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INTEGRATED ANALYSIS OF ROCK MASS DEFORMATION WITHIN SHAFT PROTECTIVE PILLAR

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Abstract: The paper presents an analysis of the rock mass deformation resulting from mining in the vicinity of the shaft protection pillar. A methodology of deformation prediction is based on a deterministic method using Finite Element Method (FEM). The FEM solution is based on the knowledge of the geomechanical properties of the various geological formations, tectonic faults, types of mining systems, and the complexity of the behaviour of the rock mass. The analysis gave the stress and displacement fields in the rock mass. Results of the analysis will allow for design of an optimal mining system. The analysis is illustrated by an example of the shaft R-VIII Rudna Mine KGHM Polish Copper SA.

Keywords: rock mass stress, rock mass deformation, shaft, protective pillar

1. INTRODUCTION

The extraction of mineral resources brings not only economic benefits but also can have many negative impacts on the mining area, its development and management. The main purpose of mining activities is to provide the most economical method of mining with the maximum safety and proper operation of the mine shafts (Dżegniuk et al., 2003). The problem is the quantitative and qualitative determination of effects of mining operation operating on the rock mass behaviour within the protection pillars of the shafts (Niedojadło and Gruszczyński, 2010).

Mine shafts are protected by safety pillars. Mining authorities are interested in maximum extraction of mining deposits while maintaining adequate security of the

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shaft. The mining extraction in the vicinity of the protective pillars can cause changes of stresses and deformations not only on the surface, but also throughout the subsurface, including the shaft structure. So far, Knothe's empirical prediction theory has been used in modelling surface subsidence in LGOM area (Knothe, 1984). However, Knothe theory does not provide information on the deformation within the rock mass. It does not give information about the state of stress in the rock mass and therefore cannot be used for physical interpretation. The Finite Element Method (FEM) gives the information on both the deformation of the surface and within the rock mass.

The paper presents a method for predicting the impact of mining activities carried around and within the shaft protection pillar R-VIII Rudna Mine KGHM Polish Copper SA. The analysis was carried out in two stages. In the first stage the in-situ rock geomechanical parameters of the model were verified on the basis of results of geodetic monitoring surveys. The second step was to forecast the impact of planned mining within the pillar on the displacements on the surface and inside the rock mass.

To develop a methodology for prediction of the impact of mining activities carried around and within the limits of the shaft protection pillar the monitoring and geomechanical data were provided by the Divisions of KGHM Polish Copper SA, Rudna Mining Plant and Lubin Mining Plant.

2. DETERMINATION OF IN-SITU GEOMECHANICAL PARAMETERS

One of the most important issues in the modeling and prediction of rock mass deformation using FEM is the knowledge of in-situ rock parameters. In-situ values of Young's modulus and strength parameters of the rock mass may be very different from laboratory values of rock material. In general, the in-situ Young's modulus of the rock mass is smaller than the value obtained from the laboratory (Bieniawski, 1984, Sakurai, 1997). In some cases the rock mass classification systems may be used to scale laboratory values (Bieniawski, 1984; Tajduś, 2009).

Choice of behaviour model of the rock mass is another important problem in deterministic modeling of deformations. The hard rock mass behaviour is widely characterised using linear-elastic model (Jing, 2003). Model describing the behaviour of the rock mass as a transversally isotropic material with a constant orientation of anisotropy was adopted by (Tajduś, 2009) and (Burtan, 2011). In these models the non-tensional behaviour of the brittle rock mass was not considered. In reality the brittle rock mass behaves as a non-tensional material (Zienkiewicz and Taylor, 1968). (Szostak-Chrzanowski et al., 2011) introduced the directional transversally isotropic model based on the redistribution of stresses caused by mining activity. The latter approach has been used in the work presented in this paper.

