object, in this case the rock mass, as a “black box” (Welsch, Heunecke 2006). In this case the physical parameters of the investigated object are unknown. The mathematical model uses only empirical parameters to characterise the rock mass and mining activity. In Poland, the most popular nonparametric method in use is the Influence Function Method based on theory developed by Budryk–Knothe (Knothe 1984). The method was adapted to determine the rock mass deformations within the safety pillars (Dżegniuk et al. 2003; Niedojadło 2008; Popiołek 2009; Niedojadło, Gruszczyński 2010). It was assumed that the rock mass at the depth of the mining excavation, or at the depth of the bottom of the shaft has zero degrees of freedom (Niedojadło 2008; Niedojadło, Gruszczyński 2010). This assumption was used in the analysis of the geodetic monitoring (Popiołek, Ostrowski 2001; Patykowski, Kądziołka 2010). The Budryk–Knothe nonparametric theory does not provide the determination of stresses in the rock mass surrounding mining workings.

To address the need for the determination of the state of stress and deformations of the rock mass surrounding the mining shaft, parametric methods are more suitable. Parametric methods treat the deformable object as a “white box” (Welsch, Heunecke 2006). In this case the physical parameters of the investigated object are known. The parametric method is based upon the principles of continuum mechanics and allows for a mathematical formulation of the boundary value problem. The solution of the boundary value problem must satisfy the equation between stresses and displacements, kinematic and constitutive relations. In the case where there is underground mining activity boundary conditions, zero degrees of freedom must be specified at the required distance from the mining excavation, in order to not affect the solution.

Burtan (2010A; 2011B) and Pawelus (2013) used a closed form solution of the boundary value problem to calculate deformations around the mining opening. Zorychta et al. (1999A; 1999C; 1999D) used a closed form solution to determine the deformations of layered rock mass. In the model, each layer of the rock mass was represented as a simple beam.

The Finite Element Method (FEM) became a preferable numerical method used to solve the equations describing the boundary value problem (Szostak-Chrzanowski 2008). In order to gain a better understanding of the deformation of an investigated object, FEM results may be verified using the results of geodetic monitoring (Chrzanowski, Szostak-Chrzanowski 2010; Warchala, Szostak-Chrzanowski 2016). Figure 2 shows the diagram of Integrated Analysis. It shows the interaction among the steps of deformation analysis (Chrzanowski, Szostak-Chrzanowski 2010).

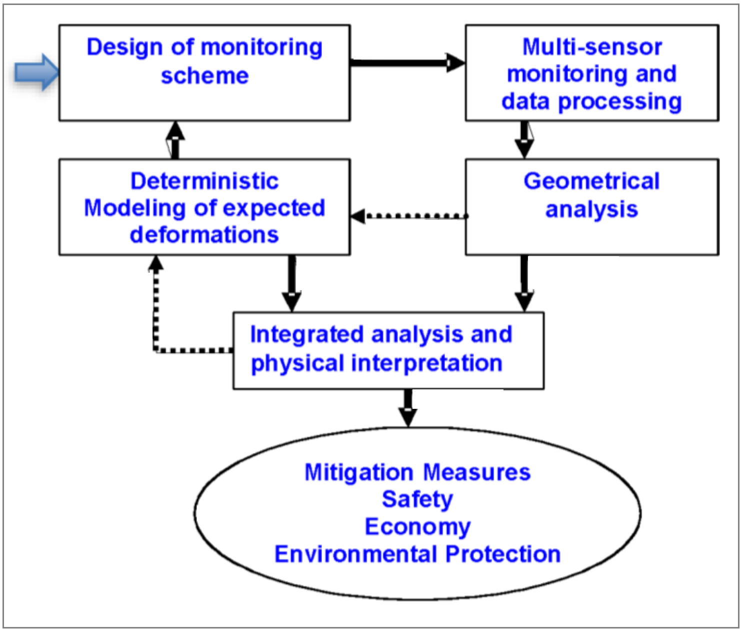

Fig. 1. Integrated system for deformation monitoring and analysis

2. FEM MODEL OF MINING ACTIVITY

Three-dimensional problems may be simplified by two-dimensional analysis using properly selected cross-sections. Generally, geological, mining, geomechanical and geodetic data as well as mining plans are used for conducting FEM analysis. An example of the cross-section covering both the exploitation and the protective pillar and

the space covered by possible influences is shown in Fig. 2 (Warchala, Szostak-Chrza-
nowski 2016).

Deterministic modeling of rock mass deformation is a challenging process because the in situ rock mass is an inhomogeneous material and the determination of the in situ rock properties poses difficulties. Linear-elasticity models are still most widely used in the modeling behaviour of rocks, especially hard rock (Jing 2003). In the case of brittle rock mass subjected to tensional stress, the transversely isotropic elasticity model may be used to form the constitutive matrix (Szostak--Chrzanowski, Chrzanowski 2008). Use of more sophisticated constitutive models in rock mechanics may not be practical because of the difficulties of the determination of rock material parameters. For the analysis subsequently discussed, the linear-
-elastic and transversely isotropic models were chosen to model the behaviour of the rock mass.

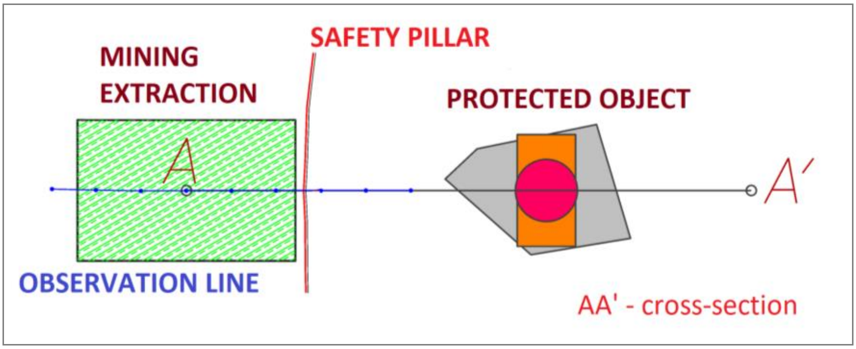

Fig. 2. Example of a cross-section for FEM analysis

The FEM analysis conducted focuses on the impact of crosscuts and mining activities on rock mass deformations inside and on the surface of the protective shaft pillar. The influence of mining extractions was also investigated. The mining panels were located around the safety pillar in three regions: NW (panel I and panel II), SE (panel III) and SW (panels IV–VII). The locations of the mining panels is shown in Fig. 3. The rock mass and mining extraction parameters were accepted as given in Warchala and Szostak-Chrzanowski (2016). The linear-elastic and transversely isotropic models were chosen to model the behaviour of the rock mass.

Cross-sections A-B and C-D were chosen to analyze the influence of mining activity on deformations of the safety pillar. A-B cross-section included panels I, II, and III, located on both sides of the protective pillar and C-D cross-section included panels IV, V, VI, and VII located on one side of the pillar. The main purpose of the analysis was to obtain the impact of crosscuts inside the shaft protective pillar.

3. FEM MODEL OF MINING ACTIVITY

Seven mining panels are located around the shaft safety pillar. Panels I and panel II are located North-West from the shaft. They are separated by a geological fault. Panel III is located South-East from the shaft. Panels IV, V, VI, and VII are located South-West from the shaft. The plan of the mining activities is shown in Fig. 3. The crosscuts are located within the safety pillar at the level of mining workings II, III, and IV.