3. FEM MODELING AT R-VIII SHAFT OF RUDNA MINE

The mining area of Rudna mine includes the exhaust shaft R-VIII. Fig. 1. shows a plan of the mining operation in the vicinity of the safety pillar of shaft R-VIII. In the area of the mining is located the fault Biedrzychowa. In vertical section the Biedrzychowa fault starts at the level of approx. 450 m below the surface. The fault is a large dislocation involving the vertical displacement of rock mass layers without interrupting their continuity. It is a nearly vertical with the displacement $h = 40$ m.

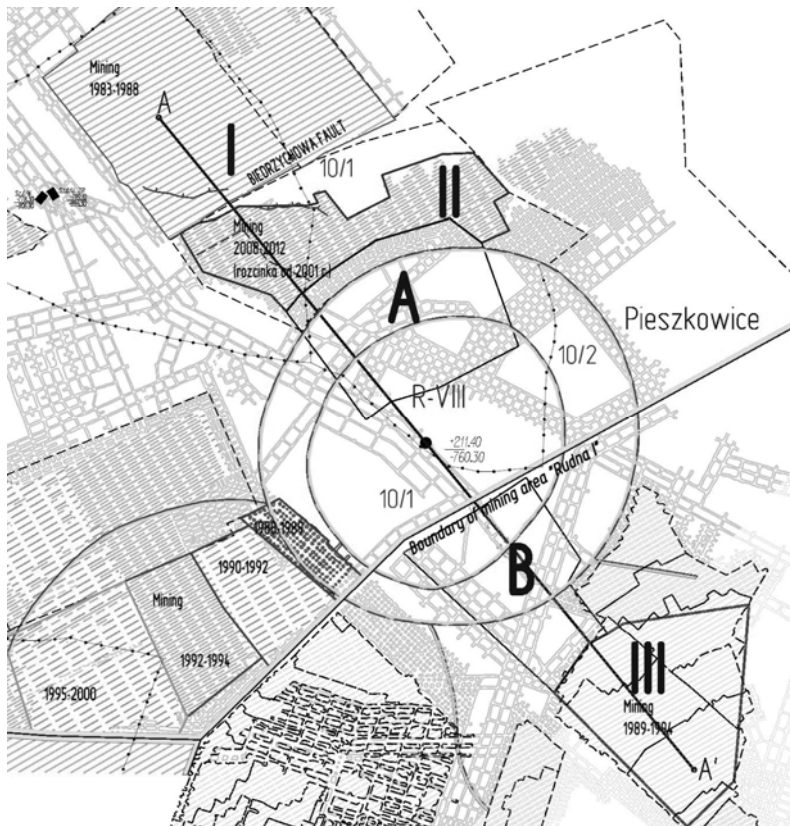


Fig. 1. Mining plan and AA' cross-section

Fig. 2. shows a geology with the location of Biedrzychowa fault in the cross-section AA'). Fig. 2 shows also the location of mining exploitation boundaries of panels I, II and III, and the safety pillar of shaft R-VIII. The height of terrain on the geological AA' cross-section of the shaft axis is about 211.0 m above sea level.