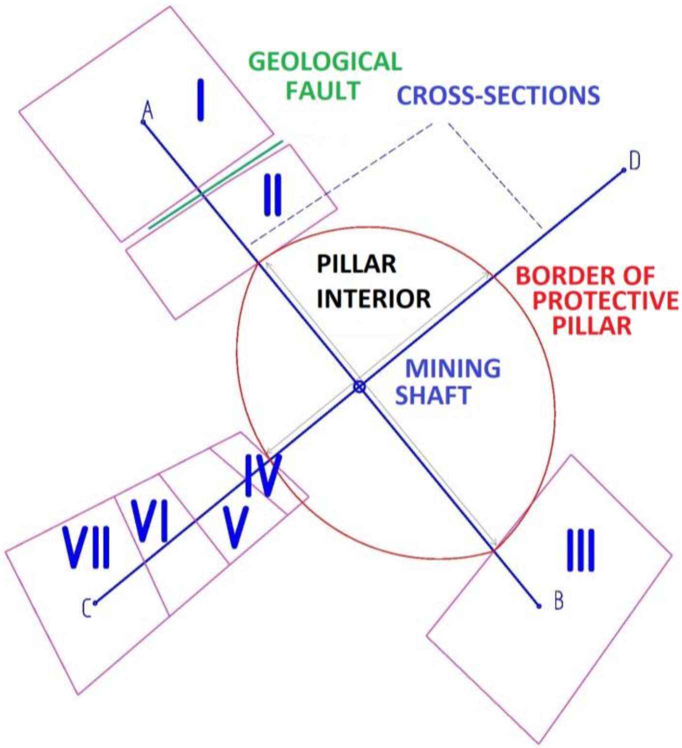

Fig. 3. Plan of mining activities

The geology of the rock mass was accepted based on data obtained from the mine. The rock mass of the investigated cross-sections was divided into six tabular geological formations. The geology of A-B and C-D cross-sections is shown in Figs. 4 and 5, respectively.

The values of geomechanical parameters of each geological formation were taken from Warchala and Szostak-Chrzanowski (2016). The geomechanical parameters are given in Table 1. The geomechanical parameters of geological formations located around a geological fault had lower Young modulus values based on the lower rock mass quality. Based on Rock Mass Rating (RMR) system (Bieniawski 1974). Young modulus values of the corresponding rock mass geological formation on both sides of the fault were scaled by factor of ten in respect to their original *in-situ* values (Warchala et al. 2017). The scaled geological formations around the fault are marked as: 2U, 3U, 4U, 5U, and 6U. The geological parameters of the fault rock mass are given in Table 1.

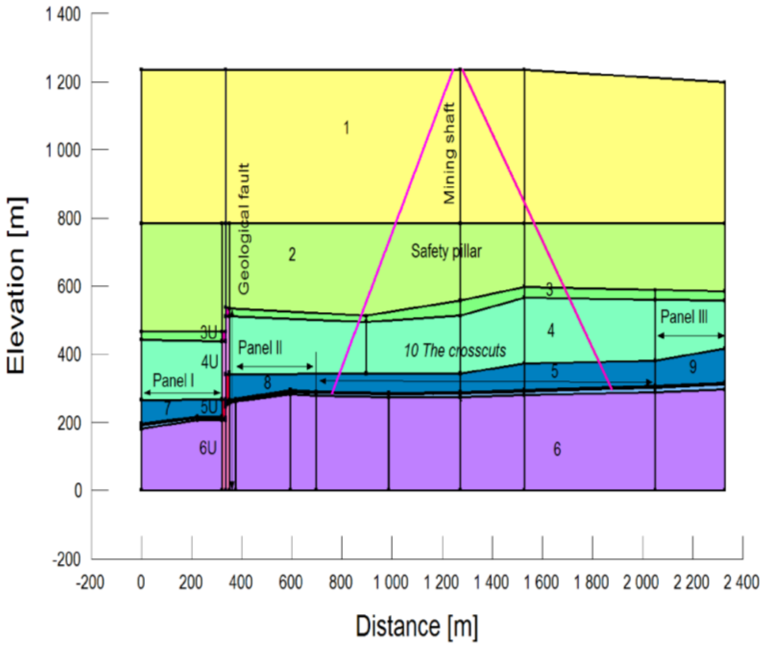

Fig. 4. A-B geological cross-section

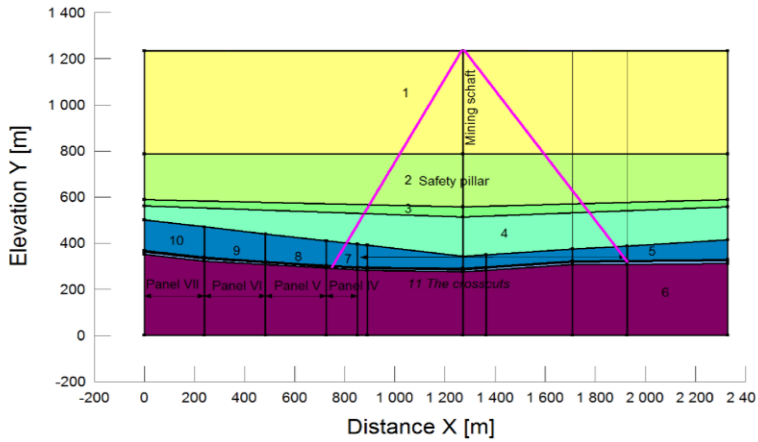

Fig. 5. C-D Geological cross-section

Table 1. Geomechanical parameters of geological strata

Layer	Young modulus [MPa]	Unit weigt [kN/m^3]	Poisson ratio
1	3 000	24	0.25
2	16 000	25	0.12
3	8 000	25	0.12
4	16 000	29	0.12
5	25 000	27	0.12
6	6 000	27	0.12
2U	1 600	25	0.12
3U	800	25	0.12
4U	1 600	29	0.12
5U	2 500	27	0.12
6U	600	27	0.12

Mining exploitations regions were modeled taking under consideration their mining methods. The Young moduli of all exploitations were verified using results of geodetic monitoring. The values of Young moduli are shown in Table 2.

Table 2. Young moduli of mining panels: I–VII

Panel	I	II	III	Panel	IV	V	VI	VII
Young modulus [kPa]	15	100	1	Young modulus [kPa]	100	70	50	60

4. DEFORMATIONS AND STRESSES DUE TO MINING ACTIVITY AND CROSSCUTS IN SHAFT SAFETY PILLAR

The state of stress and deformations due to mining activity were accepted as the initial state and the analysis was marked as F1. Next, the impact of crosscuts on the stress distribution and deformations was determined. The crosscuts, whose geometry was three-dimensional, were represented in two-dimensional analyses by equivalent geometry and geomechanical parameters. Three separate assumptions regarding values of Young modulus and Poisson ratio in linear-elastic analyses were accepted. The analyses are marked as F2, F3, and F4. Additionally, the equivalent rock mass of crosscuts was characterised using the transversely-isotropic model (Analyses 5 and 6). The values of Young modulus and Poisson ratio are given in Table 3.

Table 3. Geomechanical parameters of crosscuts

Analysis	*E* [MPa]	*ν*
F1	25 000	0.2
F2	12 500	0.2
F3	6250	0.2
F4	12 500	0.4
F5	Directional *E*	
F6	2500	0.2

5. DEFORMATIONS CALCULATED USING FEM

Surface subsidence in A-B and C-D cross-sections are shown in Figs. 6 and 7, respectively. The crosscuts do not have influence on vertical deformations of the surface.

Vertical strains in the centre of the shaft in A-B and C-D cross-sections are shown in Figs. 8 and 9, respectively. Horizontal strains in the centre of the shaft in A-B cross-section and C-D cross-section are shown in Figs. 10 and 11, respectively. The largest change of horizontal strain is at the bottom of the shaft and reaches 0.3 mm/m case of A-B cross-section and 0.34 mm/m case of C-D cross-section.