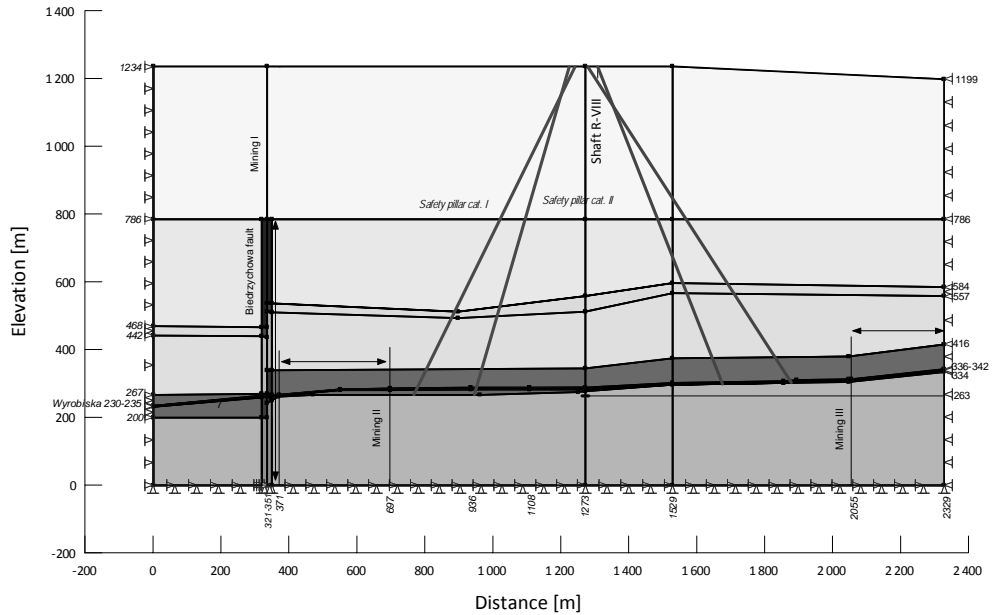


Fig. 2. Geological AA' cross-section

The values of the mechanical parameters of individual geological layers used in FEM analysis are given in Table 1. The analysis included also the zone of Biedrzychowa fault. The parameters of the fault were determined using the Rock Classification Systems. Using the Rock Quality Classification (RQC) the Young modulus within the fault zone was estimated as 10 times smaller than the surrounding rock (Szostak-Chrzanowski et al., 2014).

Tab. 1. Geomechanical parameters

Level	Geology	E (kPa)	γ (kN/m ³)	ν
1	Quaternary and tertiary deposits	3 000 000	24	0.25
2	Sandstone	16 000 000	25	0.12
3	Gypsum	8 000 000	25	0.12
4	Cechsztyń – Anhydrite	16 000 000	29	0.12
5	Cechsztyń – upper Anhydrite, Dolomite, Cooper deposit	25 000 000	27	0.12
6	Floor Sandstone	6 000 000	27	0.12
7	Panel I	20 000	27	0.12
8	Panel II	100 000	27	0.12
9	Panel III	10	27	0.12
10	Panel A	200 000	27	0.12
11	Panel B	200 000	27	0.12

4. FEM ANALYSIS OF ROCK MASS DEFORMATION

The FEM method was used to calculate surface subsidence and the displacement along the vertical axis of the shaft resulting from the mining operation of panels I, II and III. The calculations were performed using the software GeoStudio 2012 (Krahn, 2012). The mining in the panel I was carried out in the years 1983-1988 using room and pillar mining method with roof caving. The average deposit thickness was 5 m with the distance from the shaft of about 930 m. The mining of panel II was carried out in 2009-2012 with room and pillar system where the average deposit thickness was 4.2 m and the distance from the shaft was about 580-900 m. Mining of panel III was conducted in 1989-1994 using room and pillar mining method with roof caving. The average deposit thickness was 6 m and the distance from the shaft was about 800 m. Date of geodetic measurements: 1967.07.01–2012.05.05.

The model was calibrated using the displacements of the surface obtained from geodetic measurements. Calibration was carried out for two stages of operation. The calculated and measured subsidence due to extraction of three panels is shown in Fig. 3. The difference subsidence inside the safety pillar may result from the to summation of influence from the mining operation conducted around the pillar in the same years. This phenomenon is the subject of research.