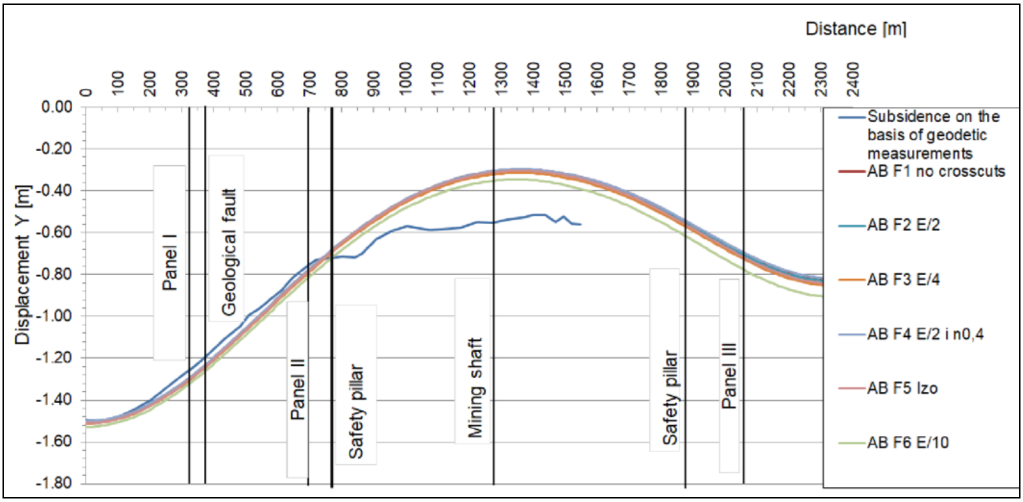

Fig. 6. Surface Subsidence A-B cross-section

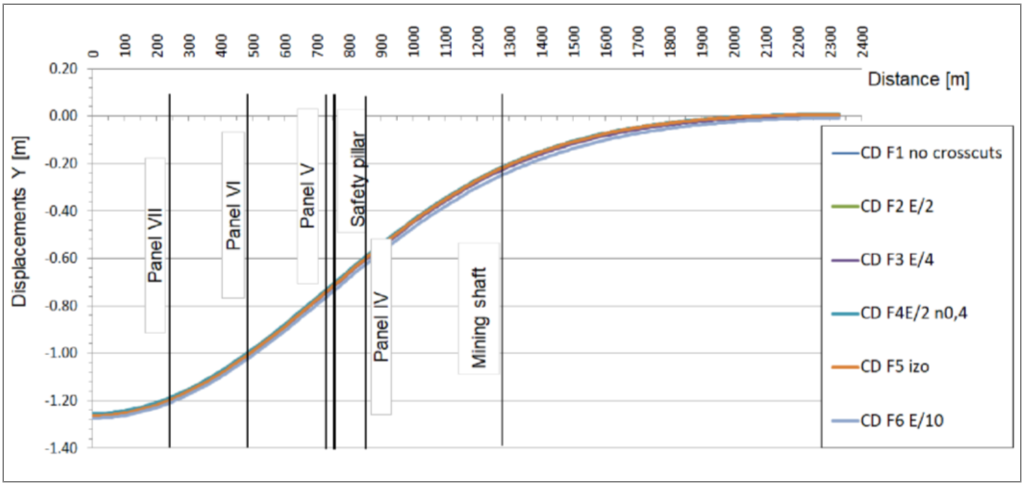

Fig. 7. Surface subsidence in C-D cross-section

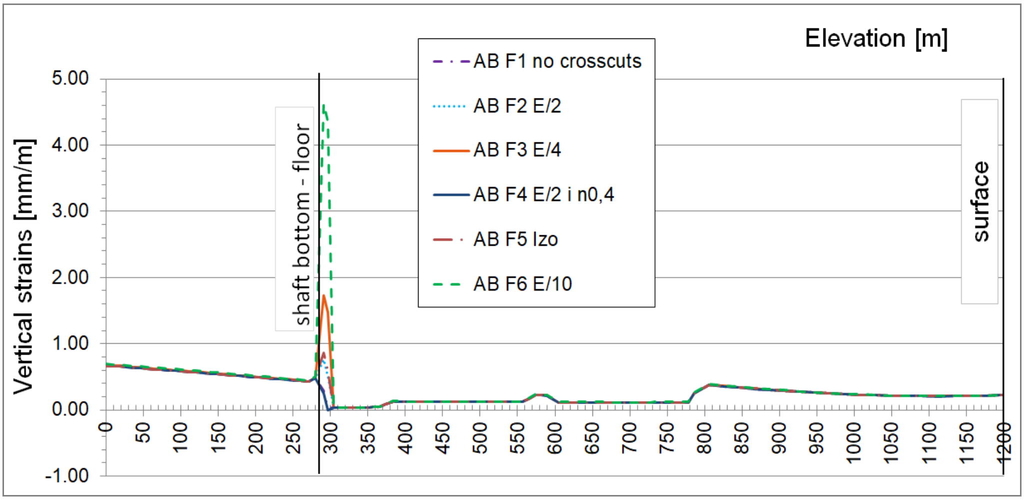

Fig. 8. Vertical strains of the shaft axis A-B cross-section

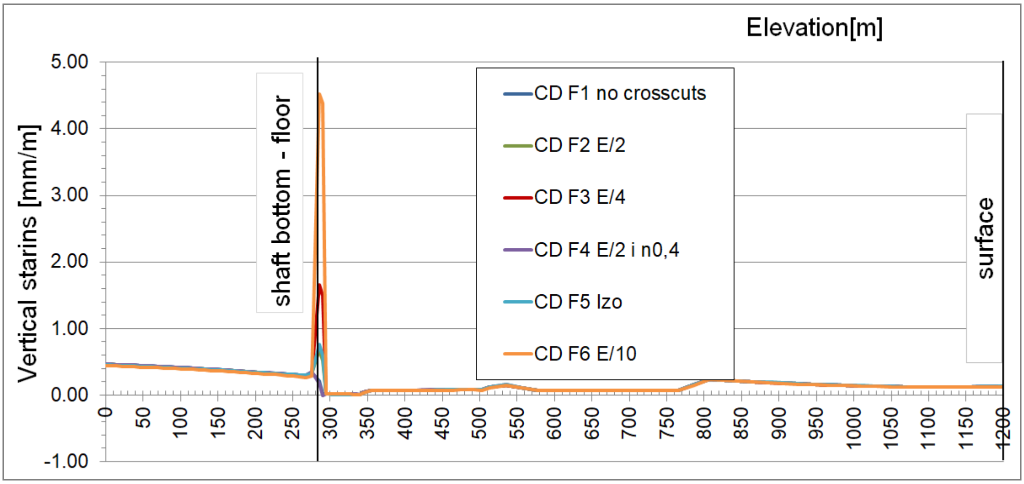

Fig. 9. Vertical strains of the shaft axis – C-D cross-section

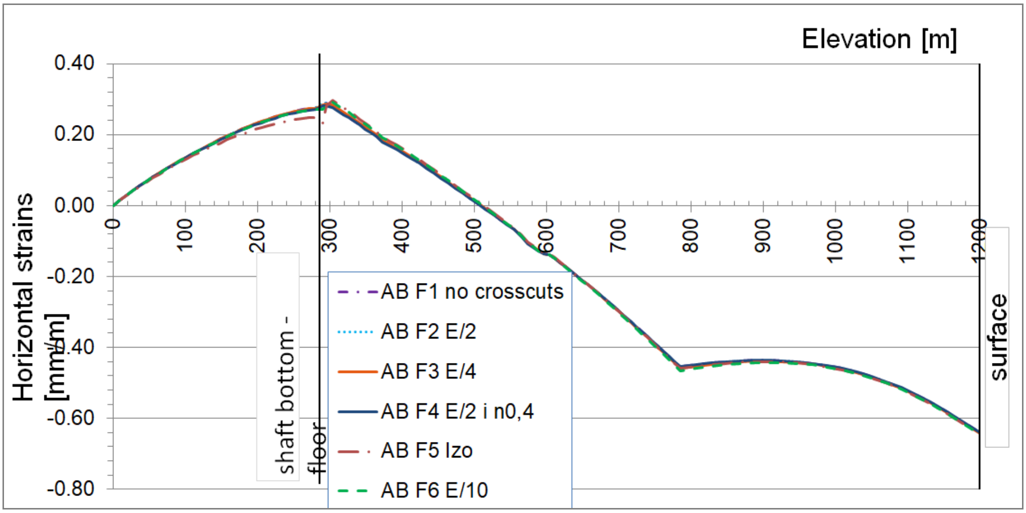

Fig. 10. Horizontal strains of the shaft axis – A-B cross-section

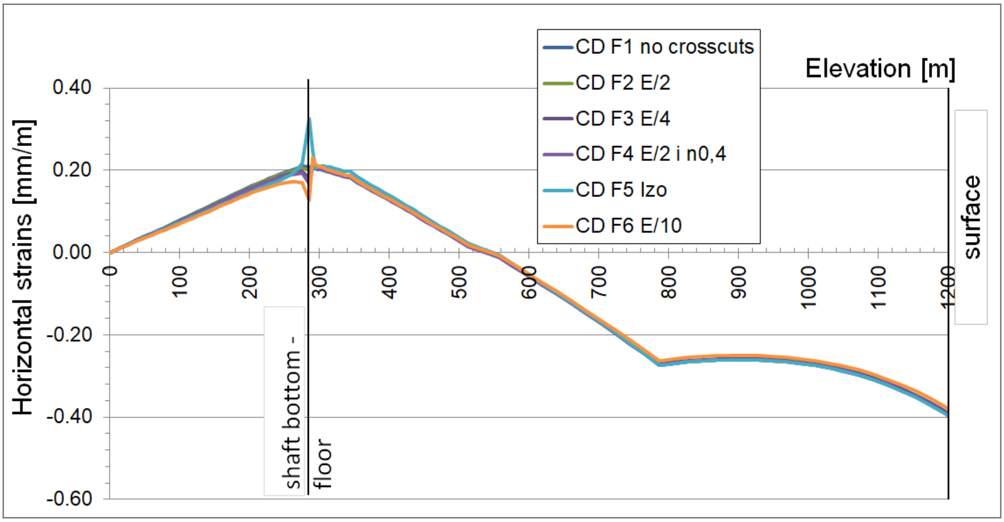

Fig. 11. Horizontal strains of the shaft axis – C-D cross-section

6. CONCLUSIONS

Results of the FEM analysis give information on the deformations and strain redistribution in the rock mass in the vicinity of the shaft which were caused by cross-cuts within the protective shaft pilar and by existing and planned mining activities around the pillar. The largest vertical displacements of the ground surface