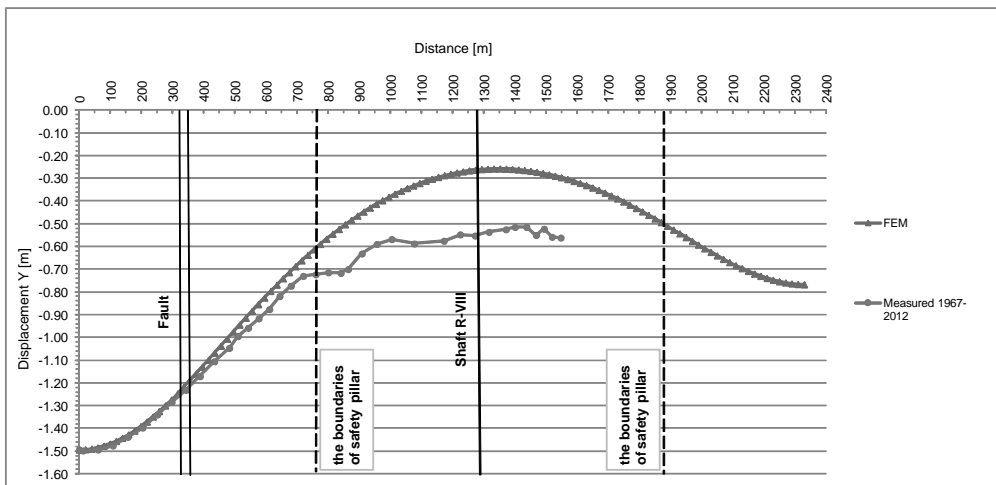


Fig. 3. Vertical displacements calculated and monitored

Calculated vertical (dY) and horizontal (dX) displacement of the shaft axis R-VIII of Fig. 4 for a point on the surface are -0.27m and -0.16 m respectively. The calculated stress distribution is shown in Fig. 5.

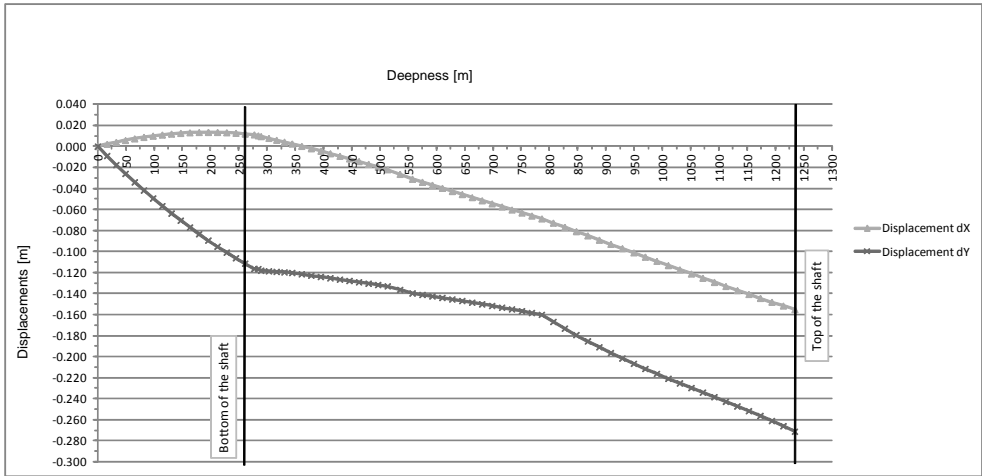


Fig. 4. Vertical and horizontal displacements in the axis of R-VIII

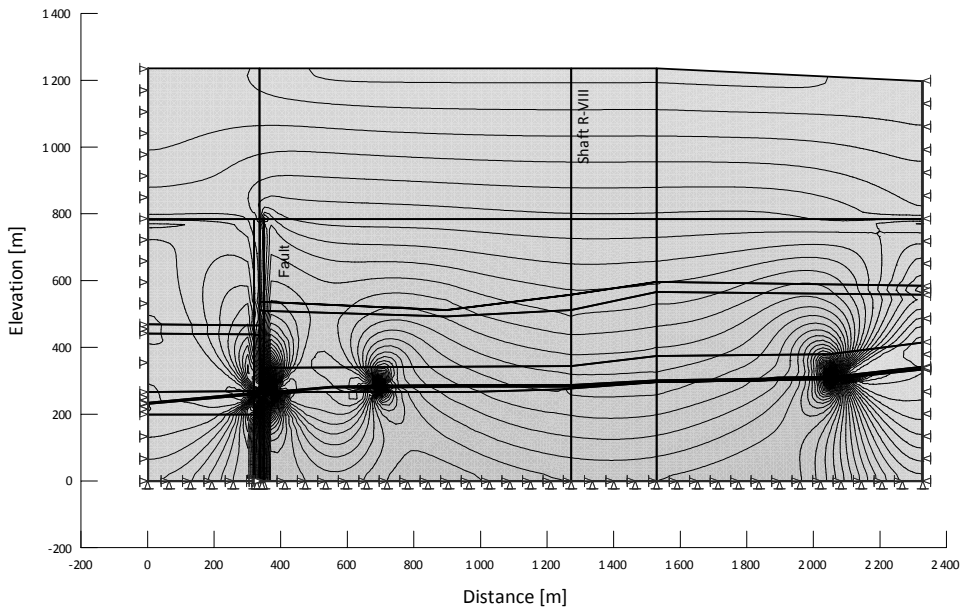


Fig. 5. Maximum stress distribution caused by mining of panels I, II and III

5. DEFORMATIONS OF THE SHAFT PROTECTION PILLAR CAUSED BY NEW MINING OPERATION

The Influence of two mining extractions of panels A and B located symmetrically on both sides of the shaft R- VIII within the safety pillar was studied. Fig. 1 shows the location of the mining panels A and B.

In case of mining extraction in a protective pillar the proper mining method must be chosen. The mining method should limit the surface subsidence of the pillar surface. In panels A and B the selected mining method was room and pillar method with hydraulic backfill. An average thickness of the deposit in panels A and B is up to 15 m, with tilt angle of 8°. Panels A and B going to be mined about 5 years each. During mining operations are made geodetic measurements for the verification the parameters of the rock mass. It was assumed that the extraction was carried out simultaneously on both sides of the shaft. The horizontal and vertical displacements of the shaft were calculated using FEM. The geomechanical parameters used in the analysis are given in Table 1. The geological cross-section is shown in Fig. 6.

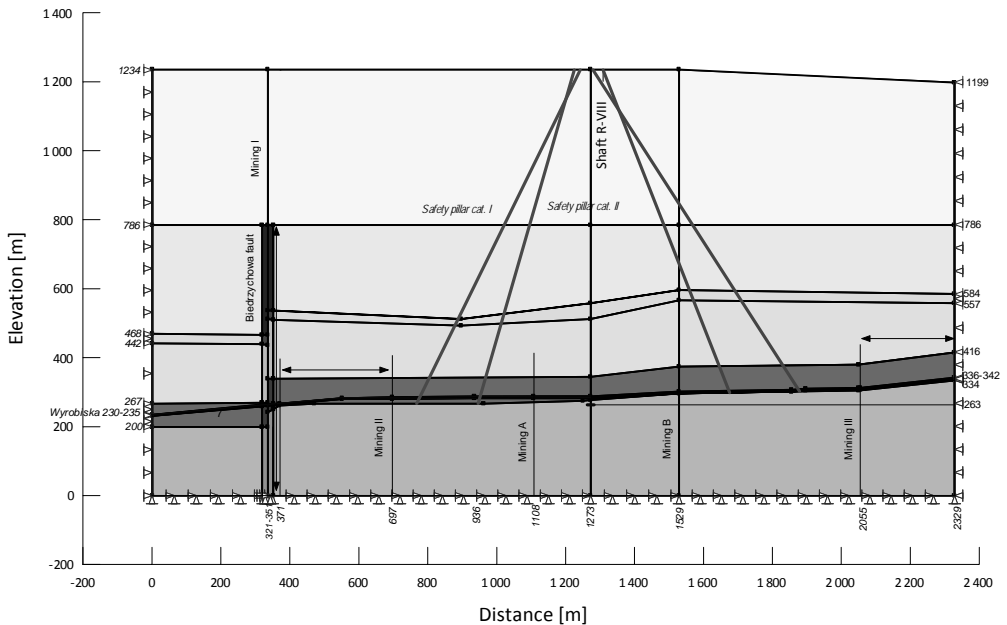


Fig. 6. Geological AA' cross-section with extracted panels A and B

Fig. 7 and 8 show vertical and horizontal displacement along the axis of the shaft R-VIII resulting from the mining of the proposed A and B panels. In Fig. 9 the calculated strains are shown along the axis of the shaft R-VIII.