caused be cross-cuts were 90 mm for A-B cross-section and 20 mm for C-D cross-section. The largest displacements were obtained using the transeverly-izotropic model of the cross-cuts region. The calculated displacements were very small and they did not pose a safety threat to objects on the surface. The crosscuts within the shaft protective pillars do not have significant influence on vertical deformations of the surface.

The presented methodology will allow for the determination of the deformations and strains in case of farther development of crosscuts within the protective shaft pillar and by planned mining activities around the pillar.

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LITERATURE

BIENIAWSKI Z.T., 1984, *Rock Mechanics Design and Tunneling*, Balkema.

BURTAN Z., 2010, *Geomechaniczny model górotworu uwarstwionego*, Górnictwo i Geoinżynieria, R. 34, z. 3/1.

BURTAN Z., 2011, *Kształtowanie się zagrożenia sejsmicznego w trakcie eksploatacji rud miedzi w rejonie strefy uskoku Biedrzychowa*, Górnictwo i Środowisko, Górnicze Zagrożenia Naturalne, nr 4/2, s. 34–42.

CHRZANOWSKI A., SZOSTAK-CHRZANOWSKI A., 2010, *Automation of Deformation Monitoring Techniques and Integration with Prediction Modelling*, Geomatica, pp. 221–231.

DŻEGNIUK B., NIEDOJADŁO Z., SROKA A., 2003, *Podstawy wymiarowania i eksploatacji szybowych filarów ochronnych*, Szkoła Eksploatacji Podziemnej, s. 77–93.

JING L., 2003, *A review of techniques, advances and outstanding issues in numerical modeling for rock mechanics and rock engineering*, Int. J. of Rock and Mining Sciences, Vol. 40, Issue 3, pp. 283–353.

KNOTHE S., 1984, *Prognozowanie Wpływów Eksploatacji Górniczej*, Publisher Śląsk.

NIEDOJADŁO Z., 2008, *Problematyka eksploatacji złoża miedzi z filarów ochronnych szybów w warunkach LGOM*, Uczelniane Wydawnictwa Naukowo-Dydaktyczne, Rozprawy i Monografie, 177, Kraków.