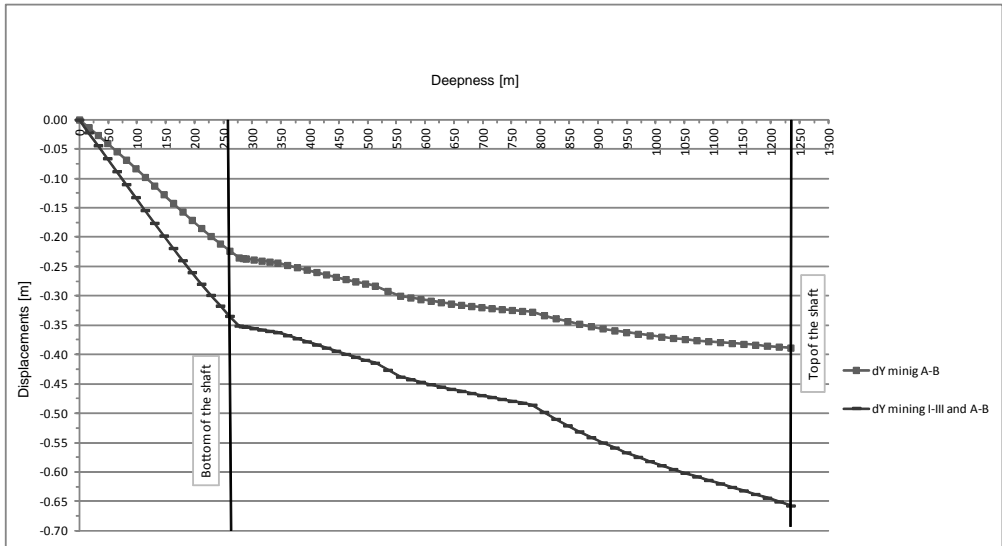


Fig. 7. Vertical displacement along the axis of the shaft R-VIII

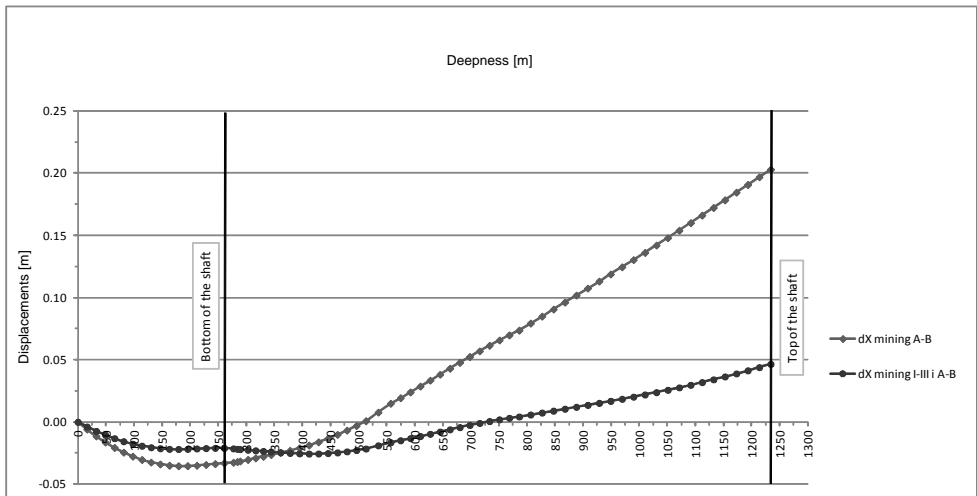


Fig. 8. Horizontal displacement along the axis of the shaft R-VIII

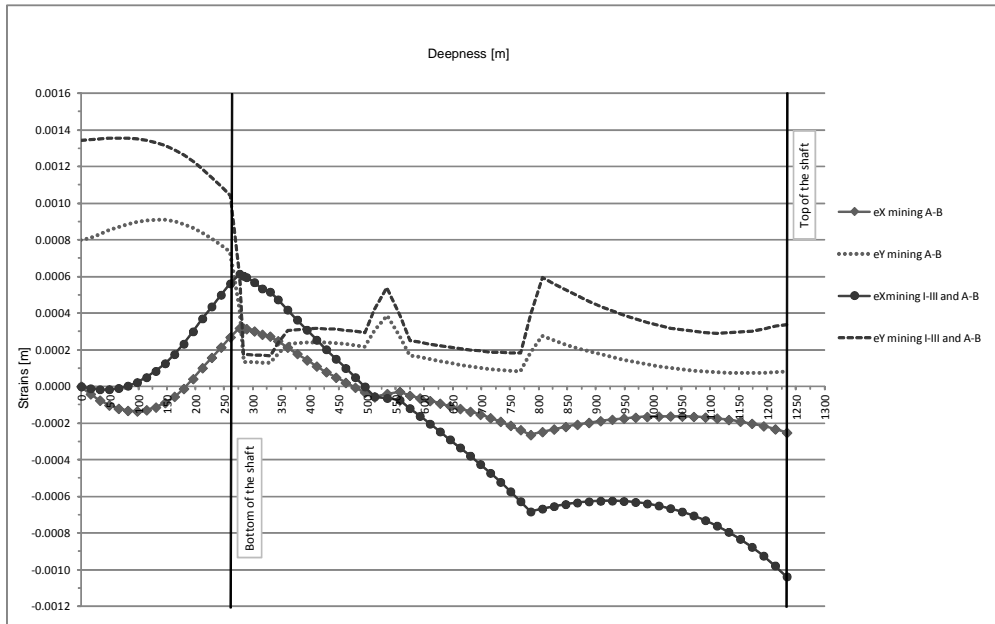


Fig. 9. Strains along the axis of the shaft R-VIII

Due to extraction of panels A and B the horizontal and vertical displacements of the shaft were calculated $dX = 0.20$ m, $dY = -0.38$ m respectively. The horizontal and vertical strains were calculated as $\epsilon_x = -0.25$ mm/m, $\epsilon_y = 0.10$ mm/m. respectively.

The total effect, including protection pillar made inside the shaft R-VIII going to be: displacements $dX = 0.04$ m and $dY = -0.65$ m; deformations $\epsilon_x = -1.04$ mm/m and $\epsilon_y = 0.36$ mm/m.

In the case of vertical deformation along the axis of the shaft, which are the basic rate of deformation representing the level of safety and functionality of the shaft structure, the vertical compressive strain limit given by (Popiołek et al., 1996) is:

$$\epsilon_y = -2.0 \text{ mm/m.}$$

In the present case, the maximum vertical strain reached value of -0.6 mm/m.

6. CONCLUSIONS

Mining around the protection pillar has an influence on the vertical and horizontal displacement and deformation of the shaft. The presented analysis using FEM gives a prediction of deformation of the rock mass in whole rock mass and inside a protective

pillar. It may also provide information for evaluating the safety of the shaft and buildings on the surface, as well as the status of other mine workings. The FEM solution gives the distribution of the rock mass stress in the entire area from the surface to a depth below the mining.

For the design of further mining activity within and around the protection pillar, as described in this article, it is recommended to use the finite element method (FEM) for the prediction of deformation on the surface and inside the rock mass, especially throughout the depth of the shaft.

The FEM analysis of the mining effects also has an economic impact, because it gives ability to design proper mining extraction method of the deposit within shaft protective pillars.

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