NIEDOJADŁO Z., GRUSZCZYŃSKI W., 2010, *Dokładność prognozowania wpływów eksploatacji górniczej na szyby w warunkach LGOM*, Przegląd Górniczy, nr 34, s. 65–74.

PARISEAU W.G., JOHNSON J.C., MCDONALD M.M., POAD M.E., 1996, *Rock Mechanics Study of Shaft Stability and Pillar Mining*, US Bureau of Mines, Report of Investigations 9618, 36 pp.

PATYKOWSKI G., KĄDZIOŁKA K., 2010, *Analiza wpływu eksploatacji w uwolnionej części filara ochronnego szybów L-IV i L-V na powierzchnię terenu*, Przegląd Górniczy, nr 10, s. 172–181.

PAWELUS D., 2013, *Ocena stateczności wyrobisk korytarzowych w rejonie szybu R-XI z wykorzystaniem sprężysto-plastycznego modelu górotworu i kryterium Coulomba–Mohra*, Cuprum: Czasopismo Naukowo-Techniczne Górnictwa Rud, nr 4, 21–40.

POPIOŁEK E., 2009, *Ochrona terenów górniczych*, Wydawnictwa AGH, Kraków, ISBN 978-83-7464-229-3.

POPIOŁEK E., OSTROWSKI J., 2001, *Geodezyjne obserwacje wpływów eksploatacji górniczej prowadzonej w rejonie szybów górniczych kopalni rud miedzi "Rudna"*, Cuprum: Czasopismo Naukowo-Techniczne Górnictwa Rud, nr 18, 53–75.

SZOSTAK-CHRZANOWSKI A., CHRZANOWSKI A., 2008, *Canadian Contributions to Monitoring and Physical Interpretation of Ground Subsidence*, Markscheidewesen, Jahrgang 115, Nr. 3, October, pp. 14–20.

SZOSTAK-CHRZANOWSKI A., CHRZANOWSKI A., 2013, *Development of INTEGRAN Method for*

Integrated Analysis of Rock Mass Deformation in Underground Mining, Vol. 1. *Methodology*, March 31, Project: Integrity and Security Monitoring of Critical Infrastructure, Sub-Project WP4000, 190 pp.

WARCHALA E., SZOSTAK-CHRZANOWSKI A., 2016, *Analiza deformacji górotworu w filarach ochronnych szybów górniczych*, Wydział Geoinżynierii, Górnictwa i Geologii Politechniki Wrocławskiej, Wrocław.

WARCHALA E., SZOSTAK-CHRZANOWSKI A., STEFANEK P., 2017, *Wykorzystanie MES do prognozowania przemieszczeń terenu wywołanych eksploatacją górniczą*, Zeszyty Naukowe Instytutu Gospodarki Surowcami Mineralnymi i Energią PAN, nr 99, s. 171–183.

WELSCH W.M., HEUNECKE O., 2006, *Models and terminology for the analysis of geodetic monitoring observations*, Official Report of the Ad-Hoc Committee of FIG Working Group 6.1, FIG Publication No. 25.

ZORYCHTA A., BURTAN Z., CHLEBOWSKI D., 1999A, *Metoda określania stanu zagrożenia tąpaniami w sąsiedztwie dyslokacji tektonicznych*, Cuprum: Czasopismo Naukowo-Techniczne Górnictwa Rud, nr 10, 13–26.

ZORYCHTA A., BURTAN Z., CHLEBOWSKI D., 1999C, *Wpływ eksploatacji na możliwość powstania wstrząsów w górotworze uwarstwionym*, Cuprum: Czasopismo Naukowo-Techniczne Górnictwa Rud, nr 11, 37–52.

ZORYCHTA A., BURTAN Z., CHLEBOWSKI D., 1999D, *O pewnej możliwości powstawania wstrząsów w uwarstwionym ośrodku skalnym*, Cuprum: Czasopismo Naukowo-Techniczne Górnictwa Rud, nr 11, 21–35.